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Economic Impact of Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

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Economic Impact of Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

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You have come too far to quit now…

You may never know, this might be the one

Keep walking, keep walking, you are going to make it…

You have an unstoppable power in you

Don’t you stop…!

Dedicated to my beloved late father

Abstract

Tea is an important agricultural industry in Sri Lanka that supports the economy by contributing to the Gross Domestic Production, earning foreign exchange and providing livelihoods for many people. The sustainability and production capacity of the tea industry in Sri Lanka has been challenged by some government policy decisions. The island-wide ban on Glyphosate that was in place from 2015 till 2018 adversely affected the tea industry and participants in it. In this study, the economic impact of the Government policy of banning Glyphosate on the tea industry in Sri Lanka is evaluated by investigating how the ban affected the farm sector and other key market levels in the whole tea industry. The study was conducted by gathering detailed information about the effects of the ban from tea industry participants and stakeholders using primary and secondary data collection methods. An Equilibrium Displacement Model on the tea industry was developed to measure the economic losses of the ban on main market levels in the value chain.

The withdrawal of Glyphosate from tea producers' farm management decision choices has directly affected weed management; essential in commercial tea cultivation for sustained high yields, quality and profit. Tea grower groups, regardless of the size of their operation have experienced quantitative and qualitative losses with increasing weeding costs, costs of production and narrowed gross margins as they have substituted for Glyphosate with alternative weed management methods. Moreover, the ban has also resulted in an unintended consequence, a decline of tea exports in the international tea market. An annual loss of Rs. 3.5 billion on the tea industry was estimated as the direct impact of the Glyphosate ban while the unintended consequence was estimated to have led to a loss of Rs 0.35 billion.

The findings of the study have implications for policy makers, decision makers at the farm level, key participants in the value chain of the tea industry and other researchers. Policies introduced to minimize suspected and actual adverse impacts resulting from market failures ought to be executed with full attention given to the scientific, economic, social and political realities of the case at hand, and the likely consequences for the affected parties and their responses.

Declaration

This is to certify that:

i. this thesis comprises only my original work towards the degree of Doctor of Philosophy, except where indicated in the preface,
ii. due acknowledgement has been made in the text to all other material used, and
iii. this thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Chinthani Kumari Rathnayake

Date: 14th February 2022

Preface

This thesis contains content from the following

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List of Acronyms and Abbreviations

ac	acre
CKDu	Chronic Kidney Disease of unknown aetiology
CTC	Cut, tear and curl
EDM	Equilibrium Displacement Model
ETL	Economic threshold level
FOB	Freight on board
GDP	Gross Domestic Product
ha	hectare
MCPA	2-methyl-4-chlorophenoxyacetic acid weedicide
MRL	Maximum residue limit
Rs	Sri Lankan Rupees
RPC	Regional Plantation company
SLTB	Sri Lanka Tea Board
TRI	Tea Research Institute
TSHDA	Tea Small Holdings Development Authority
VAT	Value added tea
VP	vegetatively propagated

Glossary

Bulk tea	made tea, which is handled and marketed in large quantities, usually more than 10 kg
Green leaves	freshly harvested tender tea shoots
Infilling	planting vacancies in a tea cultivation with tea plants
Made tea	tea manufactured from the leaves, leaf buds and immature stalk of the tea plant
Mature tea	tea cultivations in production stage after several years of pruning
Mossing	the practice of removing mosses developed in tea bush trunk and branches
Pruning	removal of dead and diseased branches in a tea bush
Replanting	replacing an old tea cultivation with new tea plants
Shade management	lopping or cutting off of shade tree branches in a tea cultivation
Tipping	decapitating new shoots developed from a pruned tea bush
Vacancy	a vacant spot with exposed ground in a tea cultivation resulting from a tea bush casualty

Chapter 1 Introduction

1.1 Background and research problem identification

Tea is a commercially cultivated crop in Sri Lanka. Since commercial cultivation of tea commenced in 1867, an entire industry has been built around cultivating tea, made tea manufacturing, secondary processing of tea, export marketing and related subsidiary activities. Tea production has become an economically important industry to Sri Lanka, contributing to the GDP of the country, generating foreign exchange and providing employment to many people, both directly and indirectly. Sri Lanka is a key participant in the international tea market, being one of the major producers of black tea and exporting around 90 per cent of the production to tea markets all around the world. Although Sri Lankan tea is the highest earner foreign exchange all the major exporters of tea on the international markets, in recent years increasing costs of production have reduced the competitive advantage of the Sri Lankan industry.

Several issues at the farm level and further along the value chain has led to declining competitive advantage of the tea industry. Increasing labour costs is an issue. Government policies are another issue. Some policies implemented at the farm level have recently challenged the production capacity of tea producers. The island-wide ban on the use of Glyphosate from mid-2015 till the late 2018 has been one of the most challenging recent policies affecting tea production.

Glyphosate is an agrochemical used widely as a weedicide in agricultural and non-agricultural industries globally. Glyphosate has recently been subjected to use restrictions and bans, following public debates on health implications of its use. The use of Glyphosate has been questioned in many countries after it was classified as a 'probable carcinogen' for humans by the International Agency for Research on Cancer (IARC) in 2015. Following this global classification, the use of Glyphosate in Sri Lanka came under scrutiny over the incidence of the Chronic Kidney Disease of unknown aetiology (CKDu), found in the north central and Eastern regions in the dry zone of the country. A possible association between CKDu and Glyphosate use in these areas was hypothesized by Jayasumana *et al.* (2014). Afterwards activists and a few public groups pressured the government to ban the use of Glyphosate in the country. Consequently, the decision to ban Glyphosate was implemented without further scientific investigations or facts. Sri Lanka became the first country in the world to implement a whole of country ban on the use of Glyphosate. Subsequently, the ban on Glyphosate affected many agricultural production industries possibly leading to nation-wide costs. The tea industry is one of the industries affected by the ban on Glyphosate implemented on 2015 along with coconut, rubber, paddy, maize, sugar cane, chili etc. The ban was in place only for three years until late 2018 when it was lifted for tea and rubber industries following a concerted lobbying effort by industry stakeholders.

Under the circumstances of the Glyphosate ban, the impact on the economy of Sri Lanka of the costs and losses on the tea industry has been large. Unavailability of Glyphosate for weed management, exacerbated the labour shortage that was already occurring as a result of general growth in the economy resulted in sharp rise in labour costs and weeding costs in tea growers' budgets. The use of other herbicides with high toxicities in place of Glyphosate has led to exceeded MRLs of herbicide residuals in some of the made tea consignments, resulting in rejection of some tea exports from buyer countries. For instance, tea produced in Sri Lanka and exported to Japan faced the risk of losing the Japanese market due to the use of the weed control herbicide MCPA as an alternative for Glyphosate on tea cultivations. In addition, according to the Planters' Association in Sri Lanka, there were crop losses from not being able to use Glyphosate of Rs 35 billion rupees over the period of the ban, with an annual loss of Rs 10 – 20 billion.

Only a limited number of studies have been conducted into the effects of the ban on Glyphosate particularly on the tea industry in Sri Lanka. Moreover, none of those studies have investigated the effects on farm sector profitability of alternative weed control approaches in the presence of a withdrawal of Glyphosate use and impacts that can result in subsequent market levels along the value chain of the tea industry. No previous study has done a welfare analysis on the tea industry for the Glyphosate ban or any other related policy. Hence, a study that investigates the full range of impacts of a restriction on Glyphosate or a key input in the tea production is warranted.

1.2 Research aim, questions and objectives of the study

Research aim

The aim of this study is to evaluate the likely economic impact of the government policy of banning Glyphosate on the tea industry in Sri Lanka.

Primary and secondary research questions

The primary question that will be answered by this study is 'How has the ban on Glyphosate affected the tea industry in Sri Lanka?'

This primary question consists two secondary questions as

(i) What have been the impacts of the ban on Glyphosate on the farm sector of the tea industry during the period of the ban?

(ii) What have been the effects of the ban on Glyphosate on participants in the tea value chain?

Research objectives

The research objectives that help address research question are as follows:

(i) to study the factors affecting decisions about weed management as a result of the ban on Glyphosate and the effects of the ban on the farm sector

(ii) to quantify changes in weed management practices, production and tea production gross margins in the farm sector of the tea industry

(iii) to develop an economic modelling framework for the tea industry in Sri Lanka

(iv) to estimate welfare changes of the ban on Glyphosate on participants in the main market levels along the tea value chain and the on the industry

(v) to evaluate overall implications of the ban on Glyphosate on the tea industry

The first objective is about studying the changes that have taken place in tea-grower decision-making regarding weed management approaches taken in tea cultivations before and during the ban on Glyphosate and identify factors that affect choosing weed control approaches. Moreover, issues faced by the farm sector in weed management following the Glyphosate ban are investigated under this objective.

To achieve the second objective the changes in weed management practices and tea production pertaining to any changes in tea field activities are quantified and used in developing gross margin budgets for representative landholdings.

To achieve the third objective of the study, an economic model is developed for the tea industry in Sri Lanka, after examining in detail the tea value chain and interactions across market levels.

Objective 4 involved developing an economic model to estimate welfare changes across market levels in the tea value chain as a result of additional costs incurred with the Glyphosate ban and the related shifts in the supply of the commodity. Finally, implications of the Glyphosate ban on the tea industry are evaluated by aggregating and collectively analysing the outcomes obtained from all other objectives in the final objective.

1.3 Methods used in the study

Several methods were used in this study to achieve the Objectives of the research. In Table 1.1 is a representation of research questions, objectives and corresponding methods adopted in achieving each objective of the study and analysis of data.

Table 1.1. Summary of research questions, objectives, methods and analyses involved

Main research question	Secondary research questions	Objectives	Method/s	Analysis
How has the ban on Glyphosate affected the tea industry in Sri Lanka?	What have been the impacts of the ban on Glyphosate on the farm sector of the tea industry during the period of the ban?	To study the factors affecting weed management related decision-making with the ban on Glyphosate and effects of the ban on the farm sector	In-depth interviews with tea value chain participants	Thematic analysis of qualitative data Descriptive analysis of quantitative data
		To quantify changes in production processes, production and tea production gross margins in the farm sector of the tea industry	In-depth interviews with tea grower groups Literature review Published secondary data from gov. institutes	Gross margin budget analysis
	What have been the effects of the ban on Glyphosate on participants of the tea value chain?	To develop an economic modelling framework for the tea industry in Sri Lanka	Literature review Published secondary data from gov. institutes	Validation of the Equilibrium Displacement Model
		To estimate welfare changes of the ban on Glyphosate on participants in main market level along the tea value chain and the on the industry	Published secondary data from gov. institutes Price elasticity data from previous studies/literature and expert recommendations	Welfare analysis using the Equilibrium Displacement Model
		To evaluate implications of the ban on Glyphosate on the tea industry	Literature review In-depth interviews with tea value chain participants Published secondary data from gov. institutes	

As listed in the table, the main methods of data collection in the study are detailed interviews with tea industry participants, secondary data collected from published government sources and literature review.

Data collected from detailed interviews with tea industry stakeholders consists of qualitative data that are analysed descriptively and thematically. The thematic analysis facilitated by the NVivo software enables sorting of interviewee responses into similar groups and to represent qualitative data. Annual reports of institutes closely involved in the tea industry such as the Sri Lanka Tea Board, Tea Small Holdings Development Authority, Tea Research Institute of Sri Lanka, Ministry of Plantation Industries and Export Agriculture as well as the Central Bank of Sri Lanka, Department of Census and Statistics and the Export Development Board are the data sources providing secondary data on prices, quantities of tea products along the value chain. Farm total variable cost and gross margin budgets are developed to quantify changes in weed management practices and green leaf production businesses respectively, in the farm sector.

An Equilibrium Displacement Model is developed on the black tea industry in Sri Lanka in this study. It is a comparative static modelling approach that represents an industry using a system of equations in log difference form reflecting the demand and supply of products in each market level in the value chain. The model development is dependent on the knowledge about the flow of these products across market levels and their demand and supply. Secondary data sources as explained above providing data on equilibrium prices and quantities in the market along with elasticity estimates of exogenous product supplies and demands from literature or derived through subjective judgement are required for the model validation. The impacts of the ban on exogenous product supplies and demands are the shocks on the system of equations that result in a displacement from the initial equilibrium and shift to a new equilibrium with new market prices and quantities. The consequential changes of the economic surplus in market levels – consumer and producer surplus changes – are estimated in the welfare analysis. Probabilistic sensitivity analysis is also performed with the @RISK program to take into account uncertainties about the estimates of elasticity of supply and demand in the various markets.

1.4 Significance of the study

An outcome of the study will be information about the economic impact of the government policy that banned Glyphosate on tea industry. This information is important for policymakers, participants in the tea value chain, especially tea growers, and other researchers. Currently, many countries are showing increased recognition of the role of more environmentally friendly agricultural practices that reduce or minimize the use of agrichemicals, not only Glyphosate. Key outcomes from this study will provide insights for decision makers about future policy decisions restricting the use of key inputs in agricultural industries and how such policies can affect the economy. Moreover, research and development on a sustainable alternative for Glyphosate may also be encouraged.

1.5 Outline of the thesis

The outline of chapters in the thesis is presented in Figure 1.1 below. This provides a guide for the readers to follow through each chapter, to help understand how chapters are interconnected with the information flow to subsequent chapters through to the final chapter.

This thesis is structured as follows.

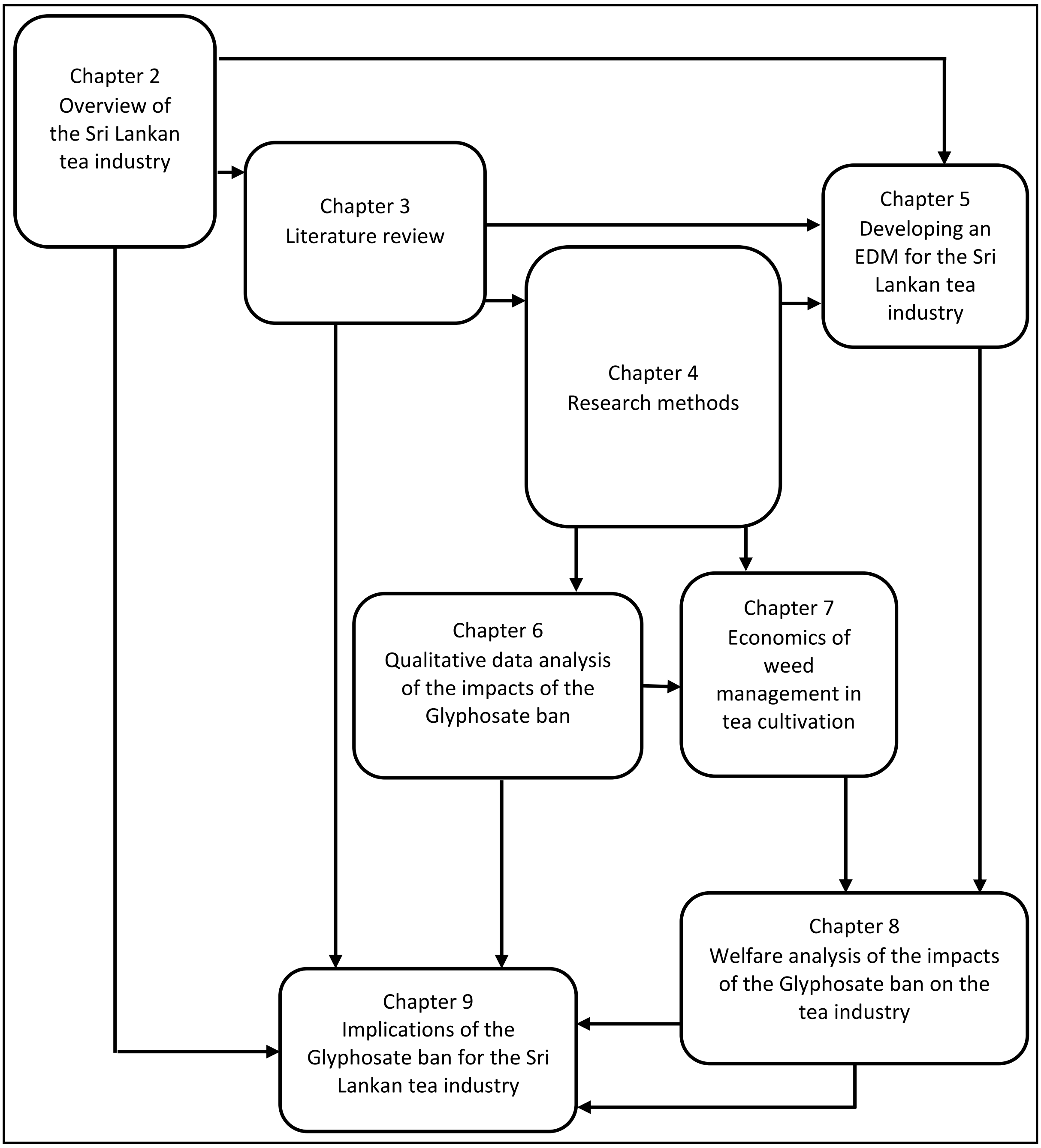


Figure 1.1. Flow of chapters in the thesis

Chapter 2 is an overview of the tea industry in Sri Lanka. Important background information about the tea industry is provided in this chapter. This includes a value chain description of the tea industry, eventually narrowing down to identifying issues in the farm sector of the industry. The whole value chain of the tea industry, consisting of green leaf producing or the farm sector, black tea manufacturing sector, secondary processing sector and domestic and export marketing sectors as the key market levels, is discussed. Subsequently, the farm sector and issues faced by them that affect their performance is described and explained.

A literature review of two main areas is presented in Chapter 3. First is a review of literature about tea production, costs and weed management in tea cultivations of two main tea grower sectors – the tea smallholders and the estate plantation sector - are provided. Second, literature on the use of Glyphosate, policies adopted on its use and impacts of a potential ban are reviewed, providing evidence on what has happened in the rest of the world. This section is followed by a review of available literature about Sri Lanka and economic impacts of the Glyphosate ban in place from 2015 till 2018. Finally, research propositions that will be studied in this research are presented.

In Chapter 4, all methods involved in achieving the research objectives are presented, with comprehensive explanations on each method. Details about the methods adopted by similar studies conducted in other countries are used as inputs in this chapter to help to decide on the most appropriate ways of collecting data in this study.

The specification, development and calibration of the EDM of the tea industry in Sri Lanka is presented in Chapter 5. Conceptualization of the tea industry into horizontal and vertical market levels and mapping the market levels in the industry in terms of a system of equations reflecting demand and supply of different market levels at equilibrium were done based on the review on the value chain of the tea industry in Chapter 2 and literature review in Chapter 3. Information about equilibrium prices quantities, and market elasticity estimates from secondary data sources and literature respectively, are explained in detail in Chapter 4. This information is to validate the model and investigate hypothetical shocks to the markets that can shift equilibria to new prices and quantities. Finally, a sensitivity analysis is done to check uncertainties of market parameter estimates on economic surplus changes of the hypothetical exogenous shocks.

A comprehensive analysis of the qualitative data collected from interviews with tea industry participants presented Chapter 4 comprises the content of Chapter 6. First, a descriptive analysis of demographic data about tea grower groups interviewed in the study is presented. Information from those interviews analysed under different themes is presented. Next, in the subsequent section, factors are set out that affect the decision-making of tea growers on weed management approaches in cultivations, with and without the ban on Glyphosate and weed management, for the pre- and post-ban situations. This section is followed by an analysis of issues faced by tea grower sectors with the ban on Glyphosate.

Similarly, in Chapter 7 is a quantitative analysis of the variable cost and gross margin budgets developed for different weed management practices and green leaf production in the farm sector. As explained in Chapter 4, data on weed management and other field activities are provided from findings of interviews conducted with tea industry participants and secondary data from published government reports. Consequently, budgets are developed based on some assumptions about corresponding yield reductions as a result of the ban on Glyphosate. In the second half of the chapter is presented a scenario analysis of selected weed management combinations before and during the ban, as specified from the qualitative data analysis in Chapter 6, for both grower groups and financial parameters of each weed management combination are calculated and compared. The percentage changes in total variable costs in representative landholdings from both grower sectors with the ban are used as inputs for the EDM in the next chapter.

Chapter 8 is where a welfare analysis of the impacts of the ban on Glyphosate on the tea industry is conducted. One form of impact of the ban is as a percentage change in total variable costs in the tea smallholder and estate sector; the result of increased costs of production from the ban which were calculated in Chapter 7. These changes in costs are used as inputs in the technically validated EDM in Chapter 5. An unintended consequence of the ban, which is the reduction in export demand of bulk tea exports to Japanese tea markets is analysed as an exogenous shock in the EDM. Welfare analyses estimating changes in economic surpluses across all market levels specified in the EDM are conducted for these scenarios. Finally, the @RISK software is used to conduct probabilistic and sensitivity analyses on each scenario to address uncertainties of elasticity estimates for supply and demand in the markets and used in the EDM.

Key findings from Chapters 2,3,6,7 and 8 are highlighted in the concluding discussion in Chapter 9. Implications of government policy of banning Glyphosate on the tea industry. In the following section, conclusions, and insights for future research are discussed.

Chapter 2 Overview of the Sri Lankan Tea Industry

2.1 Introduction

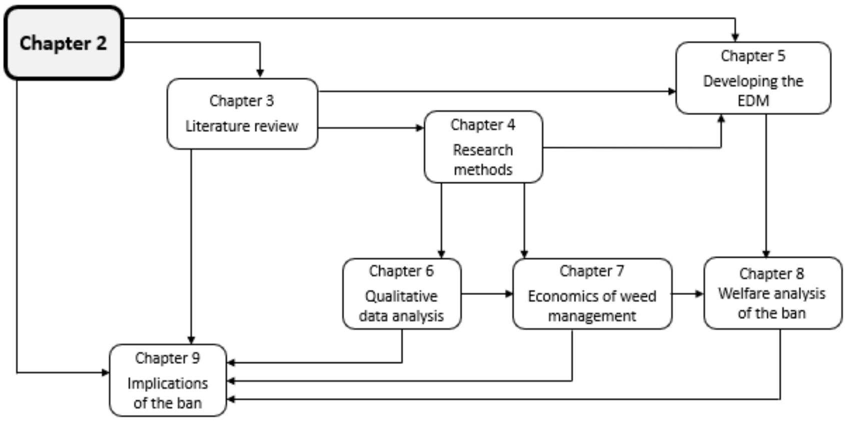


Figure 2.1. Flow of chapters in the thesis

In this chapter an overview of the agriculture in Sri Lanka and the tea industry is presented. The first section is a brief introduction to Sri Lanka, the agricultural activities conducted and the contribution of agriculture to the economy. The performance and value chain of the tea industry is set out in Sections 2.3 and 2.4. Sections 2.3 and 2.4 draw on the paper titled 'The Ceylon[1] Black tea Value Chain' by Hettiachchige and Rathnayake (2021). This information about the value chain of the tea industry in Sri Lanka is used in specifying the EDM on the industry in Chapter 5. The focus of Section 2.5 is on the farm sector and covers the history of tea cultivation, other key market levels involved in and institutions working with the tea industry. The policy framework of the industry is discussed in Section 2.6 where the ban on Glyphosate as a policy barrier is described in more detailed in Chapter 3 as presented in Figure 2.1. Issues faced by the farm sector as in Section 2.7 draws on the paper by Rathnayake *et al.* (2021) titled 'Current Issues in the Farm Sector of the Tea Industry in Sri Lanka'.

2.2 Agriculture in Sri Lanka

Sri Lanka is an island in South Asia with an area of 65, 610 km2. Known as 'the pearl in the Indian Ocean' Sri Lanka is located on the Bay of Bengal, southeast of India and northeast of Maldives. It is a country rich in biodiversity with many endemic species of flora and fauna.

[1] Ceylon was the former name of Sri Lanka until 1972. Tea produced in Sri Lanka and exported to international markets in the past was known as Ceylon tea.

Sri Lanka has a tropical climate, located as it is in between 5° 55' to 9° 51' North latitude and between 79° 42' to 81° 53' East longitude. The average temperature of Sri Lanka ranges between 28 to 32 degrees Celsius though this is changing as a result of warming global climates. Temperature varies across the country from as low as 16 degrees Celsius in the central highlands to as high as 32 degrees Celsius along the eastern coast.

Sri Lanka has highlands in the center towards the southern part of the country with peaks, plateaus, valleys basins, escarpments, and ridges while the rest of the island is flatter except for some scattered small hills. The diverse topography affects the temperature, rainfall, wind patterns and humidity. Sri Lanka is categorized into three regions, based on the elevation: (i) low country (<300 m), (ii) mid country (300 – 900 m) and (iii) up country (>900 m).

Rainfall in Sri Lanka is categorized as being mainly monsoonal, convectional and expressional with monsoonal rain being the major source of rainfall. Depending on the annual rainfall received, Sri Lanka is classified into three climatic zones as shown in Figure 2.2 (i) Dry zone (Annual rainfall <1750 mm), (ii) Intermediate zone (Annual rainfall 1750 – 2500 mm) and (iii) Wet zone (Annual rainfall >2500 mm).

Climatic zones are further sub divided into 24 agroecological regions - ten for the wet zone, nine for the intermediate zone and five for the dry zone – based on rainfall expectancy, altitude, soil class and landform. Thus, each region represents a uniform agro-climate, soils and terrain conditions as in Figure 2.2 (right). Agroecological zones support farming systems in terms of figuring out where a certain range of crops and farming practices suit the most.

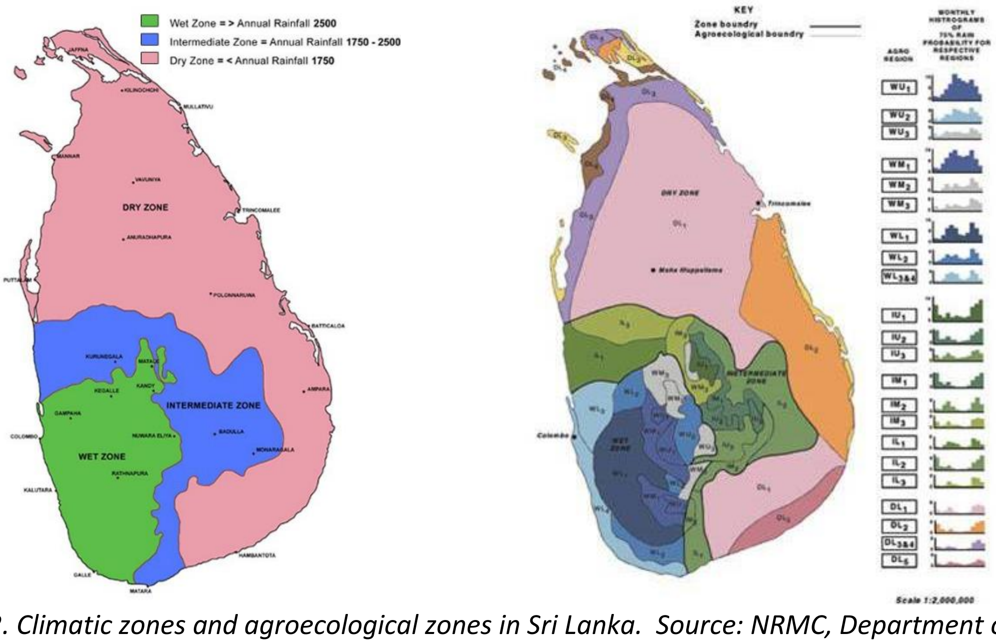


Figure 2.2. Climatic zones and agroecological zones in Sri Lanka. Source: NRMC, Department of Agriculture, Peradeniya, Sri Lanka

Evidence of agriculture in Sri Lanka dates back long before the pre-colonial era to when kings ruled the country. People who migrated to Sri Lanka from Bengal, East India had settled in the dry zone of the country and introduced an agriculture-based economy. The introduction of Buddhism to the country supported agriculture in terms of concepts such as the Tank-Temple-Village system.

During the pre-colonial era Sri Lanka was known as the granary in Asia, achieving self-sufficiency in rice. Towards the end of this era dry zone rice cultivation had shifted to wet zone export crop cultivations, mainly cinnamon and other spices. At the time of the colonial era, the invasion of Portuguese colonists had moved Sri Lanka towards an export agricultural economy from its traditional self-sufficiency and domestic market agricultural economy. Progressively with the invasions of the Portuguese, Dutch and British, a plantation system started dominating the economy, with cultivations such as cinnamon, pepper, cardamom etc. developing. Policies imposed throughout the colonial era enabled the conversion of a static feudal economy into modern commercial agriculture. Tea plantations had expanded in the hill country during this period and establishment of settlements of Indian Tamil immigrants on the estates for labour had occurred.

By the time the country gained political independence, there was a relatively affluent open agricultural economy where plantation crops such as tea, rubber and coconut dominated Sri Lankan exports, while substantial quantities of rice, wheat, and other food products were imported.

As in the present context related to agriculture, rice is the primary food crop, grown solely for domestic use and the most important economic activity of most people in rural areas. Tea, rubber and coconut are the major plantation crops grown on around 1 million ha of land, mainly for exports, as well as for domestic use. Tea is a major source of foreign exchange. The contribution of these commercial crops to GDP declined greatly over several decades.

In addition to these major crops, other significant crops include vegetables, fruits, pulses, yams, field crops and spices. Field crops include condiments; chili and onions, grain legumes such as green gram, cowpea, black gram, pigeon pea and chickpea, oil seed crops such as groundnut, soybean, sesame and sunflower and non-rice cereals including maize, sorghum, finger millet and other minor millets. These are all grown mostly in home gardens and used for domestic use and very little is exported.

Forestry and fishing are less important components in the economy. Even though the country has abundant fishing resources, the potential has not yet been exploited. The livestock sector in Sri Lanka is small, consisting mainly of dairy and poultry sections.

2.2.1 The share of agriculture in the GDP

In the 1970s, the agricultural sector accounted for more than 35 per cent of GDP, over 90 per cent of export earnings, and 50 per cent of total employment (World Bank Data 2020). During this time, Sri Lanka's economy depended heavily on the performance of the tree crop or export sector, the tea, rubber, coconut, and minor tree crops.

Over the years, the share of agriculture in employment declined significantly as in Figure 2.3, but increased labour productivity did not make up the gap. This is mainly because the rapidly growing industry and service sectors drew large amounts of rural labour out of agriculture and the share of labour involved directly in agriculture declined from about 47 per cent in 1990 to around 36 per cent in 1999. More recently, these numbers have further decreased and the contribution of agriculture to the economic growth of the country is declining over time.

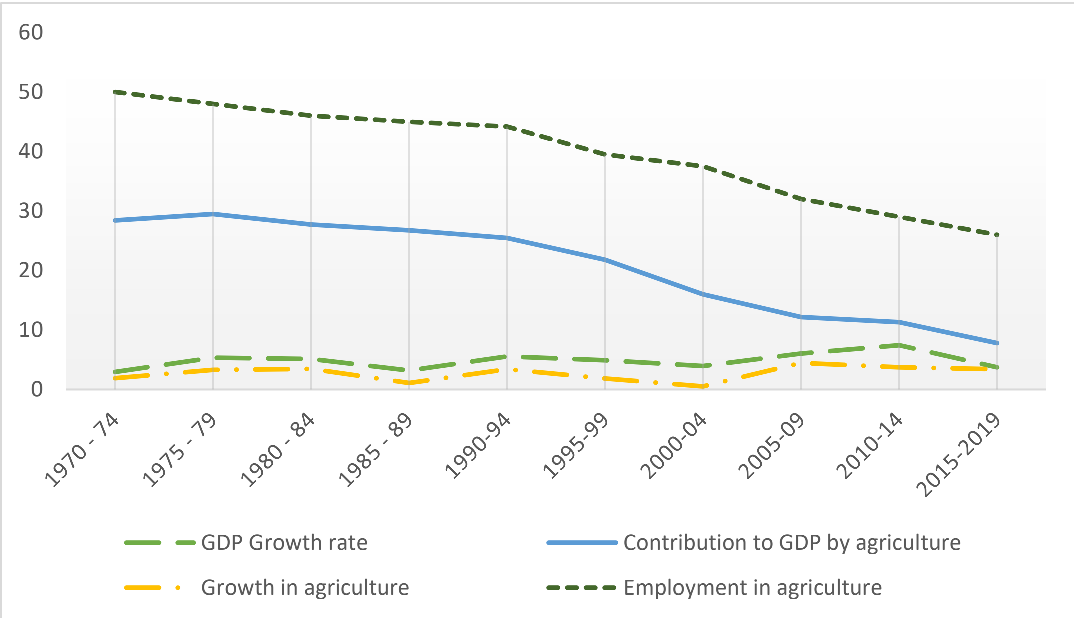


Figure 2.3. Contribution of agriculture to the economic growth over time (1970-2019). Source: World Bank Data (2020), TheGlobalEconomy.com (2020)

2.3 Tea production in Sri Lanka; from the field to the teacup

Sri Lanka has been popular over many years among tea drinkers across the world as a producer of fine quality black tea with characteristic aroma and flavour, known as 'Ceylon tea'. Sri Lankan tea has been a significant export commodity since 1965. The country is currently the fourth largest producer of tea in the world, accounting for 5 per cent of world tea production (Tea Exporters Association Sri Lanka 2020) and the third largest exporter selling 15 per cent of world exports of tea, competing with other major tea producers and exporters such as China, India, Kenya, Indonesia and Vietnam (International Tea Committee 2019).

2.3.1 Tea growing regions

Tea cultivation/green leaf production in Sri Lanka is carried out in 14 districts in three distinct regions in the wet zone: up country, mid country and low country. The distribution of tea producing districts are presented in Figure 2.4. The three main tea cultivating regions are i) low grown area with an elevation from sea level to 600m, subjected to long period of sunshine, relatively dry environmental conditions, ii) mid grown area at an elevation between 600m to 1200m with an intermediate climate with cool and warm conditions; and iii) high grown area in elevations above 1200m, exposed to cool conditions, chill winds and limited hours of sunshine.

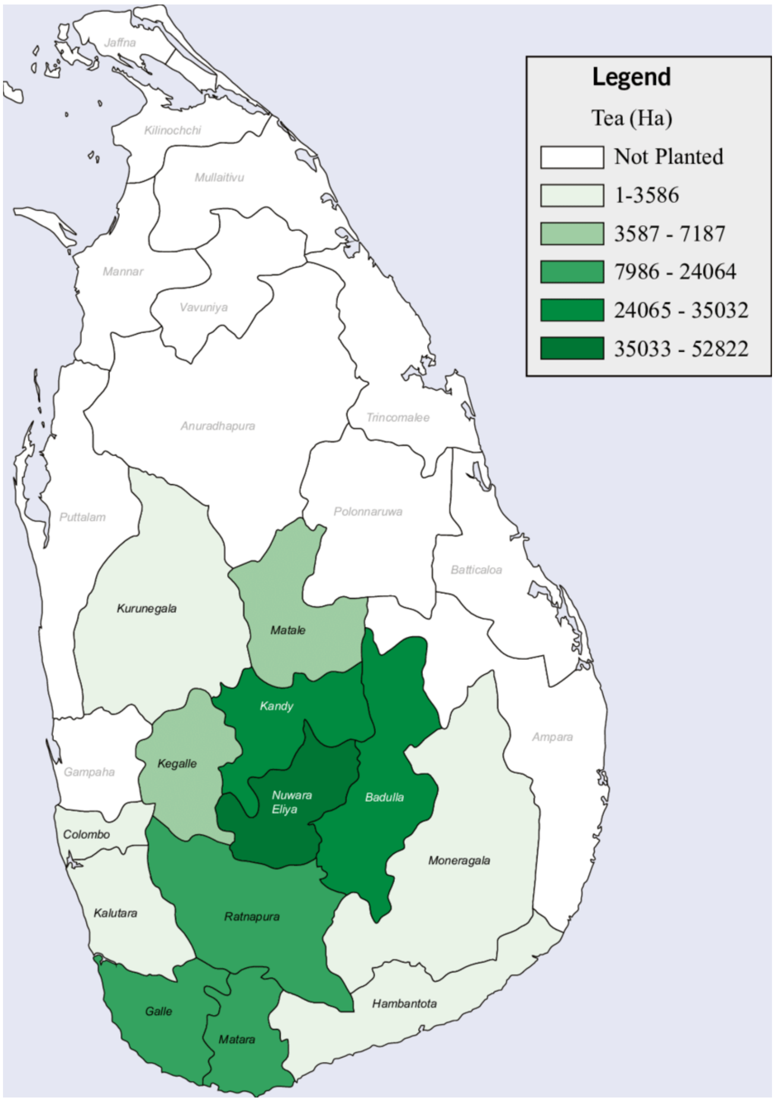


Figure 2.4. The distribution of tea cultivating districts in Sri Lanka. Source: Economic census (2013/14) The Department of Census and Statistics

The contribution to the national tea production by low-grown tea cultivating regions is higher than the high and mid-grown regions because of favourable weather conditions, nutrient rich soil, and better agricultural practices. The breakdown of tea production by elevation in 2007 was 24 per cent, 18 per cent and 58 per cent for high grown, mid grown and low grown areas, respectively. By 2018 the contributions have changed to 21 per cent, 16 per cent and 63 per cent, respectively (Sri Lanka Tea Board 2019).

2.3.1 Types of tea

Although Sri Lanka is well-known for its black tea production, green tea and Oolong tea are also produced simultaneously. These types of tea originate from the same plant but differ due to their manufacturing procedures. Black tea undergoes full fermentation in the manufacturing process, whereas green tea is produced by skipping the fermentation step in the process and performing heat treatment. Oolong tea, which is also known as half-black tea, is semi-fermented. Sri Lanka is the only tea-growing nation which manufactures all types of tea.

2.3.3 Tea manufacturing process

The manufacturing process of tea is explained by Hettiachchige and Rathnayake (2021). Accordingly, the main steps involved in the manufacturing process of black are withering of green leaves, rolling, fermentation, drying, sorting and bulk packaging for transportation to broker warehouses in Colombo for the auction (Sri Lanka Tea Board 2018d). There are two processing methods of black tea - Cut Tear and Curl and orthodox. The latter is produced using the traditional method which involves the above-mentioned steps and is mostly used for tea packets as loose tea. CTC tea, which is normally used for tea bags because of its particle size as fragments of tea are manufactured by slicing withered leaves to a uniform size using a CTC machine where they are crushed by metal rollers and torn and curled instead of the rolling process used in orthodox tea (Sri Lanka Tea Board 2018d).

Processed tea thus produced is sorted and graded according to an internationally recognized common method based on the particle size ranging from the highest size referred to as ‘orange pekoe’, and the lowest as ‘fannings’ or ‘dust’ (Tea Exporters Association Sri Lanka 2020). Differences in climatic characteristics enable the production of teas with different aromas, tastes and textures. Many teas are unique to specific regions in Sri Lanka and are not found anywhere else in the world. So, some specific types of Ceylon black tea are named for the agro-climatic region where they are grown, such as Nuwara Eliya, Dimbula, Uva and Uda Pussellawa in the high grown area, Ruhuna and Sabaragamuwa in the low grown area and Kandy in the mid grown area of Sri Lanka (see Hettiachchige and Rathnayake (2021).

2.4 Performance of the tea industry over the past decade (2010 -2020)

2.4.1 Tea production

At present, the tea industry employs around 1 million people in Sri Lanka directly and indirectly, and directly employs 215, 338 on tea plantations and estates, which is around 11 per cent of the work force of the country (Jayasuriya 1998; Ganewatte and Edwards 2000). The sustainability of the tea sector is important since a large share of the income generation and livelihood of the country depends on it.

Owing to the favourable climatic conditions prevailing in the tea growing regions, Sri Lanka maintains a continuous production of tea throughout the year, but with fluctuations according to variations in rainfall. Accordingly, the months with least tea production fall around February – March and September – October as shown in Figure 2.5.

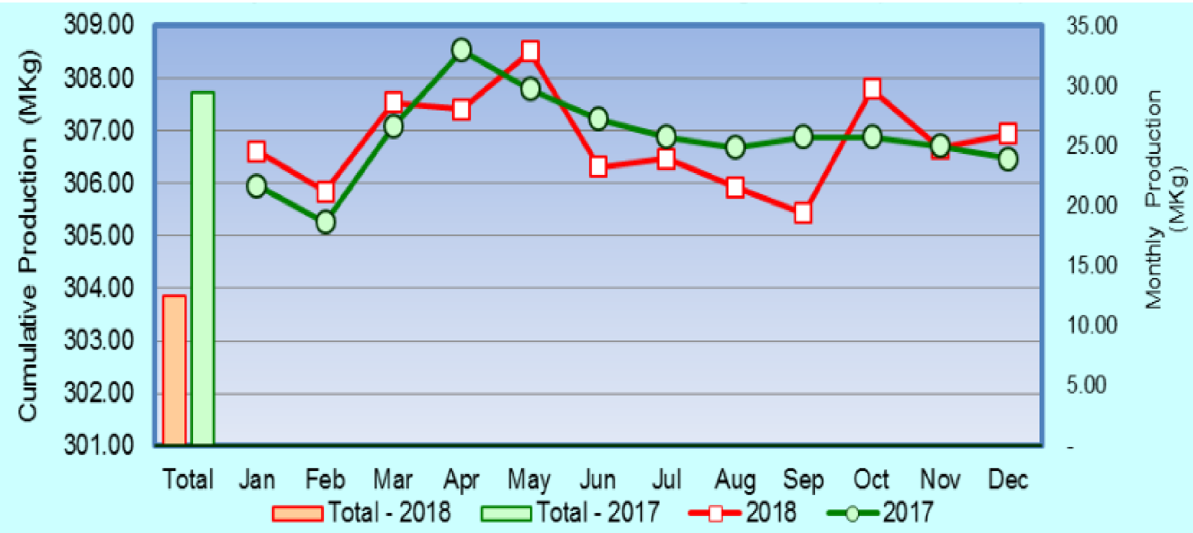


Figure 2.5. Monthly and cumulative tea production during the year (2017/2018). Source: 4th quarter Tea market update Sri Lanka Tea Board (2018)

Furthermore, the annual total tea production has exceeded 300 million kg every year except in 2009 and in 2016 as presented in Figure 2.6. Annual tea production has increased gradually from 2007 to 2013 with small fluctuations and then has decreased in recent years due to several reasons.

However, the per hectare tea production/yield has shown no growth over the past two decades with a stagnated production.

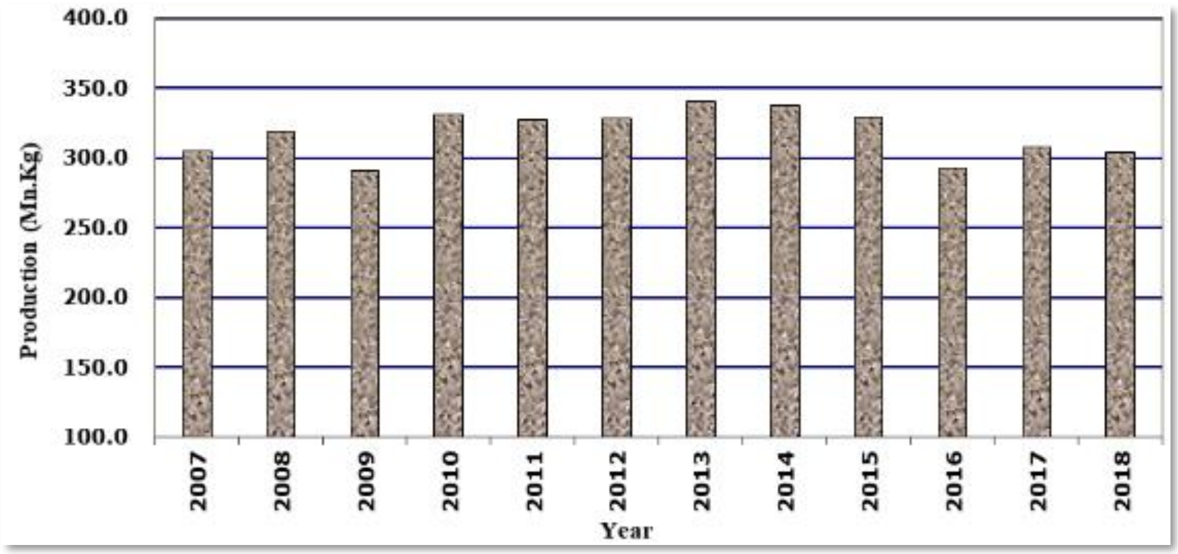


Figure 2.7. Total tea production in Sri Lanka, 2007-2018. Source: Sri Lanka Tea Board (2020)

A stagnation in the yield can be observed throughout the years with an average of 1500 kg of made tea per hectare as in Figure 2.7. This has been a challenging situation to the tea industry in the country as other tea producers including China, India and Kenya are continuously increasing their production and areas under cultivation (Hilal and Mubarak 2016).

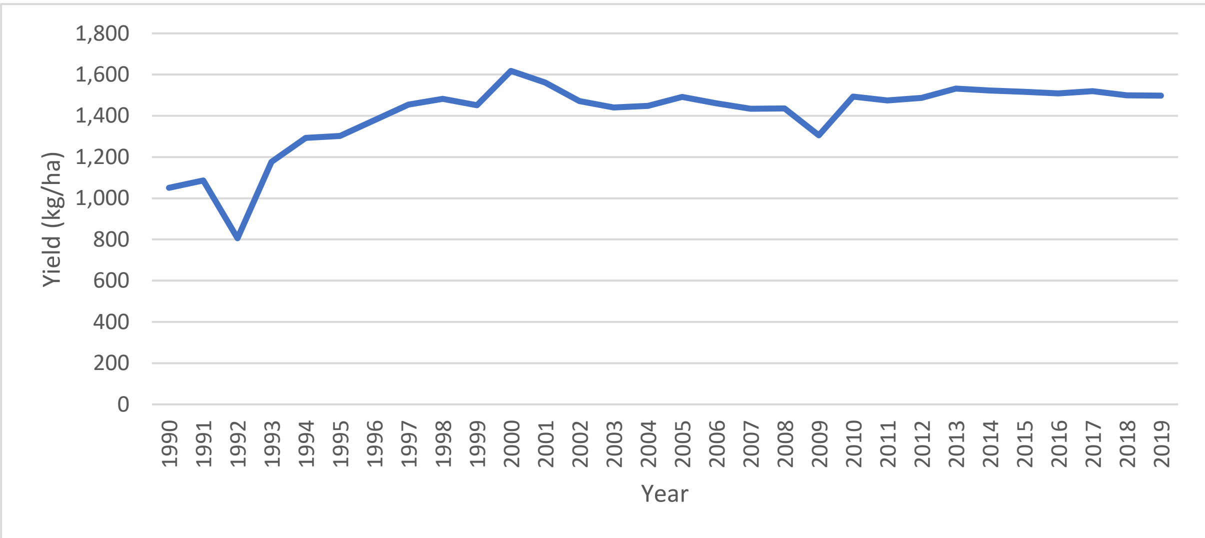


Figure 2.6. Trend in tea production per hectare (1990 – 2019). Source: Food and Agriculture Organization (FAOSTAT) 2020

As shown in Figure 2.8, the tea harvested area in Sri Lanka increased by about 10 per cent in 2002, then remained relatively steady until the onset of a downward trend in 2014.

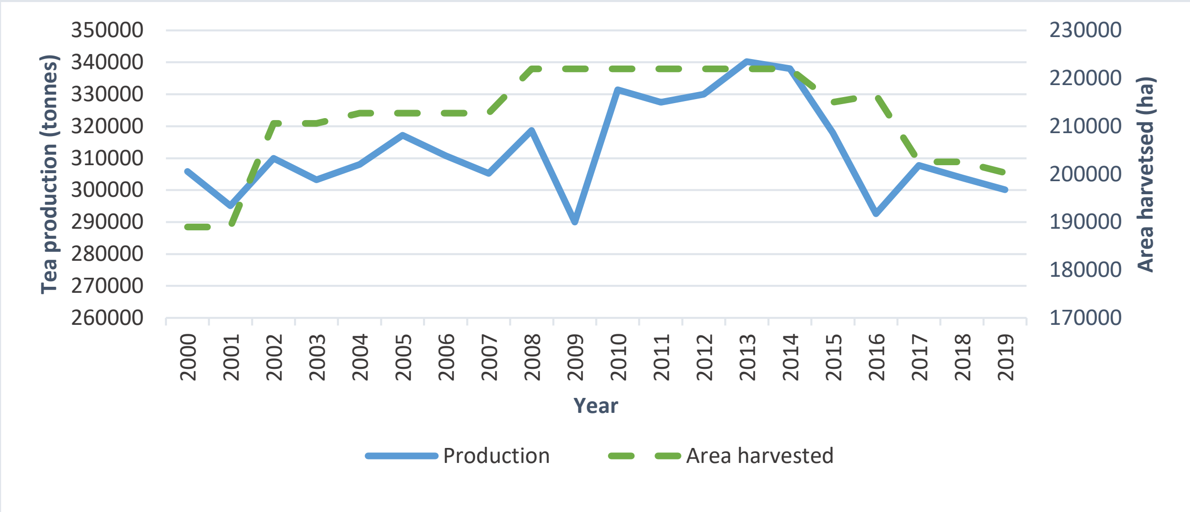


Figure 2.8. Tea production and harvested area (2000 – 2019). Source: Food and Agriculture Organization (FAOSTAT) 2020

Tea production fluctuated around 31,000 tonnes until 2014 but then declined in parallel with the reduction in harvested area. The highest average national yield of 1.53 tonnes of made tea per hectare during the past decade was recorded in 2013. Since then, yields have declined to 1.35 and 1.49 tonnes of made tea per hectare in 2016 and 2019, respectively.

2.4.2 Contribution to the country's Gross Domestic Production (GDP)

The contribution to the country's GDP by the tea production in Sri Lanka follows a gradual decline over the years. The GDP share has fallen from 1.2 per cent in 2008 to 0.7 per cent in 2018 (Central Bank of Sri Lanka 2019). This share has followed the gradual decline in the harvested area and in production given yield has remained static. The contribution to the Gross Domestic Product of the country by the tea sector has a gradual declining trend over the years as shown in Figure 2.9.

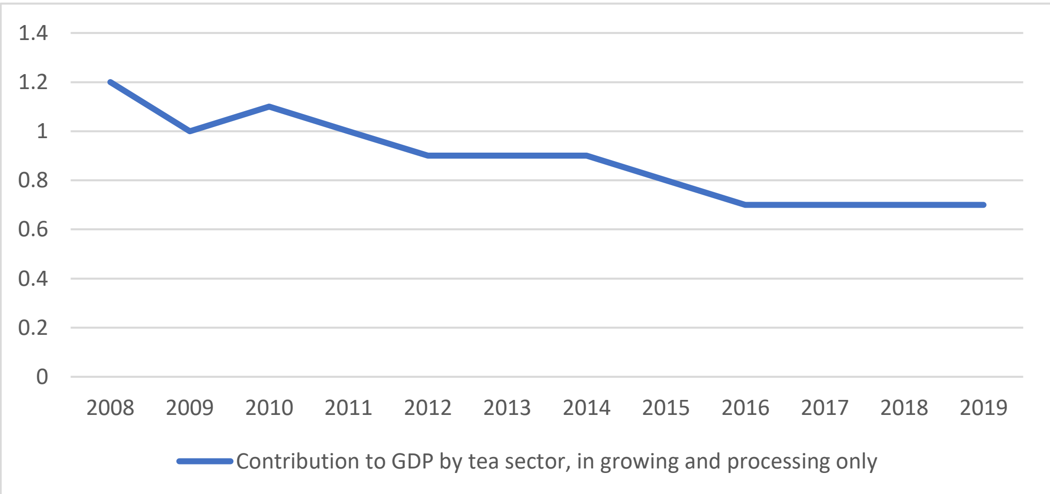


Figure 2.9. Contribution from tea production to the GDP of Sri Lanka. Source: Economic and Social Statistics of Sri Lanka, Central Bank of Sri Lanka (2019)

2.4.3 Tea exports to international markets

The types of tea exported from Sri Lanka to international markets involve an array of products varying in sizes and degree of value addition as bulk tea, tea packets, tea bags, instant tea, green tea and ready to drink tea (Sri Lanka Tea Board 2019). Over the years, Sri Lanka has shifted from exporting a majority of bulk tea to value added tea exports trying to adapt to competitiveness. The growing competition from the newly emerging and growing exporting countries has exerted pressure on the Sri Lankan tea industry.

One outcome is that Sri Lanka has recently lost share in the global market (Herath et al. 1998; Kasturiratne 2008), with a sharp decline since 2015/16 according to Figure 2.10. Sri Lanka has lost shares in traditional markets such as Pakistan and United Kingdom recently to Kenyan teas because of the high cost of production in Sri Lanka (Hilal and Mubarak 2016).

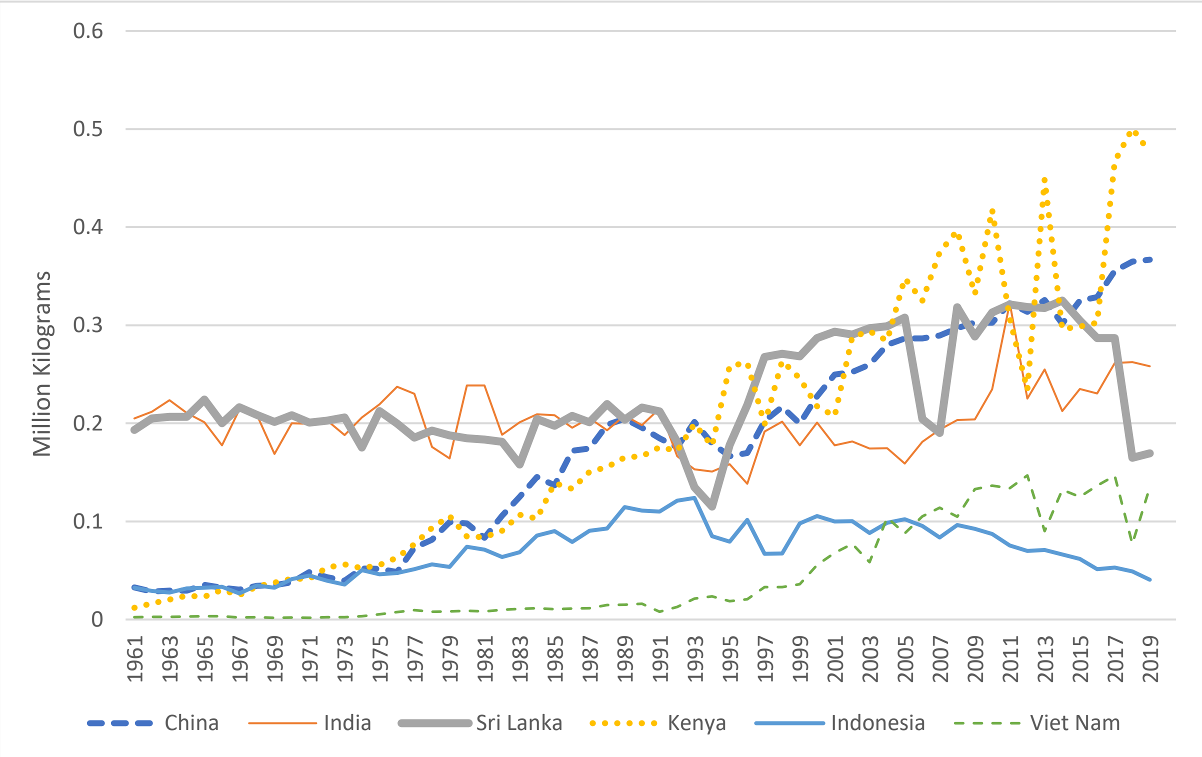


Figure 2.10. Export quantities by top exporting countries in the world. Source: Food and Agriculture Organization (FAOSTAT) 2020

2.4.4 Tea prices

Prices for made tea manufactured in the country are decided at the Colombo tea auction which is the second largest tea trading center in the world next to the Mombasa tea auction in Kenya. Sri Lankan teas fetch substantially higher prices than other auctions each year for several reasons including good quality in tea produce, demand growths, supply changes, high cost of production and currency depreciation trends (Sri Lanka Tea Board 2016d).

Average sale prices of tea from the high, medium and low grown areas received at the Colombo tea auction is given in Figure 2.11. Low grown teas have received higher prices at the tea auction compared to the other two elevations. Tea prices have steadily increased from 2007 to 2017 except in 2011, 2015 and 2018. The average Colombo auction price recorded around a 99 per cent increase in the decade while all three elevations also recorded the highest ever price in 2017 at more than Rs.550 per kg. The average Colombo auction price in all three elevations have declined by 6 per cent in 2018 compared with 2017.

The key reason for the price decline is that the Sri Lankan rupee depreciated sharply over the last four months of 2018. Furthermore, reduced demand for tea from Japan has greatly affected the prices of high-grown tea in the Colombo tea auction (Fernando 2019).

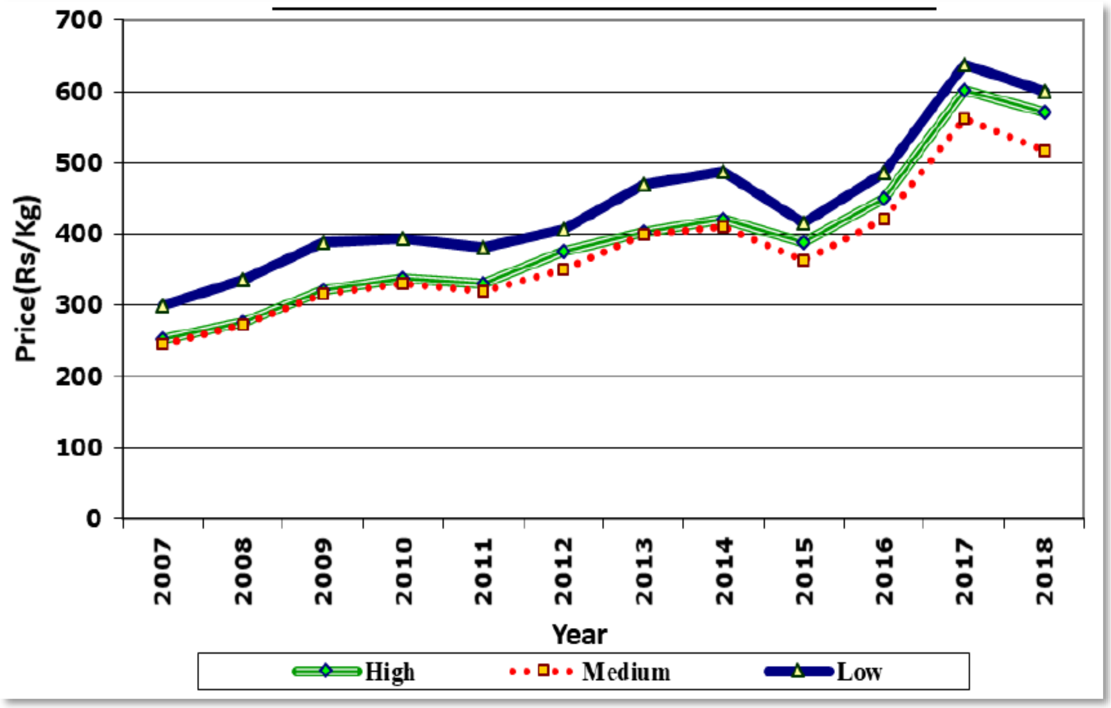


Figure 2.11. Colombo auction average black tea prices, 2007-2018. Source: Sri Lanka Tea Board (2020)

2.5 The tea production and market levels involved

2.5.1 First commercial tea cultivation

The introduction of tea to Sri Lanka had taken place during the colonial period under the British in the 19th century after coffee plantations were destroyed by the fungal disease; *Hemileia vastatrix* which is widely known as Coffee rust, Coffee leaf disease or coffee blight. The first commercial tea plantation was established in 1867 by a Scottish planter, James Taylor at Loolkandura Estate in the Kandy District of Sri Lanka (Sri Lanka Tea Board 2018). Tea plantations soon expanded in the hill country and then in Uva basin and the country became a leading tea producer thus playing a vital role in the economy of the country as a foreign exchange earner.

2.5.2 Nationalization and privatization of tea lands (from British planters to Regional Plantation Company, state-owned plantations and smallholdings)

During the early stages of the plantation industry, tea lands were mostly owned and run by Europeans and gradually with the emerging local middle class particularly low country Sinhalese, they too became owners of tea estates. There were a few small holders in tea cultivation but none in the processing of tea as the manufacturing or processing was only limited to large scale operators due to the requirement of substantial capital for those activities.

In the post-independence period, foreign ownership of tea lands declined because of the growing interest of investment opportunities in other colonies and the development of a voice for nationalization of tea lands by political groups. As a result, during the period between 1972 to 1975, the government implemented the major policy change of nationalization of plantations including tea plantations in achieving a socialist society by implementing the Land Reform (Amendment) Act (Sri Lanka Tea Board 2018e). Subsequently, the government acquired all holdings under control of land areas above 20 ac (8 ha) leaving lands less than 20 ac under private ownership which accounted for only about 40 per cent.

Performance of tea small holders had grown significantly after 1980s, during 1992/93 due to the boom in the interest for low grown tea from the Middle East, Russia and Commonwealth of Independent States and encouragement provided by the government to the tea smallholding sector by establishing the TSHDA and providing incentives such as subsidies for planting, replanting and inputs such as fertilizer and planting material (Sri Lanka Tea Board 2018e). Simultaneously there has been a sharp decline in the contribution of the state-run plantations to the national tea production, making the sector more unproductive.

This led to the introduction of the restructuring program where tea lands under the state control were handed over back to the private sector management. Today the estate or plantation sector comprises 23 Regional Plantation Companies and the ownership is held by large companies /conglomerates.

2.5.3 Key market levels and participants in the tea industry

The key market levels in the value chain of the tea industry in Sri Lanka consist of the tea cultivation sector, tea manufacturing sector, secondary tea processing and traders/marketers.

Farm sector

Tea plantations in Sri Lanka can be classified as being grown and managed by either smallholders or the private sector and the estate sector (Tea Small Holdings Development Authority). There are several definitions given for tea smallholders in Sri Lanka with varying land sizes falling under the category of smallholders. However, as per the definition given by the Tea Control Act, tea lands less than ten ac (4 ha) are considered as tea small holdings. The Tea Small Holdings Development Authority was entrusted with powers by the Minister of Plantation to perform development activities of tea lands ranging between 10 to 15 ac (4 to 6 ha) under the purview of Sri Lanka Tea Board (Tea Small Holdings Development Authority 2018). Therefore, tea lands less than 50 ac (20 ha) with private ownership have been receiving assistance services required for the development from the institution.

The estate sector has been categorized as an agricultural holding of 20 ac or more in extent and under the same unit of management. It was not considered as an estate when different blocks of landholding may add up to 20 ac or more. The estate sector consists of RPCs, State Plantation Board, Janatha Estates Development Board and other entities such as Tea Research Institute, Tea Small Holders Factories Ltd. Etc. (Tea Small Holdings Development Authority 2018).

Nearly 75 per cent of the national tea production comes from many smallholdings who are concentrated mainly on the low elevation tea producing areas operating in relatively smaller scales than estate holdings which are mostly found in the higher elevation tea producing regions contributing to the rest of 25 per cent (Sri Lanka Tea Board 2017). Breakdown of the tea production by each management group is presented in detail in Rathnayake *et al.* (2021).

The extent under tea cultivation in each district in Sri Lanka can be categorized into smallholding sector and the estate sector. The distribution of tea growing districts in Sri Lanka by respective sectors is presented in Figure 2.12.

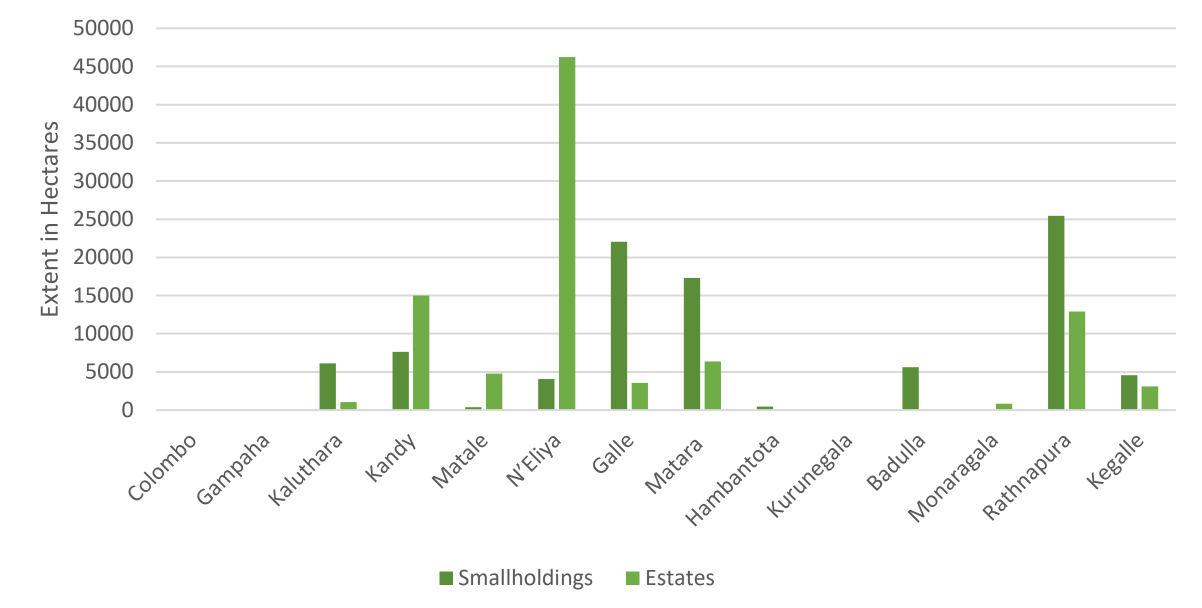


Figure 2.12. Area under tea in by sector in tea growing districts in Sri Lanka. Source: Census of Agriculture 2002, Department of Census and Statistics, Sri Lanka

Green leaf dealers/collectors

Green leaf dealers are the middle-people between green leaf producers and tea processors engaged in trading harvested green leaf. The Sri Lanka Tea Board reported that in 2009, 1703 registered green leaf dealers were distributed around the country (Wijayasiri 2013). Licensed green leaf dealers act as intermediaries between tea growers and tea factories in collecting and delivering green leaf. They are responsible to pay a reasonable price to the tea growers based on the factory net sale average.

Tea processing factory managers

Green leaves harvested from tea estates undergo the manufacturing process in tea factories operating under private owners, state sector and RPCs. Of the total manufacturing factories in Sri Lanka, 60 per cent, 34 per cent and 6 per cent on average were owned by private, RPCs and government (Wijayasiri 2013; Hemaratne 2016).

The RPC factories receive green leaves from their own tea lands and therefore are mainly own leaf processors but also supplied by smallholders or bought leaf. Private factories do the manufacturing process with bought leaf received from smallholders, private tea estates and licensed green leaf dealers whereas state sector factories operate with own leaf from state owned estates and bought leaf from smallholders and green leaf dealers.

Private factories maintain a close association with smallholders and collectors to create a beneficial state for all the parties. Such factories pay the highest price for a kilogram of green leaf and offer loan services, inputs including fertilizer and agrochemicals, planting material on credit systems, transportation of goods etc. They also provide technical assistance through extension and training programs as well to ensure the regular and improved supply of green leaf and also to provide an incentive for their growers not to switch to other factories (Wijayasiri 2013).

Tea brokers

There are around eight tea brokers in the country who act as intermediaries between tea processors and their buyers.

Registered secondary processors, packers and exporters

There are more than 450 tea exporters and tea packers in Sri Lanka who sell tea to the global market. Some of these processors also reclaim black tea from factory remnants which are of low quality, also known as refuse tea. This is bought by licensed refuse tea processors and undergo a value adding process maintaining hygienic standards under close monitoring by the authorities (Hemaratne 2016). In addition, processing factories also buy made tea from tea factories and further process it to add value to the initial product, which they then send to the Colombo tea auction for marketing.

Made tea is marketed and traded mainly in the tea auctions through the licensed produce brokers (auctioneers) and they act as accredited agents of all tea manufacturers for cataloguing of tea, quality assurance, warehousing, selling at the auction etc. There are eight selling brokers that closely work with the Colombo tea auction (Hemaratne 2016). The auction is held twice a week throughout the year and provides a convenient and competitive market for tea buyers and sellers.

Types of buyers in the tea auctions are registered exporters, and registered packers of tea. Both these buyers after purchasing made tea engage in cleaning, blending with other teas and/or ingredients (flavored tea; herbs, flower petals, fruits) and packing in bulk, packet and/or tea bag form (Ariyawardana 2001). These finished products are exported to international destinations based on the demand from buyer countries. They are also made available and marketed in Sri Lanka for the domestic consumers.

There are also local dealers who purchase made tea from tea factories and reclaimed processors and deliver to the local market for wholesale and retail. They also do value addition through product diversification with quality teas.

2.6 Policy framework of the tea industry

There are several policies imposed on different market levels in the tea industry by the government. Such policies are implemented through government institutes working closely with the tea industry.

2.6.1 Government institutes working with the tea industry

Several institutes have been set up over the past decades with the aim of coordinating and administering government interventions, eventually uplifting and assisting the production, manufacturing, marketing, trade, and promotion of the industry. These are the Sri Lanka Tea Board, Tea Small Holdings Development Authority, Tea Research Institute of Sri Lanka and the Ministry of Plantation Industries and Export Agriculture that work with the tea industry stakeholders to achieving the stated objectives.

Accordingly, in terms of tea production related activities, TSHDA, SLTB and TRI engage with smallholders, medium-scale private sector growers and corporate sector (RPCs and state-owned plantations) respectively. The SLTB, being the prime body responsible for regulation and administration of the tea industry in Sri Lanka, performs a wide range of operations in collaboration with the rest of the government institutes and private organization collectively to achieve recognition and reputation for Sri Lankan tea in the global market.

In addition, the Ministry of Plantation Industries assists the tea industry while working with other plantation crops while the Export Development Board works for export promotion of Ceylon tea products.

There are several non-government institutes such as Tea Shakthi Fund and Dilmah Tea Foundation with significant contributions to the development of the tea industry in Sri Lanka.

2.6.2 Production and trade policies

Unlike any other commodity there were direct and indirect taxes applied in the tea industry during the 1950s to late 1990s. At present, the Cess[2] is in place as a commodity tax that is levied on tea exports by the government. Proceeds are diverted back to development activities of the tea industry for research and development, tea promotion and also as subsidies.

[2] Cess is a form of tax charged/levied over and above the base tax liability of a taxpayer.

Taxes

There had been several direct and indirect taxes on tea exports until the 1990s when all were abolished. These taxes had been disadvantageous on industry competitiveness (Ganewatte and Edwards 2000). Currently there is only one commodity tax existing on tea exports called Cess. This tax is paid by tea exporters as a promotional levy. Bulk teas and value-added teas are charged Rs. 13.50 and Rs. 7.50 respectively for every kilogram of tea exported (Silva 2018). Funds collected through the Cess are injected back to the industry welfare and development via financing Tea Board operations, nominal subsidy provision to smallholders, assistance and advertising schemes, research and development, and public relations with Ceylon tea importing countries (Ali *et al.* 1997; Ganewatte and Edwards 2000; Silva 2018).

Subsidies

According to Ali, Choudhry *et al.* (1997); Ganewatte and Edwards (2000), subsidies in the tea industry fall into four groups. These are, (i) field rehabilitation and development subsidies, (ii) short term production subsidies, (iii) factory development subsidy and (iv) marketing subsidies.

Field rehabilitation and development subsidies

There are several field rehabilitation and development subsidies available for producers for enhancing production and maintaining the sustainability and good farming practices of tea cultivation. They are re-planting, in-filling and new-planting support programs.

The main objective of undertaking the re-planting program for all producer groups is mainly to address the land degradation problem, particularly the soil erosion taking place in tea cultivating areas because of the high rate of vacancies in tea fields with seedling teas (Ganewatte and Edwards 2000). It is expected through these subsidy programs to offer financial assistance and make capital available for tea growers to rehabilitate and develop tea lands.

Tea estates in the corporate sector and private sector (more than 10 ac of extent) operating in large scale are provided with low interest loans with the loan repayment guarantee by the government through the subsidy program that is coordinated by the Tea Commissioner's division of the Sri Lanka Tea Board (Sri Lanka Tea Board 2019).

The subsidy provided to tea smallholders is facilitated by the TSHDA in a systematic and stepwise approach. The TSHDA has introduced a 'land development subsidy scheme' that consists of replanting with soil rehabilitation, replanting without soil rehabilitation and crop rehabilitation programs. Tea replanting programs (with and without soil rehabilitation) offer cash subsidies for entitled smallholders with supervision and recommendation on the activity by tea extension officers. It was expected to uproot and replant an area of 1450 ha of tea lands by this program in the year 2016 (Tea Small Holdings Development Authority 2016).

The crop rehabilitation program provides a crop rehabilitation incentive allowance (cash) to entitled smallholders mainly for infilling of tea plants along with some other activities such as trimming, soil conservation, and shade control in fields, that are usually done after tea bush pruning (Tea Small Holdings Development Authority 2016).

A separate program on tea new planting is also conducted by the TSHDA with government provisions to increase the area under tea production, where 109 ha of land has been planted with tea in 2016 (Tea Small Holdings Development Authority 2016).

Short term production subsidy

The fertilizer subsidy provided by the government is included in this short-term production subsidy. The subsidy on fertilizer has been provided to smallholders cultivating plantation crops including tea since 2006, administered by the TSHDA (Weerahewa *et al.* 2010). This fertilizer subsidy program is a significant burden on the treasury of the country (Weerahewa, Kodithuwakku *et al.* 2010). This cost of the fertilizer provision is eventually borne by taxpayers of the country (Ganewatte and Edwards 2000). The goal of this program is to back small-scale tea growers facing increased input costs in cultivation and fall in green leaf prices (Ali, Choudhry *et al.* 1997). Assistance for smallholders by providing fertilizer improves yields and income, and ultimately aids rural development and national economic development (Shyamalie *et al.* 2011).

In 2016 the fertilizer subsidy policy was reformed. Instead of providing fertilizer at a subsidized price, the government introduced a Fertilizer Cash Grant system, expecting farmers to buy fertilizer from the market. The newly introduced policy was in place only till 2017, and it was changed back to the previous system from 2018.

Factory development subsidy

The factory development subsidy is administered by the Sri Lanka Tea Board. The subsidy is permitted for corporate and private sector tea factories. Funds will be granted for factories to correct and upgrade existing limitations for the made tea production process; related to machinery and equipment

(Sri Lanka Tea Board 2018). The capital for this program is generated through the Cess collection from the year being available for the tea manufacturing sector development. This subsidy has contributed to the efficiency enhancement of made tea manufacturing while converting factories’ tea processing method from orthodox to CTC tea varieties (Ali, Choudhry *et al.* 1997).

Marketing subsidies

Marketing subsidies are issued for the strata of the industry dealing with tea marketing. Such subsidy programs are grants for tea promotion, import duty rebates and grants from the Export Development Board. This has encouraged tea exports and promoted the Ceylon tea brand across the global tea market and various other countries.

Price regulations

The government has intervened in regulating prices of inputs and commodities to facilitate the producer sector. The green leaf price formula is one such regulation that the government has implemented to assure a fair price paid by tea manufacturers to green leaf producers avoiding exploitation (Ganewatte and Edwards 2000).

Additionally, a guaranteed minimum price for green leaf harvest has been set by the government during time periods when green leaf prices drop as made teas at the auction fetch low prices, to avoid low payment to green leaf suppliers (Silva 2018).

Made tea produced in tea manufacturing factories are usually disposed through the public auction, direct sales and private sales from the factory. Private and direct sales of made tea from the factory that bypasses the tea auction were restricted in 2008 by the government (Wijayasiri 2013). This was to ensure a fair price for all the made teas facilitating a regulated disposal of tea. Therefore, the main method of made tea disposal from the factory is the publicly held tea auction (Sri Lanka Tea Board 2017).

There are restrictions imposed by the government on tea imports from other countries. The policy has been favored and opposed by a few groups of stakeholders in the tea industry, and at present, tea is imported at regulated quotas by tea processors and exporters for the purpose of value addition through blending.

The government plays an active role in creating an environment for and involving in negotiations with trade unions, employers of the corporate sector on setting up minimum wage for estate workers.

Research and development

Tea Research Institute of Sri Lanka is the only national institute that discovers and invents new technologies through research and disseminates that knowledge through extension. Research conducted in the TRI is mainly based on tea cultivation and processing. Accordingly, following research and experiments, the TRI has introduced numerous recommendations which are updated for all tea cultivation practices, pest and disease management, land and soil conservation, tea processing methods. Moreover, new machinery and equipment have been introduced as a result of research and development conducted.

Knowledge and technology dissemination

Generated new knowledge and technology including updated recommendations, machinery, techniques of cultivation practices and processing are disseminated to the respective target groups through government bodies working with the tea industry.

Accordingly, TRI, Sri Lanka Tea Board, and TSHDA are the responsible government bodies for knowledge flow through events such as extension forums, publications, circulars ad news. Extension to the corporate sector engaged in tea cultivation and manufacturing is provided by the TRI.

Both the Sri Lanka Tea Board and TSHDA have field level extension officers assigned for every division within all tea growing districts. These extension officers visit their respective grower groups and provide knowledge through extension events such as training and awareness programs, workshops and consultation sessions. Training sessions have been useful in introducing new machinery, proper cultivation practices, skill development in tea plucking, pruning, shade tree management. In addition, officers pay individual visits to tea growers and offer site specific and customized knowledge and advice. Extension officers of the Sri Lanka Tea Board also work with private tea manufacturers in addition to private tea estate owners and offer knowledge and technology related to tea processing.

Promotion, advertising and marketing of made tea

The promotion division of the Sri Lanka Tea Board is the national body that supports and supplements the promotion, marketing and advertising activities of Sri Lankan tea exporters and brand holders in the global tea market. The main intentions through promoting, advertising and marketing is to identify and establish trade links with potential niche markets, expanding the markets available for Ceylon tea while lowering the threat of losing volatile markets.

The Sri Lanka Tea Board itself owns the 'Ceylon Tea' brand with the famous 'lion logo' among the global tea drinking community. The trademark (Ceylon tea with the lion logo) displayed on a tea product from Sri Lanka implies that 'the tea grown, manufactured and packed entirely in Sri Lanka confronting to strict quality standards laid down and administered by the Sri Lanka Tea Board' (Silva 2018). Usually, this trademark is displayed on the product packaging of made tea processors and exporters trading Sri Lankan tea to the global market. Strict regulations have been imposed by the Sri Lanka Tea Board to avoid misuse of the trademark.

There is a network of promotional offices of the SLTB located abroad that facilitate marketing and promotion operations of Ceylon tea. Participation in international trade fairs, events and forums by the Tea Board, representing Sri Lanka to promote Ceylon tea among the global population is at a satisfactory level. The SLTB also facilitates tea exporters participating in such events, while organizing local campaigns open to foreign traders to market, advertise and promote Ceylon tea.

Research, promotion and advertising are direct public good provisions as an outcome of the government intervention in the tea industry (Ganewatte and Edwards 2000). Financial assistance for all these activities is funded by the revenue collected through the export tax earned by tea exporters.

Quality control of made tea

The government has been involved in assuring the required quality and monitoring the minimum quality standard of tea through the tea exports section of the Sri Lanka Tea Board. Hence, certifications for Good Agricultural Practices (GAP), Rainforest Alliance (RA), quality assurance for food safety and Good Manufacturing Practices (GMP) such as ISO 22000, Hazard Analysis and Critical Control Point (HACCP) and Sri Lanka Standards (SLS) series, have been introduced over the years. Every manufacturer, processor, and exporter are required to acquire respective certifications under the strict monitoring and regulation of the Sri Lanka Tea Board.

In addition to the funds collected from export taxes and government provisions, financial assistance is received by donor organizations such the Asia Development Bank to improve the tea industry of the country through infrastructure development and providing loans to estates and smallholders.

According to Ganewatte and Edwards (2000), the sole intention of government intervention is not correcting market failures by fair and efficient allocation of resources and social welfare. Sometimes there are underlying political motives behind all these policy frameworks that operate for the favor of influential groups, manipulating policies and regulations for their desire and advantage.

Nevertheless, there are common problems, issues and challenges faced by all participant groups in the industry themselves. Such matters hinder their potential capacities and achievement of the set objectives of these policies of the industry, economic and national interest.

2.6.3 Government regulations on industry banning chemical use in tea cultivations

Chemical use policies

Several chemical use restrictions, either direct or indirect, have been applied in different stages of the tea industry over the past years. The national policy to restrict the use of some weedicides, in particular Paraquat and Glyphosate, used in the country on agriculture has indirectly affected the tea industry over the past decade.

Paraquat had been a popular weedicide in the tea industry as well as in other crop cultivations such as paddy until it was completely phased out in 2012. The public health issue arose in the country due to Paraquat poisoning was the reason behind the government intervention to restrict its use. This has created an indirect impact on the tea industry as Paraquat was the commonly used weedicide in tea fields.

Soon after the Paraquat phase out, Glyphosate took over its place and became the most used and cost-effective weedicide until it faced the same fate as Paraquat did. Accordingly, the use of Glyphosate on all crops was restricted by placing an island-wide ban in 2015 till 2018. It was due to the national policy in addressing a major public health issue of the CKDu in the country.

2.7 Current issues in the farm sector of the tea industry

Challenges and issues faced by the farm sector are comprehensively highlighted and discussed by Rathnayake, Malcolm *et al.* (2021). Accordingly, stagnant or shrinking areas under tea cultivation, low land productivity, low labour productivity, labour shortages, high costs of production, low reinvestment rates, land degradation, constantly shrinking profit margins, and climate change have been identified as key issues in the farm sector (Jayasuriya 1998; Ganewatte and Edwards 2000; Jayasuriya 2003; Kasturiratne and Poole 2006; Samansiri *et al.* 2011; Wijayasiri 2013; Thushara 2015; Shyamalie 2015a; Shyamalie 2015b; Gunarathne and Peiris 2017; Wekumbura *et al.* 2017).

2.7.1 Labour issues

Labour related issues have increasingly challenged both tea grower sectors. Labour scarcity and labour outmigration can be commonly observed in the cultivation sector (Dharmadasa and De Zoysa 2012; Wekumbura, Mohotti *et al.* 2017) eventually leading to increased labour demand.

Labour productivity in the estate sector has been found to be sub-optimal because of low land productivity and inefficient labour use (Ganewatte and Edwards 2000). A reduction in the available supply and quality of labour is common in most tea estates. Subsequently, low labour productivity has resulted in low yields and higher costs of production in tea grower sectors (Ali, Choudhry *et al.* 1997; Ganewatte and Edwards 2000).

Government intervention in minimum labour wages and successful labour union activities demanding higher wage rates have sharply increased wage rates of both estate and private tea grower sectors over the past few years. Continuously escalating wages are an issue for tea growers regardless of the scale of operation.

2.7.2 High cost of production of green leaves

Low land and labour productivity and associated relatively high cost of production are closely related. Higher costs of production can make an industry less competitive in the global market (Ali, Choudhry *et al.* 1997; Ganewatte and Edwards 2000) and less profitable (Shyamalie 2015b). Sri Lanka has the highest cost of production in comparison with other tea producing countries, in turn affecting its competitiveness (Ganewatte and Edwards 2000; Munasinghe *et al.* 2017). For instance, green leaf production cost in the smallholder sector has escalated by 34 per cent from 2014 to 2018 (Tea Small Holdings Development Authority 2014; Tea Small Holdings Development Authority 2018).

The private tea grower sector has a comparative advantage over the estate sector over the share of fixed costs that influence the cost of production. The estate sector has implicit fixed costs owing to the scale of production and management hierarchy.

With the increasing cost of production of green leaves, and associated decreasing profit margins in businesses, tea growers have, to the extent it is possible, adapted techniques that demand less labour and fewer inputs such as chemical weeding, even at the cost of human health and environment. Even so, because of increasing production costs and low profit margins from green leaf sales, most tea landholders or estate managers have been reluctant to invest in new techniques, and in essential field activities such as soil rehabilitation and replanting that require extra capital (Munasinghe, Deraniyagala *et al.* 2017).

2.7.3 Government policy barriers

Recent government policies implemented on the agriculture sector in Sri Lanka has adversely affected the tea industry leading to costs and unintended consequences.

The island-wide ban on Glyphosate use has resulted in several effects on the farm sector including increased costs on weeding because of incorporating more labour and unsuccessful weed control efforts with alternative weedicides in the absence of Glyphosate (Abeywickrama *et al.* 2017). The ban has also facilitated the entry of illegal Glyphosate products into the country through informal channels (Marambe and Herath 2019) in turn narrowing down the profit margins of green leaf production businesses of those who used such products. Such Glyphosate products with unknown formulations were reported to be highly concentrated and toxic, with instances of damaged tea bushes and soils resulting from their use, but less effective on weeds in most cases.

Another policy change implemented in the agriculture sector in 2016-2017 was changing the price subsidy on fertilizer to a cash voucher system with the intention of reducing the chemical fertilizer use in agriculture (Wijetunga and Saito 2017). This policy adversely affected the productivity of tea cultivations as tea smallholders reduced recommended frequencies and/or quantities of fertilizer because of its high price in the open market. This in turn caused yield declines.

2.7.4 Climate change

During the recent past, 2016 and 2017 have been years with extreme weather events which have affected tea production (Wijeratne et al., 2007; Sri Lanka Tea Board, 2016a, 2017). This has directly affected the farm sector in production since rainfall and temperature are significant parameters that the crop production is dependent on.

2.7.5 Poor agricultural practices

The sustainability of tea cultivation in the farm sector depends on good agricultural practices. The yield will be adversely affected unless otherwise. Better prices can be ensured for made tea at the auction when good agricultural practices are adopted that results in high quality of the green leaves (Karunathilaka and Samaraweera 2017). Not following recommended practices in the field such as underuse and overuse of fertilizer and agrochemicals, delayed infilling, pruning and replanting that can also affect the health of tea bushes are widely seen in tea smallholders unless they have been registered in a certification scheme.

2.7.6 Lack of managerial skills and entrepreneurial attitudes

Many tea growers operating on a small scale have poor skills in managing their business. They often have little grasp of the detail of expenses, green leaf sales and income of their business, relying on the information about their operation from their green leaf dealers. Lack of managerial and entrepreneurial skills in the business is a weakness that eventually affects the performance of the business.

The adoption of labour-saving mechanical technologies in field operations is limited among both the smallholder and the estate sector in Sri Lanka (Herath and Weersink 2007). Even though numerous attempts have been made by the TRI and government institutes to introduce machinery into field operations, especially mechanical harvesters for green leaf harvesting, they have not been successful.

2.8 Summary

In this chapter an overview was presented of the tea industry in Sri Lanka. As a commercially cultivated crop, tea plays a significant role in Sri Lankan economy, being the highest foreign exchange earning agricultural commodity. The industry is equally important in creating employment and providing a livelihood for a significant proportion of the population, directly and indirectly. Sri Lanka is a significant participant in the international tea market, being one of the largest black tea producers. However, the competitiveness of the industry has degraded over time, for several reasons, including changes in the world market and performance-related factors in the value chain of the industry and farm sector.

The main market levels in the tea industry are the private and estate tea grower sectors, tea manufacturers, brokers, secondary processors and marketers including exporters and retail marketers. There are issues related to each sector in the value chain, but problems faced by the farm sector are critical as they are the primary producers in the industry. Currently, the farm sector is experiencing issues with labour, high costs of production, government policy barriers, climate change.

Although government policy frameworks implemented are ostensibly intended to be beneficial to the industry, some policies and other public interventions have adversely affected the performance and sustainability of some market levels and the industry itself. Examples from the recent past on policy decisions that challenged the tea industry are chemical use policies and fertilizer subsidy changes.

Chapter 3 Review of Literature

3.1 Introduction

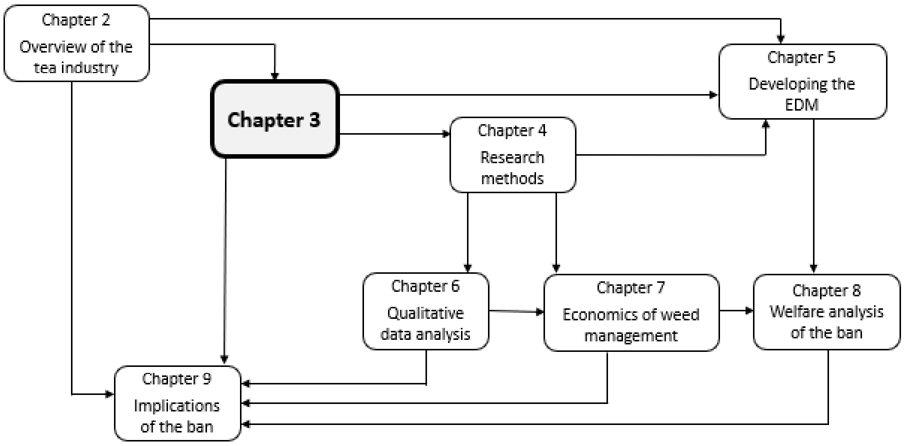


Figure 3.1. Flow of chapters in the thesis

A review on the literature from various aspects in tea cultivation and Glyphosate use is presented in this chapter. Sections 3.2, 3.3, 3.4 and 3.5 in the chapter provide information from the literature on mature tea upkeep, cost structures in tea cultivations across the two grower groups, factors influencing the production, and weed management in tea cultivation in Sri Lanka. The second half of the chapter reviews literature on Glyphosate use trends in the world and in Sri Lanka. Section 3.8 discusses Glyphosate use policies in the world and Sri Lanka with emphasis of economic impacts of a potential ban on agricultural industries in the following Section 3.9. Methods used by studies that evaluated economic impacts of such Glyphosate withdrawals is highlighted in Section 3.10 by providing insights to designing the method of this study as presented in Chapter 4 and developing the EDM for the tea industry in Sri Lanka that can capture impacts of a Glyphosate ban in Chapter 5 as presented in Figure 3.1. Finally, in Section 3.11 the literature propositions reviewed in this study are presented.

3.2 Mature tea upkeep in commercial tea cultivation

Tea – *Camellia sinensis* – grows in a wide range of tropical and sub-tropical climates, mainly in mountainous regions with altitudes ranging between 600 to 1500 m above sea level. This woody perennial shrub can grow up to around nine meters tall if left untended and can have a lifespan of more than 100 years. Tea requires a rainfall of 1,200mm per year minimum with at least 60mm per month during dry periods for its growth. Deep well-drained acidic soils are essential for better growth of the tea plant where the preferable pH ranges between 4.5 to 5.5 (Sri Lanka Tea Board 2018a).

Tea bushes in a commercial tea cultivation start producing four to five years after planting and the economic life span of tea bushes usually ranges between 30 - 50 years. Production drastically declines thereafter. Better management of tea bushes through good agricultural practices can extend the economic lifespan of the cultivation. The harvest of a tea cultivation is young shoots having two to three tender leaves and dormant shoots (Tea Research Institute of Sri Lanka 2003). The continuous production of foliage is ensured by encouraging tea bushes to remain in the vegetative stage of their life cycle by conducting frequent plucking and pruning once in three to four years.

Tea propagation can be done either through seedlings from polyclonal, bi-clonal or hybrid seeds and vegetatively through single leaf nodal cuttings of plants with superior characteristics (Mukhopadhyay and Mondal 2017). The latter is the most practiced and popular among tea growers at present. Vegetatively propagated (VP) tea cultivars have been subjected to many improvements of attributes over the years to address requirements such as biotic and abiotic stresses, agro-ecology and consumer preferences in final products reaching international markets.

Field activities involved in tea cultivation and mature tea upkeep are common across all grower sectors including tea smallholders, medium and large-scale estates. Tea cultivation starts with the clearing of all trees, shrubs and scrubs of a sloping hillside and replacing the land with tea bushes (Sri Lanka Tea Board 2018a). In the land preparation process for tea planting, first, the land is surveyed and lined to mark the contours so that the future tea bushes lie along these contours with the same altitude. Shade trees and grasses are planted amid the tea bushes to provide partial shade and further control soil erosion. Next, the position of each tea bush is marked, drained and holes are made to receive the plants. Usually, VP cuttings kept in the nursery are transplanted into holes. Then the young tea plant is encouraged into a bearing phase by forming a low spreading bush with a thick canopy with as many plucking points as possible to enable convenient harvesting. This includes pruning of the tea bush, tipping and fertilizer application to induce growth of the tea bushes.

The mature tea upkeep stage involves harvesting of fresh tender tea leaves – green leaves - mostly by labour manually, fertilizer application/ plant nutrition management, weed management, pest and disease management, shade tree management, pruning and post pruning practices such as dolomite application, tea bush sanitization, and tipping (Sri Lanka Tea Board 2018a). All these field operations involve labour as mechanization is not widely practiced in the majority of tea cultivations.

As highlighted by Hettiachchige and Rathnayake (2021), tea cultivation in Sri Lanka takes place in three distinct regions classified on the elevation as up-country, mid-country and low-country all belonging to the wet zone and receiving relatively higher rainfall throughout the year. Climatic conditions including hours of sunshine and winds vary across each region giving rise to unique characteristics in the final produce and slight variations in tea cultivation and upkeep practices as well. Hence, there are differences in frequencies of plucking, fertilizer management, weed management and shade tree management along with resource allocation on these activities. For example, longer sunshine hours in low-country tea growing regions than in up or mid-country regions induce fast growth in tea shoots, weeds and shade trees, hence green leaf harvesting, weed management and shade tree management are carried out within shorter intervals than other regions. Also, these differences in prevailing weather conditions have resulted in yield variations across the tea growing regions.

3.3 Economics of tea cultivation

Roberts (1989) highlighted that the green leaf production in the estate sector in Sri Lanka follows constant returns to scale. However, this idea was rejected by several researchers including Wickramasinghe and Cameron (2003) stating a scale neutral production in tea cultivation. They argued that labour used in field management activities absorbs the highest expenses in the green leaf production despite the extent of the landholding because economies of size in production does not apply in tea cultivation.

Costs incurred by the two main tea grower sectors – tea smallholders and RPC estate management are discussed in this section. There are slight variations in the cost structures of green leaf production in these sectors owing to differences in the management and related factors.

3.3.1 Cost structure in leaf production by the tea grower sectors

Despite the scale of production of green leaves in the estate sector with large plantations and the smallholder sector with small pieces of landholdings the same technology is adapted by both sectors in conducting management practices (Roberts 1989).

Labour allocation on management practices in smallholder production units subject to variability depending on the labour availability unlike in tea estates that employ a relatively fixed number of labourers for each practice from their residential labour force despite increasing concerns over labour scarcity. The estate labour wage rates had been very cheap since the 1980s (Herath and Weersink 2009). Wage rates have started escalating following the establishment of labour unions in estates, related union actions and subsequent government policy changes on wage rates over the past few years. Subsequently, the gap between wage rates of the residential estate labour and casual hired labour in the smallholding sector has narrowed. This effect has been reflected on the production cost margins within the two producer groups, reducing the comparative advantage of green leaf production by large-scale growers (Herath and Weersink 2006). On the other hand, there can be inefficiencies associated with the large plantation sector being managed by a centralized body of authority and high cost of labour, supervision and shirking (Herath and Weersink 2006). Smallholders inherently gain a comparative advantage over estate plantations because of the management by the owner and the dependence on family and hired labour for conducting field activities that can lower transaction costs (Wickramasinghe and Cameron 2003).

Large plantations under tea cultivation belonging to the estate sector in Sri Lanka cover an extent of 200-250 ha on average. The estate is managed by an estate manager (superintendent), around 30 staff, and a residential labour force of about 600. There has been a significant increase in the number of small holdings of tea since the 1970s because of the changes made on land reform policies by seizing tea farms larger than 50 ac (Jayasuriya 1998; Wickramasinghe and Cameron 2003; Herath and Weersink 2009). The tea smallholder sector started receiving government attention and policy support during the 1990s (Wickramasinghe and Cameron 2003) and continues to receive provisions now. The government policies that are implemented on the tea industry were discussed in the previous chapter.

The majority of low country tea cultivations managed by smallholders that had been established after the 1990s are mostly cultivated with VP tea clones that give a higher yield than seedling teas (Jayasuriya 1998), while up and mid-country tea plantations mostly managed by plantation companies are still using old seedling tea. This has become a critical factor that has resulted in yield variations across the two sectors in addition to geographical variations.

3.3.2 Cost of green leaf production by tea grower sectors

The breakdown of variable costs in mature tea cultivation, upkeep, and the production of green leaves by tea smallholders and estate sector are presented in the below section. There is limited updated information on the cost structure in the estate sector compared with the smallholder sector.

Tea smallholder sector

The TSHDA that closely works with tea smallholders in the country provides production cost estimation of green leaves annually in their annual report. Costs pertaining to green leaf production from VP tea in the low-country tea growing region are used for the computation. There could be slight variations in the frequencies of field activities related to the differences with the other tea growing regions.

Variable cost structure of the mature tea upkeep and production cost calculation of green leaves in the tea smallholder sector is presented in Table 3.1.

Table 3.1. Variable costs in mature tea upkeep and production cost of green leaves in the tea smallholder sector for the low country - 2019

Activity	Frequency of Practice	Labour units	Cost of material (Rs)	Total Cost (Rs)	Cost as a %
Variable costs					
Plucking (20 kg per individual per day)	1/2 labour 45 times	381		304,800	58.67
Weeding	10 labourers per month	58		62,640	12.06
Fertilizer mixture and application					
Adding fertilizer mixture to matured tea crops	8 labourers each (up to 2-4 occasions)	24	22,724	48,644	9.36
Adding Dolomite	4 labourers each (2 occasions cycle)	2	4,135	6,295	1.21
Adding Zinc	5 labourers each (2 times)	5	550	5,950	1.15
Shade management	5 labourers each (2 times)	10		10,800	2.08
Pruning	30-40 labourers each (2 occasions cycle)	20		30,000	5.77
Mossing	12-20 labourers each (2 occasions cycle)	6		6,480	1.25
Tipping	12-20 labourers each (2 occasions cycle)	6		6,480	1.25
Draining	36 labourers each (2 occasions cycle)	18		19,440	3.74
Infilling vacancies	16 labourers for 375 plants	8	9,375	18,015	3.74
		538	36,784	519,544	100
Green leaf yield per year per ha			9,537 kg		
Average production cost per kilogram of green leaves			54.48 (Except general expenses)		
Transportation expenses			1.80		
Cost of Production			56.28		
Notes: 2-year time cycle has been used for Lowlands Fertilizer mixtures and volumes are in accordance with the recommendations of TRI and the prices are that existed within the year. The transportation cost has been included in the cost of raw materials					
Price of a tea shoot plant (Rs)			25		
Daily wage of a labourer (Rs)			1080		
Daily wage of tea leaf plucking (Rs)			800		
Daily wage for pruning (Rs)			1500		
1 Metric Ton of Dolomite (Rs)			6200		
1 Kilogram of Zinc Sulphate (Rs)			50		
1 Metric Ton of UT-397/VPLC/U 709/ UT 752 (Rs)			23,000		

Source: TSHDA Annual report 2019

The highest cost of nearly 60 per cent of the total variable cost is absorbed by plucking as it is the most labour-intensive activity carried out by manually harvesting green leaves, while the second highest cost is incurred for weed management. The variable cost of production of green leaves has amounted to Rs 56.28 on average in 2019.

Estate Sector

There is little publicly available information on the gross margin budget or cost of production computations of green leaves for the estate sector. The Department of Census and Statistics Sri Lanka provides made tea cost of production calculations annually. As in Table 3.2, cost information on the mature tea cultivation, upkeep and green leaf production in the estate sector are extracted from the same source and costs are converted to per kilogram of fresh green leaves using the conversion factor 4.65.

According to Table 3.2, 71 per cent of costs in tea cultivation are incurred for labour wages since Sri Lankan tea cultivations are highly dependent on labour for carrying out field activities. The dependence on machinery is seen less frequently in tea fields.

Detailed information on the costs of mature tea upkeep in the corporate sector across different growing regions is given by Jayakody and Shyamalie (2002).

Table 3.2. Mature tea upkeep and cost of production of green leaves in the estate grower sector 2018/19

	For a kilogram of made tea	For a kilogram of fresh green leaves	Cost as a %
Labour wages on weeding, upkeeping etc. including weeding, upkeep of fences, establishment of cover crops, control of pests and diseases, manuring, plucking, pruning, supply of vacancies, terracing and draining, field watchers and miscellaneous activities	214.37	46.10	71
Material cost on fencing, pest and disease control, fertilizer, other materials and tools (plucking baskets)	28.73	6.18	9
Transport costs incurred in production	61.32	13.18	20
Cost of production of a kilogram of green leaves		65.46	

Source: Department of Census and Statistics Sri Lanka

The cost structure of mature tea upkeep in the up-country tea cultivations where most of the estate sector plantations can be found is presented in Table 3.3.

As shown in the table, pest management incurs the highest cost next to green leaf harvesting in the estate sector. This is because the incidence of pests and subsequent damage to tea bushes is high in these large-scale cultivations and a substantial effort should be invested in control.

Table 3.3. Mature upkeep cost in an up-country VP field (Rs/ha/year)

Items	Worker days	Worker cost (Rs)	Material cost (Rs)	Total cost (Rs)	Cost as a percentage
Plucking	637	86,577.60	19,062.62	105,640.22	62.29
Fertilizer application	25	3,400	11,202.80	14,602.80	8.61
Foliar application					5.64
Zinc sulphate	10	1,360	440	1,800	
Urea	7.5	1,020	252	1,272	
Epsom salt	10	1,360	1,344	2,704	
Manganous sulphate	7.5	1,020	1,200	2,220	
Fertilizer Boron	10	1,360	202.50	1,560.50	
Weed management					2.74
Manual	6	816		816	
Chemical	6	816	3,021.56	3,837.56	
Pest management					11.77
Tea Tortrix control	4.4	598.40	15,360	15,958.40	
Mites control	4.4	598.40	3,410	4,008.40	
Disease control					4.70
Blister Blight Control	29.7	4,039.20	3,927.53	7,966.73	
Shade management					1.04
Medium shade lopping	8	1,088		1,088	
High shade lopping	5	680		680	
Soil conservation measures					3.21
Stone terraces	10	1,360		1,360	
Desilting of drains	25	3,400		3,400	
Maintenance of roads and paths	5	680		680	
Total	810.1	110,173.60	59,423.01	169,596.61	100

Source: Jayakody and Shyamalie (2002)

3.3.3 Comparison of variable costs of production in tea smallholder and estate sectors

A comparison of the cost of tea cultivation by the two grower sectors in the tea industry in Sri Lanka was conducted by Shyamalie (2015b). An extract of the information from the study is presented in Table 3.4 with variable costs incurred and their shares across main field operations. The variable cost of production in the estate sector is higher than in the smallholder sector as the total labour requirement for tea field activities and the green leaf yield are much higher in smallholdings than estates. Consequently, the tea smallholder sector has reported a higher gross margin than the estate sector.

Table 3.4. Comparison of the variable cost of production of green leaves in tea grower sectors

	Smallholder sector					Estate sector				
Parameter	Worker Requirement (man days)	Worker Cost (Rs)	Material Cost (Rs)	Total Cost (Rs)	Cost as a %	Worker Requirement (man days)	Worker Cost (Rs)	Material Cost (Rs)	Total Cost (Rs)	Cost as a %
Operation										
Plucking	511	204,483	-	204,483	61	470	268,700	29,364	298,064	70
Fertilizer application	27	10,405	25,965	36,371	11	14	8,008	25,070	33,078	8
Other field operations	153	66,033	28,567	94,600	28	135	77,175	15,954	93,129	22
Total variable costs (Rs)	692	80,921	54,532	335,453	100	619	353,883	70,388	424,271	
Annual green leaf yield (kg/ha)		9,770					8,798			
Variable cost of production (Rs /ha)		34.33					48.22			

Source: Shyamalie (2015b), Agricultural Economics Division, TRISL, 2011

Furthermore, Shyamalie (2015b) highlighted that the fixed costs in the estate sector are 3.6 times higher than the smallholder sector owing to capital items and a distinct management hierarchy with supervisors, managers etc. involving additional costs. Hence, the fixed cost ratios, i.e., total fixed cost/gross revenue, are 0.17 and 0.07 in the estate and smallholder sector respectively. The annual green leaf yields in the tea smallholder sector are comparatively higher than the estate sector as almost all smallholdings are cultivated with high yielding VP tea whereas some estate plantations still have seedling tea bush stands that are more than 100 years old as explained by Rathnayake, Malcolm *et al.* (2021).

3.4 Factors affecting the crop production in tea cultivation

The output in tea cultivation depends on the rate of shoot growth and harvested shoots that ensures the income flow to the business. Interference to the production of a cultivation affects the yield/ production per unit area. This in turn lowers the income from the harvest, thus the cost of production increases while reducing the gross margin.

Factors that influence crop production can be categorized into three groups according to Liliane and Charles (2020). Firstly, environmental factors include abiotic constraints such as soil properties, climatic conditions, and biotic constraints including beneficial organisms, pests and anthropogenic evolution. Secondly, technological factors that affect crop yields are agricultural practices and managerial decisions. Thirdly, diseases, pests and weeds that are collectively grouped as biological factors can influence the economic yield of a cultivation.

In tea cultivation, the yield obtained from clonal tea is higher than that of seedling tea, and the genotype of plants (clonal or seedling tea) affects more on the yield than the effect of the age of the cultivation and associated bush debilitation (Kamau *et al.* 2008).

Soil properties

Soil fertility is one of the most important factors for better crop production by providing macro and micro-nutrients essential for the growth. This is particularly so for tea cultivation. However, at present, the fertility of soil in almost every tea cultivation region in Sri Lanka is at an unsatisfactory level. Tea lands of a large share of RPCs are more than 100 years old. Soils are mostly degraded due to continuous cultivations with little or no soil rehabilitation and extensive soil erosion in hilly/steep lands due to poor soil conservation strategies (Carr 2018).

Therefore, the green leaf production in the country largely depends on fertilizers to provide the necessary nutrients to maintain soil fertility. As for the practice of large plantations, fertilizer is added depending on the calculated requirement of nutrients for a tea field based on the yield produced and the available soil fertility of the field (Carr 2018). In contrast, smallholders tend to miss applying fertilizer throughout the year at regular intervals. There are instances where the recommended amount is not applied to the field as the application depends on the availability of the input (Perera 2014). The addition of organic matter and green manure to soil is recommended to maintain good soil properties and fertility, but not every landholding practice this as it requires labour and material.

Tea cultivation requires a well-drained soil at an optimum pH between 4.5-5.5. Excessive and continuous application of fertilizer turns the soil of the tea cultivation more acidic lowering the soil pH. Therefore, dolomite application has been recommended mainly for the soil pH correction and provide MgO as the same time (Tea Research Institute of Sri Lanka 2000).

Climatic conditions

The yield potential of a cultivation largely depends on climatic conditions and presumably the prevailing weather decides the actual yield (Carr and Stephens 2012). Temperature, sunshine hours and rainfall are significant factors in deciding the productivity of a tea cultivation (Wijeratne *et al.* 2007). Hence, extreme climate/weather conditions such as drought, high intensity rainfall events adversely affect the shoot growth and green leaf yield in a tea cultivation. Seasonal weather conditions and seasonal rainfall distribution in a tea growing area mostly decide the productivity of a cultivation (Kamau, Spiertz *et al.* 2008). In Sri Lanka, tea cultivations experience an extensive bud break and shoot formation phase knows as the ‘rush crop’ annually when conducive weather conditions activate with monsoonal rains following several dry months where tea buds remain dormant and inactive without offering as many as shoots for plucking (Seneviratne 2017). This is the period of the year with peak yields that also demand intensive labour deployment to harvest and manage massive quantities of green leaves.

Drought is the most detrimental stress that eventually lowers production and yield (Wijeratne 1996; De Costa *et al.* 2007; Wijeratne, Anandacoomaraswamy *et al.* 2007) while wet weather is associated with high crop yields. Experiences of extreme droughts from the past indicate that there had been losses of 4 per cent and 26 per cent in yield in 1983 and 1992 respectively with respect to the previous years along with escalated production costs (Wijeratne 1996). Recently too, protracted droughts have negatively affected tea crop yields. Prolonged drought conditions lead to insufficient amount of water available for the plants to suffice the evapotranspiration (Liliane and Charles 2020). Water deficit discourages shoot initiation that is most damaging in determining the yield (De Costa, Mohotti *et al.* 2007). This water stress due to drought causes these severe damages as the practice of irrigation is not very common in tea cultivation (Wijeratne 1996). However, seedling teas are usually relatively drought tolerant where plucking can be still continued during the drought (Kamau, Spiertz *et al.* 2008).

High intensity rainfalls are the major factor behind the soil erosion in tea cultivations. Tea fields with insufficient ground cover or exposed ground are the most vulnerable to the loss of topsoil. In addition, landslides are associated with heavy rains mostly in steep areas with tea cultivations. Extended rainy seasons with cooler and gloomy days and less sunlight do not provide conducive conditions for the active shoot growth thus directly impact the production by reducing the number of shoots to be harvested (Wijeratne 1996; De Costa, Mohotti *et al.* 2007; Gunathilaka *et al.* 2018). In addition, such weather conditions favor disease incidence and weed growth that in turn would lower the green leaf production if not controlled to below the economic damaging levels.

Regular field operations too may be interfered with extended weather events, particularly during rainy seasons. Labourers usually find it difficult to engage in management practices in the field such as plucking and weeding during rainy days in hilly fields. Thus, the worker turnout is relatively low during high rainfall periods because of their behavioral responses (Gunathilaka, Smart *et al.* 2018). This is common in plantation workers as they engage in re-roofing their houses. In addition, increased leech populations during the rainy season make it extremely difficult for labourers to get into the field. Thus, it affects worker efficiency and welfare as well. Another possible incident with continuous rainy days is delayed fertilizer application rounds. If fertilizer is applied during the rainy season, nutrients tend to easily wash away before being absorbed by the tea bush.

Dutta *et al.* (2010) showed that variabilities in management practices and environmental factors if not controlled have the major impact on yield differences in tea. The age of the cultivation and optimum nitrogen application are significant for a better yield, as yields tend to be lower with increasing age of the plantation (Kamau, Spiertz *et al.* 2008; Dutta, Stein *et al.* 2010; Dutta 2011; Dutta *et al.* 2012).

A better productivity and a harvest quality can be expected from the tea cultivation as a perennial crop by continuing harvesting regularly (De Costa, Mohotti *et al.* 2007; Gunathilaka, Smart *et al.* 2018). Therefore, delays within plucking round affect the yield of green leaves.

Agricultural practices

Engaging in tea field operations regularly helps maintain the yield of the cultivation at a satisfactory level. The important agricultural practices that are required to keep away or reduce the influence of biological and environmental factors on the tea yield are shown in Table 3.5 below. Timely and proper practice of these field operations can result in a better yield of the cultivation.

Table 3.5. Mature tea upkeep practices that impact the yield in a cultivation

Weed management	to minimize the competition between weeds and tea bushes
Fertilizer application	to maintain the soil fertility
Shade management	to maintain the optimum shade/light for the production
Pruning	to promote vegetative growth of the tea bushes and remove low producing branches
Dolomite application	to maintain the optimum soil pH
Soil conservation	to conserve soil avoiding erosion and maintain optimum soil nutrient and physical conditions

Biological factors

Pest and disease damages in the tea cultivation beyond the Economic Threshold Level (ETL) can cause losses to yield in terms of quantity and quality. This can be managed by integrated pest management that involves cultural, biological and chemical methods etc.

Managerial decisions

The decision making by landholders of the tea cultivation plays a crucial role in deciding the yield. Tea grower’s decisions in adapting good agricultural practices by proper supervision and judgement can minimize losses that can happen due to biological and environmental factors influencing the yield. Profitability of the tea cultivation can be enhanced through strategic and tactical management by decision makers at the farm level (Dutta, Smaling *et al.* 2012).

Proper supervision is essential if hired labourers are used in the field to carry out field operations. Since plucking is the most important activity that assures income generation, proper supervision and practices must be adapted. It is important to make sure that plucking is done at regular intervals meeting the plucking standard. Hence, plucking very young shoots must be avoided as it can affect the future production capacity of the tea bush by affecting the tea bush physiology (De Costa, Mohotti *et al.* 2007).

Not only green leaf harvesting, but also other field operations are equally important for crop production through better planning, and decision making as highlighted in Table 3.5. They help avoid unnecessary wastage of inputs, reduce the cost and improve productivity.

Regarding weed management, tea grower's judgement and planning is crucial. It requires identifying the types of weeds in the field, weed density, identifying and selecting correct modes of controlling problematic weeds etc.

If weedicides are used in weed management, phytotoxic effects of tea bushes must be carefully observed, and necessary actions need to be taken. Phytotoxicity in tea bushes can result due to the reaction of tea bushes to the toxicity of chemicals in weedicides, and eventually influencing the growth. This is a significant concern that would affect the yield. Long term exposure of tea bushes for a single weedicide and/or higher dosages of spray drift, improper spraying, aging of tea bushes and leaching of soil applied weedicides by heavy rain are reasons for phytotoxicity in tea (Sandanam and Hasselo 1965; Prematilake 2003; Chauhan and Mahajan 2014).

A significant ($p<0.05$) reduction of 20-28 per cent of the annual yield can be observed from the 4th year onwards with a reduction in the cycle yield by 20 per cent with Glyphosate and Sulphosate treatments when compared to manual weeding at 1–4-month intervals (Ekanayake *et al.* 2013).

An efficient and effective fertilizer application can be achieved by applying the recommended dosages without overdosing or underdosing. The maximum fertilizer use efficiency could be ensured by removing competitive weeds off the field and slightly forking the soil before fertilizer application, avoiding rainy seasons etc.

Changes in the yield of tea cultivation could be minimized through better agronomic activities and soil fertility management by proper planning on fertilizer application (Dutta, Smaling *et al.* 2012). Wettasinghe (1970) estimated the decline in yield due to delayed weeding for 4,6 months consecutively as 5-9 per cent and 5-15 per cent in seedling and VP teas, respectively.

Shyamalie (2015a) attempted to quantify possible crop losses due to two scenarios of weed control; as no weed control and 50 per cent weed control under different bush cover percentages of VP tea and seedling tea fields. Table 3.6 shows that the bush cover percentage and the crop loss are directly proportional, that the crop loss due to the influence of weeds can be minimized if a good ground cover is maintained.

Table 3.6. Crop losses under different bush cover percentages in tea fields

Type of bush cover	Productivity (Made tea kg/ha/year)	No weed control		50% weed control	
		Crop loss as a %	Crop loss (made tea kg/ha/year)	Crop loss as a %	Crop loss (made tea kg/ha/year)
100%	>2500	1	25	0.5	12.5
60%	<2500-1600	7	140	3.5	100
Poor	<1600-1200	9	144	5	80
Seedling fields	<1200	15	180	10	120

Source: Shyamalie (2015a)

3.5 Weeds in tea fields and their management

3.5.1 Weeds

Plants that grow in any cultivated land besides the desired crop are generally defined as a weed. Weeding is one of the most critical and important practices in tea fields as they can interfere with the growth of the tea bush by competing with water, light and nutrients which would ultimately lead to reduced productivity of the crop. The cost incurred in weed management in tea plantation ranges between 7-8 per cent of the total cost on field management practices and second highest cost next to plucking (Peiris and Gunarathne 2015; Silva 2015). Weeds can occur abundantly due to factors such as widespread areas with exposed soil, high rainfall, delayed weed control rounds, and areas in the field that are abandoned and serving as breeding grounds for weeds (Tea Research Institute of Sri Lanka 2003).

3.5.2 Problematic weeds in tea fields

Weed species in tea fields can be classified as climbers or runners and shrubs or bushes (Peiris and Nissanka, 2016) and also as broad leaf, grasses and sedges. Problematic weeds that are found in tea fields are *Panicum repens* (Atora/Couch grass), *Imperata cylindrica* (Illuk), *Borreria latifolia* (Borreria), *Spermacoce hispida* (Heen Getakola), *Wedalia trilobata* (Arunadevi) as identified by Tea Research Institute of Sri Lanka (2003).

Climbers or runners such as *Mikenia scandens* (Thanni Kody), *Ipomea learii* (Paal Kody), *Hedyotis neesiana* (Getakola), *Commelina benghalensis* (Amalai) and shrubs or bushes such as *Clidemia hirta* (Bovitiya/Karuppati Chedy), *Crassocephalus crepidioides* (Thandam Pillu), *Pennisetum polystachyon* (Foxtail grass) have been identified as weed species found in mature tea lands causing economic damage(Prematilake *et al.* 2004; Peiris and Nissanka 2016).

3.5.3 Effects of weeds in tea cultivations

Weeds in general have direct and indirect impacts on agricultural production. Direct impacts are lowered crop production, yield and quality of the harvest leading to economic losses, because the weeds compete with the tea bushes for essential growth factors such as water, nutrients and sunlight, they harbour tea pests and diseases being alternative hosts eventually leading to low prices and income, and if the weed cover is thick, they interfere with field operations such as plucking, fertilizer application, pruning etc. (Shyamalie 2015a). Indirect effects are increased cost of herbicides by poor weed control efficiencies, increased weed control efforts, and additional costs in the following season due to extra labour use, lost productive time and reduced yields (Mennan *et al.* 2020).

3.5.4 The need for weed management in mature tea upkeep

Weeds become a massive issue in tea plantation from the time of planting of tea up to the stage when the tea bush canopy sufficiently covers the inter-row spaces (Prematilake, Froud-Williams *et al.* 2004). Prematilake *et al.* (1999) reported that the critical period of weed competition in young tea was 8-16 weeks after planting and weed infestation for more than 12 weeks adversely affects the growth of tea. Weeds have the ability to compete with the tea bush and suppress the growth which can ultimately result in an unhealthy bush with a poor bush frame, yellowish foliage and defoliation (Peiris and Nissanka, 2016). Therefore, it is vital to control such troublesome weeds in the tea plantation and maintain steady and better-quality crop levels in a commercial venture (Peiris and Gunarathne, 2015). Furthermore, weeds have a significant impact on the routine field practices in tea fields such as plucking, manuring, forking etc. resulting in a high cost of field operations as mentioned above. Weed undergrowth can also serve as alternative hosts for pests and diseases hitting the productivity and at the same time providing a place for reptiles as well, putting human health in danger. Therefore, weed management has become an activity which must be carried out in the field on a regular basis. Furthermore, weeding is considered essential in tea cultivations to ensure better crop production and high quality.

3.5.5 Weed management approaches in tea cultivation

Early planters practiced weeding in their fields and maintained a clean land losing tons of topsoil with every shower of rain. At present, weeding is kept at a minimal stage by endorsing judicial management of the weed population through integrated weed management (Jayakody and Shyamalie 2002).

The decision regarding weed management in any cultivation depends on economic thresholds. The economic threshold for weed control is described as 'the level of weed infestation at which the cost of controlling weeds is equal to the increase in crop value obtained as a result of controlling weeds' (Martens *et al.* 2018) (para. 1). However, most growers tend to rely on the threshold that indicates the farmer to implement weed control methods. A similar concept the economic crop damage level is highlighted by Peiris and Nissanka (2016) as the point where weed control must be done to avoid the economic loss overweighing the cost of weed control and explaining the importance of operating near this level to ensure minimal losses in the harvest.

The weed control approach can vary depending on the growth stage of tea bushes. During the first few years after the field establishment of tea bushes when the ground is heavily exposed, weeds that can harm the crop only are picked and the rest are left to help bind the soil (Jayakody and Shyamalie 2002; Samansiri, Rajasinghe *et al.* 2011). However, when tea bushes grow, weed management turns out to be an essential factor which determines the growth of the tea bush and subsequently the yield.

The choice of weed management in tea lands as recommended by the Tea Research Institute of Sri Lanka (2003) covers a wider range of practices; altogether known as integrated weed management which consists of preventive, cultural, manual/mechanical, chemical and biological methods. Integrating some or all the above methods of weed control in a sequential way throughout the year, also known as Integrated Weed Management (IWM) has been identified as a cost-effective and eco-friendly weed control method.

Preventive methods

Preventive methods comprise measures such as managing weeds at tender stages and in non-tea areas, avoiding ground exposure, applying different herbicides in rotation, using mulches free of weed seeds, planning a year-round weed management program etc., to minimize weed seed bank in the soil and thereby lower weeding costs.

Cultural methods

This approach takes ecological measures avoiding ground exposure and suppressing all possible factors responsible for weed growth. Planting healthy tea plants, proper tea bush management, leaving soft weeds in the field, infilling with tea/grasses, mulching, planting green manure crops etc., are done in cultural methods of weed control.

Biological methods

In this approach, other living organisms are used to control the weed population to acceptable levels by competing with the weed for growth factors. Couch grass is suppressed by *Brachairia brizantha* and *Michania scandens,* and *Wedelia trilobata* grasses are controlled by *Cuscuta chinensis* in biological methods.

Manual methods

Manual methods in weed control involve hand pulling of creepers, selective and slash weeding using hoes, blades or mechanical weeders. If manual weeding is to be practiced, hand weeding must be done at 6-week intervals or more (Prematilake, Froud-Williams *et al.* 1999). Since all most all the tea growing areas of Sri Lanka are facing a problem of labour scarcity and sometimes they must abandon even high yielding tea fields, finding additional workers for weeding is a serious challenge which is not economical at all to the industry. These reasons have made the tea estates compelled to practice chemical weeding due to shortages and high cost of labour for manual weeding (Silva 2015).

Chemical methods

Chemical weeding in tea cultivation refers to chemical methods or rational application of pre and post emergent herbicides. The widely practiced method in tea fields is applying weedicides/herbicides since it is the most convenient and effective weed management method with zero tillage, with minimal soil erosion and loss of plant nutrients which are taken away with the weeds (Sivapalan 1983; Prematilake 2003). Chemical weeding is more flexible and requires relatively less labour and working time (Shyamalie 2015a; Jacquet *et al.* 2021) unlike manual weeding or any other weed management method. Owing to issues in labour such as labour shortage and increasing wage rates, the dependence on labour intensive methods is discouraged, hence chemical weeding is favoured and the use increases as the scale of production increases (Abeywickrama, Sandika *et al.* 2017). Accordingly, more than 50 per cent of tea smallholders are relying on weedicides to control weeds at least occasionally (Abeywickrama, Sandika *et al.* 2017). Around 8 million kg of weedicides which cost Rs.4.6 billion in 2013 and 6 million kg valued Rs.3.3 billion of foreign exchange in 2014 have been imported to Sri Lanka in the consecutive years as given by the Sri Lanka Customs and a major fraction of these imports have been supplied to commercial tea plantations which practice around 4 to 5 weedicide application rounds per year (Peiris and Gunaratne, 2015).

Herbicides can be classified into various groups based on several characteristics in them as presented in Table 3.7.

Table 3.7. Classification of weedicides

Method of application	Soil applied herbicide	chemical acting through root and other underground parts of weeds
	Foliage applied herbicide	chemical primarily active on the plant foliage
Mode of action	Selective herbicide	chemical can kill specific plant species without affecting others in a mixed growth of species
	Non-selective herbicide	chemical kills most of the treated vegetation
Mobility	Contact herbicide	chemical kills plant parts with which it comes in direct contact
	Translocated/systemic herbicide	chemical which tends to move from the treated part to untreated areas through xylem/phloem
Time of application	Pre-plant herbicide	application of herbicide before sowing or along with sowing
	Pre-emergence/residual herbicide	herbicide is applied to soil soon after sowing a crop before emergence of weeds
	Post-emergence herbicide	herbicide is applied to kill young weeds standing in the crop plants or application after the emergence of weed and crop
	Early post emergence herbicide	herbicide is applied to slow growing crops, 2-3 weeks after sowing

Source: Tea Research Institute of Sri Lanka (2003)

Weedicides that have been recommended for tea cultivation for weed management are Oxyfluorfen, Diuron, Glyphosate, Paraquat, Glufosinate Ammonium, 2,4-D and MCPA (Prematilake 2003; Tea Research Institute of Sri Lanka 2003; Prematilake, Froud-Williams *et al.* 2004; Silva 2015; Shyamalie 2015a).

The list of herbicides that are recommended by the TRI to be used on weeds in tea fields and their modes of action on weeds are listed in Table 3.8.

Table 3.8. TRI recommended weedicides in tea cultivation

Herbicide (common name)	Percentage of active ingredient and formulation	Mode of action	Dosage	Susceptible weeds
Oxyfluorfen	24% w/v (liquid)	Pre-emergence Residual	1.2l/ha or 0.5l/ac or 32ml/15 l tank	Broad leaf/ grasses/sedges
Diuron	80% Wettable powder	Pre-emergence Residual Selective	1.2kg/ha or 490 g/ac or 32 g/15l tank	Broad leaf/ grasses/sedges
		Post-emergence action with a wetting agent	1.2 l/ha or 425-560 ml/ac or 32 ml/15 l tank	Broad leaf/ grasses/sedges
Direx	40% w/v (Flowable formulation)	Pre-emergence Residual Selective	0.90-1.0 l/ha or 375-400 ml/ac or 25-27 ml/15l tank	Broad leaf/ grasses/sedges
Glyphosate	36% w/v 35.5% w/v 41% w/w (liquid)	Foliage applied Systemic/translocated Post-emergence	(0.25-0.5%) 1.4-2.8 l/ha or 570-1125 ml/ac 38-75 ml/15 l tank	Total weed killer
Paraquat	20% w/v (liquid)	Foliage applied Non-selective Contact Post-emergence	0.7-1.11 l/ha or 300-450 ml/ac or 20-30 ml/15 l tank	Total weed killer Resistant weeds are Illuk, Couch grass, Amalai, Foxtail grass, Getakola, Thandampullu, Alawangupullu, Morning glory, Malhabarala, Walkohila
Glufosinate Ammonium	15% w/v (liquid)	Contact Partially systemic	1.3 l/ha or 530 ml in 225l water/ ac or 35ml in 15l tank	Getakola
2,4-D	55% E.C (liquid)	Translocated/systemic Selective Post-emergence	1.7-2.8 l/ha or 0.7-1.2 l/ac or 45-80ml/15 l tank	Morning glory, Amalai, Arunadevi, *Mikania, Polygonum* spp.
MCPA	40% and 60% E.C (w/v) (liquid)	Systemic/translocated Selective Post-emergence	1.75-3.0 l/ha or 0.72-1.23 l/ac or 45-81 ml/15l tank	Amalai, *Borreria*, and *Mikania*

Source Tea Research Institute of Sri Lanka (2003)

Information on using weedicides to control problematic weeds found in tea cultivations in Sri Lanka is summarized in Table 3.9. As highlighted in the table, some problematic weeds need mixtures of two or more weedicides in different dosages for their effective control.

However, some of these recommended weedicides listed in the above tables are currently banned or were banned for some years during the past few years because of unintended consequences of them on human health. For example, Paraquat, one of the mostly used weedicides in the tea sector, was banned in Sri Lanka during the period between 2008 – 2011 due to the realization that Paraquat along with few other herbicides had become responsible for the majority of pesticide deaths (including suicides) in the 2000s (Knipe *et al.* 2017).

Table 3.9. Management of problem weeds using weedicides

Weed	Herbicide/ Mixture	Dosage per hectare
Rhizomatous weeds		
1. Couch (*Panicum repens*)	Glyphosate	11 l in 550 l water
	Glyphosate + Kaolin	5.5 l in 550 l water+ 3.4 kg Kaolin
2. Illuk (*Imperata cylindrica*)	Glyphosate	5.5 l in 550 l water
Other weeds		
3. Borreria (*Borreria latifolia*)	MCPA (60% E.C) at 1.2 l + Paraquat (20%) at 1.1 l in 550 l water/ha	
4. Getakola (*Spermacoce hispida*)	Diuron (80% WP) at 1.1kg+Glyphosate (36%) 2.8l in 550 l water/ha Diuron (80% WP) at 1.4kg+2,4-D (55% E.C) or MCPA 60% at 1.2l in 550 l water/ha Diuron (80% WP) at 1.1kg+Paraquat (20%) 1.1l in 550 l water/ha Glyphosate (36%) at 3.5l + Ammonium Sulphate 2.8 kg in 550 l water/ha	
5. Arunadevi (*Wedelia trilobata*)	MCPA (60%E.C) at 1.5 l + Glyphosate (36%) 3.6l in 550 l water/ha MCPA (60%E.C) alone at 2.2 l in 550 water/ha	
Other compatible cocktail mixtures: 1.Paraquat + Oxyfluorfen 2. Glufosinate Ammonium + Oxyfluorfen 3. Glyphosate + 2,4-D or MCPA 4. Glyphosate + Oxyfluorfen 5. Glufosinate Ammonium + Diuron		

Source Tea Research Institute of Sri Lanka (2003)

Glyphosate use was completely banned for three years from 2015 to 2018 by the government, in a unilateral decision, over the belief that Glyphosate is the cause for the CKDu. Further details about this ban are discussed in Section 3.6.3.

3.6 Introduction to Glyphosate

3.6.1 Glyphosate as a weedicide in the world

Glyphosate is a very popular weedicide commonly used globally in non-cropped and cropped scenarios such as in tea plantation, vineyards and roadsides (Bandana, 2015). The popularity of Glyphosate was widely known around the world because of its cost-effectiveness with respect to using machinery and labour (Schulte *et al.* 2017). It is commonly used as a non-selective weed killer at present. The

Monsanto Chemical Company first introduced Glyphosate under the trade name 'Roundup' in 1974, originally to be used on weed controlling in farming and landscaping operations and on powerlines and railway tracks (Benbrook 2016). The global use of Glyphosate escalated in 1990s following the introduction of Roundup Ready seeds (Richmond 2018). The use of Glyphosate has extended thereafter to weed management in crop production from wheat, maize, soybean to fruit, nut and vegetable cultivations. The total use of the global Glyphosate active ingredient since its introduction till 2014 has been calculated as 113.4 million kg over 4 decades which is 300 times the amount used in 1974, and the highest share of the total global use is 72 per cent from 2004 to 2014 (Benbrook 2016). It is currently used by tea growing countries such as China, India, Vietnam and Kenya in addition to Sri Lanka (Brookes, 2019).

3.6.2 Glyphosate use in Sri Lanka

Introduction of Glyphosate

Glyphosate has been extensively used in efficient weed management as an important weedicide in Sri Lankan agriculture (Abeywickrama, Sandika *et al.* 2017). The popularity of Glyphosate in the tea industry escalated with the ban imposed on Paraquat in the late 2000s. Tea growers have found Glyphosate as a cost-effective herbicide with respect to the other recommended chemicals and has been broadly used on a wide range of weeds as it is a non-selective, systemic herbicide.

Chronological events on the use of Glyphosate in Sri Lanka are highlighted by Marambe and Herath (2019). Accordingly, Glyphosate was first imported to Sri Lanka in 1977 as a pre-plant herbicide to be used on annual and perennial crops on the recommendation of the TRI. Later in 1986 and 1998 its use for general weed controlling in tea and paddy cultivations respectively, was recommended. Glyphosate gained popularity among tea, paddy and maize growers following the phasing-out process in 2008 and then the ban in 2014 on Paraquat. Therefore, by 2014, Glyphosate imported to the country was used mostly by the tea industry (36 per cent), followed by maize and other field crops (33 per cent), wet zone paddy (25.8 per cent), and dry zone paddy (4.4 per cent) (Marambe 2018).

Use in the tea cultivation

Glyphosate was first recommended by the TRI to control troublesome weeds in pruned tea fields and mature fields in production/plucking (after three pruning cycles), and later for general use (Marambe 2018). Tea growers have found Glyphosate a cost-effective herbicide with respect to the other recommended chemicals by the TRI and had been broadly using on a wide range of weeds as a non-selective, systemic herbicide till it was banned in 2015. Given that there is an acute labour shortage in tea plantations for manual weed management, chemical weeding with Glyphosate and Paraquat has been the economically viable practice for most plantations till bans were placed on them (Silva 2015). An area of 113,000 ha of mature tea lands under the management of RPCs used Glyphosate (Silva 2015). Use of Glyphosate by the tea smallholdings for weed management is not as readily observed as the use by the estate sector with large acreage owing to the time efficiency and labour shortages (Shyamalie 2015a; Danne *et al.* 2019). However, based on the severity of the labour shortage experienced and the land extent under cultivation, Glyphosate/chemical weeding can be the best option for smallholders. Conversely, Peiris and Nissanka (2016) highlighted that although Glyphosate is widely being used in commercial tea cultivations, 20 out of 23 acutely problematic weeds that can affect the tea crop are resistant to Glyphosate and cannot be destroyed.

3.7 Issues related to Glyphosate use in agriculture

The use of agrochemicals including weedicides has been unreasonably intensive recently that it has had a greater impact on agricultural production, animal and human health, environment and ecosystems.

One of the most critical issues that is possible due to the continued use of a single herbicide over several years is the potential risk of development of resistance in weeds against weedicides that are being applied on a regular basis (Prematilake 2003). The study by Peiris and Nissanka (2015) has shown that more than 20 weed species among 23 acutely problematic weeds which have the ability to cause severe damages to tea plantations are fully resistant and cannot be controlled using the frequently used herbicides in tea such as Diuron, Paraquat and Glyphosate. It was also revealed that these herbicide tolerant weeds if present in a tea plantation for one- or two-years, can cause damage to the plantation making it unproductive and economically non-viable. Repeated use of the same herbicide over an extended period also can lower plant growth and the tea yield as result of the phytotoxicity developed in tea bushes (Prematilake 2003).

Impacts on the environment and its ecosystems by herbicides are even equally significant that it causes severe damage through surface and ground water contamination, soil and air pollution, destruction of non-target vegetation, non-target organisms such as wildlife, fish etc. (Bourguet and Guillemaud, 2016; Aktar, Sengupta and Chowdhury, 2009; Wilson, 2000).

In terms of the effect of chemicals used in agriculture on human health, serious concerns have arisen such as occupational exposure in field activities and manufacturing processes which can result in direct or indirect contact of the chemicals on body parts of workers, and herbicide contamination (residues) in foods exceeding MRLs, have been reported over time and also been identified that these agrochemicals have a linkage to other health effects such as immune suppression, hormone disruption, diminished intelligence, reproductive abnormalities and cancer incidences. A major impact on humans is pesticide poisoning happening around the globe which causes deaths and chronic diseases (Aktar et al., 2009). For instance, the use of Glyphosate has become questionable with respect to the declaration by the International Agency for Research on Cancer (IARC) that Glyphosate is a 'probable human carcinogen' even though studies have found out that it has an overall low toxicity and does not pose any unacceptable risk to human health, environment or non-target animals and plants.

3.8 Current Glyphosate use policies

3.8.1 Glyphosate use policies in the rest of the world

The use of Glyphosate in agriculture gained public attention in many countries following the classification of this chemical as a 2A substance i.e., 'probable carcinogenic to humans' by the International Agency for Research on Cancer, the specialized cancer agency of the World Health Organization (WHO) in 2015 (International Agency for Research on Cancer 2015). In the meantime, in 2017 Glyphosate was listed as a hazardous chemical causing cancer by the state of California in the United States, while there were claims raised by epidemiologists stating that Glyphosate causes the development of non-Hodgkin lymphoma (Myers *et al.* 2016; Richmond 2018; Zhang *et al.* 2019). In 2018, a case regarding the development of non-Hodgkin lymphoma in a groundskeeper in San Francisco gained attention of the whole world as the first Glyphosate cancer lawsuit to proceed to trial. The verdict went against the Glyphosate manufacturer. However, concerns over Glyphosate use were taken into consideration since 1985 when the Environmental Protection Agency (EPA) classified Glyphosate as a possible carcinogen based on experimental evidence showing tumor development in Glyphosate treated rodents (Center for food safety 2015).

Consequently, the global trend has been focusing on reducing the Glyphosate use in agricultural industries, and thereby lowering the risk on human health and environment. Under the circumstances, several countries have intensively scrutinized and revised their policies regarding the Glyphosate use by means of outright bans on Glyphosate, restrictions, issued statements of intention to ban or restrict Glyphosate-based herbicides (Böcker and Finger 2017). There have been several discussions among stakeholder groups including policymakers, public, scientists and agricultural organizations regarding the Glyphosate use policies (Kudsk and Mathiassen 2019).

Currently more than 40 countries from African, Asian, Central American, and European regions have taken steps to minimize Glyphosate use in their crop production and non-farm activities. The European Union has taken steps to reduce pesticide and herbicide use under the prevailing condition by considering either the renewal of the license on Glyphosate use or banning it in the European Union. The European Union (EU) Commission has provided approval to renew the license for Glyphosate for another 5 years (instead of the standard 15 years). Czech Republic, Belgium, Denmark, France, Italy and Netherlands from the EU and Canada have imposed partial bans/restrictions. Glyphosate is fully banned in Austria and Vietnam at present. In 2020, the Mexican government announced banning Glyphosate in 2024 (Cruz *et al.* 2021). Netherlands, France and Italy have banned the use of Glyphosate in public spaces with exit plans to reduce its use, while some Middle eastern Gulf countries and France have issued bans since 2019 and 2020 respectively (Jacquet, Delame *et al.* 2021). Interestingly, the Kellogg brand also has announced phasing out of the use of cereal products treated with Glyphosate in their supply chains (Walsh and Kingwell 2021)

Sri Lanka was the first country to place a full ban on Glyphosate. This was lifted in mid-2018 because of crop losses and overgrowing weeds in most of the commercially cultivated crops including tea.

3.8.2 Glyphosate ban in Sri Lanka (2015 – 2018)

The policy of the Sri Lankan Government regarding the use of Glyphosate has been changing over the past few years. The decision to completely ban the use of Glyphosate took place in a stepwise manner. The following Table 3.10 shows details regarding each extraordinary gazette notification issued by the Sri Lanka government regarding the Glyphosate use in the country.

The regional restriction on Glyphosate was placed only within certain agricultural regions of the country where patients of the CKDu are alarmingly prevalent. Therefore, the main reason behind the government decision was the concern on the public health issue following the study by Jayasumana, Gunatilake *et al.* (2014) published in the Journal of Environmental and Public Health earlier the same year. The research investigated the hypothesized link between use of Glyphosate in most of the CKDu prevailing regions and its unique properties that can lead to potential kidney diseases.

Table 3.10. Government extraordinary gazette notifications regarding Glyphosate use

Date issued	Issued by	Act Number	Regulation
22/12/2014	Ministry of Agriculture, Control of Pesticides Act, no. 33 of 1980	No. 1894/4	To prohibit the use, offer for sale or sale of pesticides containing the active ingredients Glyphosate, Propanil, Carbaryl, Chloropyrifos, and carbofuran within the districts of Anuradhapura, Polonnaruwa, Kurunegala, Monaragala and within the divisional secretariat divisions of Mahiyanganaya, Rideemaliyadda, Kandaketiya in the Badulla districts.
11/06/2015	Import and Export Control Department, Import and Export (Control) Act, No. 01 Of 1969	No.1918/22	To ban Glyphosate.
23/10/2015	Ministry of Agriculture, Control of Pesticides Act, No. 33 Of 1980	No. 1937/35	To cancel every license issued in respect of the pesticides containing the active ingredient Glyphosate.
13/09/2018	Ministry of Agriculture, Control of Pesticides Act, No. 33 Of 1980	No. 2088/57	To declare that every pesticide in trade names, Amiphosate, Ridweed 360, Ceypetco Glyphosate (as specified in the gazette) containing the active ingredient Glyphosate as approved and restricted pesticides.
02/10/2018	The Registrar of Pesticides, Control of Pesticides Act, No. 33 Of 1980	No. 2091/13	To modify very license issued in respect of pesticides containing the active ingredient Glyphosate to be devoid of the adjuvant Polyoxyethylene amine be used only for tea and rubber plantations.

Source: www.documents.gov.lk

The disease has created a huge impact on the paddy farming community, affecting a total population of 400,000 and with a death toll nearly 20,000 people over two decades (Jayasumana, Gunatilake *et al.* 2014). Paddy farming and other field crop farming such as maize, sugarcane, chili is the main livelihoods of the people in those areas. Glyphosate had been the most widely used weedicide in those disease endemic areas (Jayasumana, Gunatilake *et al.* 2014).

Following the regional prohibition on using Glyphosate, an island-wide ban on importation and sale of Glyphosate was imposed in mid-2015. This decision was made by the President of Sri Lanka based on the advice of scientists who carry out research on renal diseases reported in several areas of the country agrochemicals could be a reason for the CKDu (news.lk 2015).

This ban was in place for almost three years till late 2018, when the ban was lifted only for tea and rubber plantations, for a period of 36 months (news.lk 2018; Marambe and Herath 2019). Many stakeholders from the tea and rubber industries requested the government for a rational solution, considering the economic losses and consequences of the ban. The cost of the ban on the economy of the country has been estimated to be nearly Rs.15 – 20 billion rupees (news.lk 2018; Marambe and Herath 2019).

The decision to rescind the ban on Glyphosate use on tea and rubber plantations was approved after a series of discussions with the government upon conditions to prevent misuse, overuse and leakage to water bodies with a proper monitoring system. In mid-2019, the government has decided to expand the ban relaxation to a few other industries, including the floriculture industry for devitalization of propagules, and the coconut and sugarcane industries to fight against diseases (Marambe & Herath, 2019).

Overall, the ban on Glyphosate has severely affected the tea industry in addition to other industries such as rubber, paddy, maize, coconut, banana, chili, sugarcane in terms of issues in weed management (Abeywickrama, Sandika *et al.* 2017; Marambe and Herath 2019).

3.9 Economic impacts of banning Glyphosate on agricultural industries

3.9.1 Potential ban on Glyphosate

Since the classification of Glyphosate as a possible cancer-causing agent in mid 1980s and public debate on consequences of its use, studies conducted in many countries have been focusing on evaluating the economic impacts of a potential ban on Glyphosate on producers, consumers, industries and economy. The burden of a ban is usually borne by the producers of the agricultural produce in case of limitation/ban of an input (Garvert *et al.* 2013). They will be worse-off, having to bear the cost mainly and also partially by consumers and taxpayers as well.

While crop production without Glyphosate is possible, as in organic farming, it must be methodically planned with proper economic, intellectual, logistical, political and technological settings and knowledge (Beckie *et al.* 2020; Cruz, Cruz-Hipolito *et al.* 2021). Losses and consequences of a Glyphosate ban are unavoidable and should be anticipated as such perfect conditions cannot be met in reality. Hence to date many researchers have attempted to quantify losses before the actual ban is put in place by policy makers, thereby providing some insights for devising and formulating better policies.

Many studies have predicted decreased profit margins as 'first round' (Brookes *et al.* 2017) impacts at the farm level with restricted use of Glyphosate (Pardo and Martinez 2019; Böcker *et al.* 2020; Cruz, Cruz-Hipolito *et al.* 2021; Walsh and Kingwell 2021) . According to researchers, shifts in the product supply associated with the cancellation of a herbicide can be categorized into two parts as; yield loss and rise in input and application cost.

Increase in costs

A notable increase in per area annual costs of weed control would be expected to result from using more expensive alternative weed control methods involving chemicals and non-chemical approaches instead of the restricted chemicals, and if there is also a lower yield there could be marked declines in income (Taylor *et al.* 1991; Brookes 2019). A comparison of attributes such as feasibility, effectiveness and technological maturity across alternative weed controlling strategies including Glyphosate and other approaches adopted in France is presented in the study done by Beckie, Flower *et al.* (2020). According to these authors, physical or mechanical methods involving tilling, cultural methods and alternative herbicides proposed as alternative weed control options upon a Glyphosate restriction were predicted to be increasingly used. Pardo and Martinez (2019) compared the costs of different chemical and non-chemical weed control approaches for perennial crops in Spanish conservation agriculture and found that the highest cost increase was recorded on chemical control with a Glyphosate ban. The study conducted on arable farming in Germany by Kehlenbeck *et al.* (2016) also evaluated alternatives for Glyphosate application in the case of a complete ban and observed mechanical strategies as the only viable option that has an equivalent efficiency to Glyphosate in weed control.

The demand for and the costs of labour are more likely to increase under a Glyphosate ban because more mechanical strategies will be required (Bocker *et al.* 2018). Allocation of more labour over more time and consumption of energy results in expensive crop production (Cruz, Cruz-Hipolito *et al.* 2021). Weed control strategies that are more mechanical and weedicide-free were predicted to be ten times more expensive than weed control using Glyphosate by Cruz, Cruz-Hipolito *et al.* (2021) in Mexican agriculture. They showed that of the frequently used non-chemical alternatives, bush cutters as the cheapest and brushing machines or application of pelargonic acid as the most expensive. Furthermore, alternative mechanical weeding approaches in hazelnut production in Turkey was estimated to be 80 per cent more costly than using Glyphosate by Mennan, Bozoğlu *et al.* (2020).

The studies by Garvert, Schmitz *et al.* (2013), Böcker *et al.* (2017), Brookes (2019), Böcker, Britz *et al.* (2020) and Mennan, Bozoğlu *et al.* (2020) showed that a tendency in Glyphosate users operating under a ban was to include tillage and mechanical strategies as the most sustainable alternative methods with higher labour demand for weed management rather than using other selective herbicides at higher levels. Conversely, Jacquet, Delame *et al.* (2021) highlighted poor technical skills as an obstacle to adopting mechanical weeding methods in viticulture. This is because increased mechanical weed control activity can cause damage to the surface root system and plants eventually leading to yield losses. Intensified tillage could be applicable on certain crops that have deep root systems and are cultivated in flat terrains but would probably be impossible for shallow rooted crops planted on steep slopes as it can encourage soil erosion through washing off the topsoil. Glyphosate application has been practiced as an effective approach for minimizing soil erosion, so a ban on its use would pose risks on soil health and nutrition (Kudsk and Mathiassen 2019). Soil erosion is likely with some mechanical weed control strategy adopted in the absence of Glyphosate (Cruz, Cruz-Hipolito *et al.* 2021).

Regarding the reliance on mechanical approaches that involve machinery and equipment in weed control, Walsh and Kingwell (2021) showed that having to purchase new machinery which can be sometimes expensive increased weeding costs and thereby narrowed farm profit margins.

According to Cruz, Cruz-Hipolito *et al.* (2021) although weedicide-free crop production/organic farming is more suitable for small and medium scale farms than conventional farming, lower productivity, higher costs and larger carbon footprints make it disadvantageous for businesses.

In the regions where labour scarcity prevails and wage rates are high, mechanical approaches on weed control that involve tilling, ploughing would not be an option (Garvert, Schmitz *et al.* 2013). In such cases, weedicides become the best and the most viable and profitable strategy, that minimizes labour-intensive activities. This view is supported by Walsh and Kingwell (2021) pointing out that there were limited changes towards labour-intensive production in farms having issues with labour scarcity in their study following restricted use on Glyphosate. They also highlighted that family labour opted to work longer hours themselves rather than hiring labour because of the same issue.

The costs of chemicals on weeding increase in instances where the next best alternative is substituted, that is usually more expensive than the previously used banned herbicide (Szmedra 1997; Böcker, Britz *et al.* 2017; Bocker, Britz *et al.* 2018; Schneider *et al.* 2018; Brookes 2019; Pardo and Martinez 2019; Ye *et al.* 2021). Furthermore, such alternatives are very limited for access and less effective than the banned weedicide (Beckie, Flower *et al.* 2020). Many studies have commonly assumed that the next best alternative chemical will acquire a proportion of the sales of the restricted chemical related to their current share in the market (Liu *et al.* 1995). Given that it is highly unlikely to introduce an alternative weedicide that is similar to Glyphosate in terms of the efficiency on weed control, environmental impacts, resistance, cost-effectiveness etc. (Ye, Wu *et al.* 2021), Cruz, Cruz-Hipolito *et al.* (2021) identified Glufosinate Ammonium as the best alternative which is however twice as expensive as Glyphosate. Similarly, Fogliatto *et al.* (2020) listed a series of alternative weedicides recommended for tree crops in Europe replacing Glyphosate for different types of weeds. Conversely, they all argued that switching from a broad-spectrum weedicide like Glyphosate to other alternatives that are selective weedicides would create a need to use mixtures of chemicals to target each type of weed – grasses, broadleaf weeds etc. Escalated outlays on extra herbicides and alternatives directly affect the profitability of the businesses (Walsh and Kingwell 2021). With respect to the use of alternative weedicides, Garvert, Schmitz *et al.* (2013) predicted higher rates of application and one additional round of alternative weedicide to compensate for the risk associated with the increased weed pressure due to the absence of Glyphosate as outcomes.

Unlike other studies, Cruz, Cruz-Hipolito *et al.* (2021) highlighted an interesting aspect of banning Glyphosate with respect to the predicted increase of criminal activities and emergence of black markets for illicit Glyphosate products smuggled from neighbouring countries. Researchers pointed out situations such as decontrolled price increases, difficulties in ensuring the quality control of such products that can unfold as consequences of informal sources. Risks on public health and environment were suggested as highly likely over such informal markets. Furthermore, the possibility of widening the inequality between small farms and large farms was highlighted as not every farmer has the potential to afford expensive black-market chemicals and higher wage rates on labour.

Considering all of this evidence, it seems that an outcome of a Glyphosate ban on weed control could be either farmers end up using substitute herbicides with higher toxicities or those that need more tillage intensity (Böcker *et al.* 2019).

Decline in yield

Reductions in yield are most likely in instances when the same level of weed control intensity cannot be practiced with the alternative weed control approaches, thus the expected yields too become costly (Böcker, Britz *et al.* 2017; Walsh and Kingwell 2021). Switching to alternative weeding approaches that might end up with less effective and less intensive weed control would lead to higher weed growth, delayed and less efficient harvesting. Consequential decline in yield could in turn affect the income (Cashman *et al.* 1981; Walsh and Kingwell 2021). Cruz, Cruz-Hipolito *et al.* (2021) who investigated impacts of a domestic Glyphosate ban in Mexico on agriculture including the production of citrus, grapes, maize, olive, tomatoes and wheat have predicted a 40 per cent fall in food production with economic yield losses. The fall in hazelnut production in Turkey was predicted to be between 12 per cent and 21 per cent over a Glyphosate ban as shown by Mennan, Bozoğlu *et al.* (2020). Garvert, Schmitz *et al.* (2013) have found out that in the presence of yield depressions regardless of a possible price increase in the produce, declines in the farm profit margins are highly likely in all regions of Germany in case of a ban on Glyphosate. In some regions of Germany, assuming an average fall in the yield by 5 per cent on all crops, loss of gross margins by amounts such as 15 per cent and 28 per cent have been predicted whereas in some other regions gross margins have been maintained constant by the effect of a price increase. In such cases, the reduction of the farm income has been counteracted by the price increase for the produce.

Furthermore, Cashman, Martin *et al.* (1981) pointed out that higher weed pressure resulted from the absence of Glyphosate would probably affect the harvesting stage by reducing the efficiency of harvesting and increasing the costs for machinery, ultimately affecting the farm returns to fall.

Effect on the farm revenue and welfare changes

The effect on farm income following a ban is the result of the interaction between the effect of price and yield change during the ban. Net losses in the revenue of the farms could be possible when the decline in yield is proportionately greater than the effect on increased farm product price, and this effect is offset by the reduction in yield eventually leading to a shrinkage in the producer surplus (Szmedra 1997).

In some instances, it is possible for the net income from the farm produce to increase as the increased farm gate price responses following the restrictions on chemicals counteract the fall in yield and higher cost of production (Taylor and Smith 1999). Usually, a positive farm product price response can be anticipated for agricultural commodities with price inelastic demand when the supply declines (Burton and Martin 1987). Demand elasticity can be another factor that determines the decline of industry revenues (Carter *et al.* 2005). Burton and Martin (1987) found out that the farm revenue would increase in the case of a ban on all herbicides since the farm product prices are expected to be increased with respect to the increased production cost and a shift in supply. Accordingly, they suggested that the ban on a single herbicide would not make any significant impact on the national economy since the restricted herbicide can be substituted by other alternative herbicides.

Recent studies by Bocker, Britz *et al.* (2018) showed that a ban on Glyphosate could increase output prices because of the high cost of production and eventually making costly weed control strategies attractive to farmers. Similarly, Walsh and Kingwell (2021) pointed out potential price increases in grain outputs from a global ban on Glyphosate.

Economic losses in significant magnitudes on agricultural producers/farmers who are using the banned herbicides are possible under a policy to ban that herbicide (Cashman, Martin *et al.* 1981; Böcker, Britz *et al.* 2017; Böcker, Möhring *et al.* 2019; Ye, Wu *et al.* 2021). Consumer surpluses can be reduced with prices simultaneously driven up with the supply shrinks, given a stationary demand curve in the commodity industry (Szmedra 1997). Some strict restrictions on herbicides can possibly lead to a net loss to the society because of the utilization of extra scarce resources to replace the herbicides for the production process (Burton and Martin 1987).

Conversely, highlighting a positive perspective, Beckie, Flower *et al.* (2020) argued that banning Glyphosate would set an opportunity for adopting environmentally friendly weed management strategies in addition to revenue increases as a result of price effects.

Together these studies indicate key impacts of a Glyphosate ban are mainly at the producer level including declines in farm profits due to escalated weed control costs on alternative weed management approaches, yield declines and price effects. There could also be widespread impacts of the ban on producer and consumer welfare in agricultural industries.

3.9.2 Glyphosate ban in Sri Lanka (2015 – 2018)

There are limited studies conducted in Sri Lanka particularly on the tea industry evaluating the impacts of the Glyphosate ban which was in place from mid-May in 2015 till late 2018.

Marambe and Herath (2019) evaluated the impacts of the Glyphosate ban on the agriculture sector in Sri Lanka and highlighted increased production costs, fall in yield, loss of foreign earnings from exports, increased use of informal Glyphosate products in the black market as consequences of the absence of an efficient and cost-effective weedicide option. Referring to impacts on the tea industry they pointed out that the ban has resulted in an estimated annual loss of tea production by 33.2 million kg that accounts to Rs 26.7 billion per year. They viewed the ban on Glyphosate as a main contributor that the reduction in yield over the ban period in 2015 and 2017 amidst prevalence of a favourable climate. Additionally, the loss of Rs 1 billion (USD 5.6 million) from the rejected tea consignments to Japan over incidents of exceeded MRLs of alternative weedicides such as Diuron and MCPA was indicated as a huge blow on the tea industry and the country's economy. Also, the annual loss of the ban was estimated to be Rs 10 – 20 billion by the Planters' Association in Sri Lanka as a result of escalated weeding costs on using labour, thereby production costs by Rs 2.7 to 19.01 per kg and abandoning marginal tea lands without controlling weeds and harvesting.

Malkanthi *et al.* (2019) assessed the impacts of banning Glyphosate on the paddy cultivation in Sri Lanka. They have mainly compared the cost spent on weedicide and the total cost of production before and after the banning of glyphosate while also focusing impacts of the ban on the socio-economic factors of farmers. In their study, they have shown that there were significant increases in the cost of herbicides used and also in the cost of production after banning as farmers have tried out various alternative herbicides. Furthermore, MCPA, 2,4-D and Hedanol were used by 56 per cent of paddy growers although they were reported to be less efficient than Glyphosate, while others have used mechanical weeders and innovative compositions on weed control like Monosodium Glutamate. Very few farmers have used manual weeding only because of shortages of hired labour, high wage rates, and unavailability of family labour.

A comprehensive field evaluation on the impacts of banning Glyphosate on the agriculture sector in Sri Lanka was conducted by Abeywickrama, Sandika *et al.* (2017) covering small and large tea plantations, tea factories, maize farmers, banana growers and farmers cultivating field crops such as corn, chili and sugarcane. They highlighted that there were significant economic costs on all crop producers at all scales, however with the least cost to smallholders.

It was found from the field survey that farmers had to do additional harrowing whenever possible incurring additional costs on weeding, increased costs of production, product quality and quantity reductions, eventually affecting the farm income. There were several consequences of the ban as pointed out such as enhanced soil erosion following increased harrowing, use of cocktail mixtures of kerosene and Monosodium Glutamate for weed control with no prior knowledge on the toxicity and effect on environment and human health, reduction in the area of cultivation in field crops, exploitation of smallholder farmers because of their lack of resources by charging higher costs on machinery hiring.

The operation of a black market for informal Glyphosate products sourced from illegal channels was indicated in their study. They highlighted that around 50 per cent of farmers were dependent on such unknown formulations with no safety track records and recorded efficiency similar to Glyphosate that were also expensive with 300 – 350 per cent price increase with respect to the Glyphosate price before the ban.

Importantly, it was revealed from the survey that smallholders were dependent on Diuron as an alternative to Glyphosate controlling pre-emergent and post-emergent broadleaved and grass weeds, however, was less favoured over illegal Glyphosate products. More than 50 per cent of smallholders in the survey have experienced the cost of production escalations because of extra labour allocation on weed control. Consequently, they have revealed that tea yields declined due to high weed densities also leading to declined farm incomes. Tea growers with the smallest landholding sizes have somehow managed to lower the impact on yield reduction by employing family labour.

On the other hand, large plantations have reported a 30 per cent increase in labour requirements for weed control and a three-fold increase in labour costs leading to an increase in the cost of production of green leaves by Rs 5.5/kg. Furthermore, giving up harvesting in marginal tea lands because of difficulties in economical weed control with labour, enhanced chances of soil erosion in mechanically weeded exposed tea fields, increased population of reptiles and wild animals with injuries on labourers were commonly observed in tea smallholdings and estates as consequences of banning Glyphosate. Based on nationally available published data, the study has pointed out a 11 per cent reduction in tea production in the country in 2016 relative to 2015, and a decline in export earnings of 5.4 per cent amidst tea price escalations.

The studies presented thus far on evaluating economic impacts of banning Glyphosate on the tea industry in Sri Lanka provide evidence that there has been heavy dependence on labour-intensive weed control options involving costly labour, and chemical options including alternative herbicides and overpriced illegal Glyphosate products that have subsequently escalated weeding and production costs in green leaf production making it a less profitable business. Moreover, yield reductions, abandoned marginal tea fields, reduced worker efficiencies due to uncontrolled weed densities have exacerbated situations in the tea farm sector.

Although studies by Marambe and Herath (2019) and Abeywickrama, Sandika *et al.* (2017) highlight economic losses at the national level and some limited details at the farm level, a comprehensive evaluation of the changes in weed control alternatives and related costs and farm gross margins, overall economic impact at farm level and consequent market levels in the tea industry have not been explored.

3.10 Methods used to evaluate the impacts of agrochemical bans

The recent study by Ye, Wu *et al.* (2021) was focused on evaluating the effects of human health and environment and welfare of the market economy impacts on the use of Glyphosate and alternative weedicides. This is because the policy decision to ban Glyphosate in corn production depends on the tradeoff between these social welfare and economic welfare impacts. In the study, they developed two models, first, a herbicide demand model to estimate the empirical Allen–Uzawa elasticity of substitution which measures the substitutability of Glyphosate with alternative weedicides. Subsequently an EDM was developed to apply the substitution elasticity parameters and damage prices to estimate market economic and social welfare effects which is the total of producer, consumer surpluses and tax transfer.

Jacquet, Delame *et al.* (2021) evaluating micro-economic impacts of a Glyphosate ban in French vineyards quantified economic costs of alternative weed control approaches in viticulture. They have used farm level data from a national survey on crop practices to compare weed management practices that involved Glyphosate and other weedicides, and weedicide- free approaches and thereby evaluate the impact on farms if they were to adopt such alternative activities in case of a Glyphosate ban. With the collected data, they have calculated weeding costs, additional costs incurred, farmer incomes across identified alternative crop practices.

Bocker, Britz *et al.* (2018) in their study attempting to assess effects of a Glyphosate ban on weed management in silage maize production developed a bio-economic model. The model has helped representation of weed control decisions adopted in maize production. They have applied the bio-economic model to simulate economic optimal weed control across two scenarios – with current standards and a ban on Glyphosate.

The positive effects of the use of Glyphosate and consequences of a potential ban on it in German agriculture on a wide range of crops have been evaluated in the study by Garvert, Schmitz *et al.* (2013). The study takes two approaches, namely the direct costing framework and sectoral analysis in describing the said effects in terms of changes in the quantities of production, prices of the produce, profit margins and welfare economic aspect. The direct costing framework examines the effect on the cost and the level of performance per unit land extent and the sectoral analysis uses the AGRISIM model for assessing the changes in production, trade and economic welfare for the rest of the countries in the European Union. The AGRISIM model that has been used in predicting the shifts in demand and supply of the commodity is a partial-equilibrium, multi-commodity-multi-region model that has non-linear isoelastic supply and demand functions. The effect of an external shock to the equilibrium of the market, which is the yield depression and rise in the cost due to the ban on Glyphosate has been simulated using shift coefficients in demand and supply functions, for different responses of farmers assumed.

Liu, Carlson *et al.* (1995) have examined the trade-off between agricultural production and ground water contamination potential for possible herbicide withdrawals in North Carolina, USA. They have analysed the cost and benefit changes in detail in order to determine the social impact of banning those pesticides by developing theoretical and empirical models to estimate losses in consumer and producer benefits in the agricultural commodity market and changes in the groundwater quality based on seven single or multiple cancellations of corn herbicides. Losses incurred by consumers and producers have been identified as costs to the society which are reflected by the shifts in the supply curve of pesticide using crops following this herbicide withdrawal. According to researchers, shifts in the product supply associated with the cancellation of a herbicide can be categorized into two parts as; yield loss and rise in input and application cost. In quantifying and calculating cancellation costs to the society after the withdrawal policy implementation, supply functions (before and after cancellation) and demand function, have been obtained by deriving a series of equations and based on several assumptions to represent the resulting situation. With respect to control cost changes estimation, details related to the expenditure per acre treatment for each herbicide applied at a given time used to control weed species were obtained from the farmer survey. The study has also conducted an economic assessment of benefit/welfare losses using knowledge on the changes in the price and output quantity and a few assumptions.

3.11 Literature propositions reviewed in the current study

In Section 3.9, the findings from the literature after revising the impacts of a potential Glyphosate ban on agricultural industries in other countries and Sri Lanka are discussed. These findings are used as the key points for providing the basis for literature propositions reviewed in this study. Hence, the following research propositions are tested in the current study with respect to the tea industry in Sri Lanka.

The following section summarizes the research propositions with relevant literature that leads to them.

Weed management strategies changed in case of a Glyphosate ban

According to Beckie, Flower *et al.* (2020) the use of alternative weed control options such as physical, mechanical methods including tilling, cultural methods and alternative weedicides are increased during a ban on Glyphosate.

The demand for labour increased during the Glyphosate ban

Allocating extra labour over more time and energy consumption on mechanical strategies in weed control increase the demand of labour according to the findings by Garvert, Schmitz *et al.* (2013), Böcker, Britz *et al.* (2017), Bocker, Britz *et al.* (2018),Brookes (2019), Böcker, Britz *et al.* (2020) and Mennan, Bozoğlu *et al.* (2020).

The cost of weed management increased during the Glyphosate ban

As shown by Cruz, Cruz-Hipolito *et al.* (2021) and Mennan, Bozoğlu *et al.* (2020) increased demand for labour on more mechanical weed control strategies lead to expensive weed management. The costs of chemicals on weeding increase in instances where the next best alternative is substituted, that is usually more expensive than the previously used banned herbicide (Szmedra 1997; Böcker, Britz *et al.* 2017; Bocker, Britz *et al.* 2018; Schneider, Rasche *et al.* 2018; Brookes 2019; Pardo and Martinez 2019; Ye, Wu *et al.* 2021).

The ban on Glyphosate adversely affected the yields

Not being able to achieve the same level of weed control intensity with alternative approaches are more likely to result in yield declines because of higher weed growth, delayed and less efficient harvesting as suggested by Böcker, Britz *et al.* (2017) and Walsh and Kingwell (2021).

The gross margin per hectare decreased during the Glyphosate ban

Garvert, Schmitz *et al.* (2013) have shown that in the case of a ban on Glyphosate, with yield depressions regardless of a possible price increase in the produce, can reduce farm gross profit margins whereas some instances can lead to a constantly maintained margins.

The ban on Glyphosate caused economic losses for producers

Economic losses in significant magnitudes on agricultural producers who are using the banned herbicides are possible under weedicide withdrawal policy (Cashman, Martin *et al.* 1981; Böcker, Britz *et al.* 2017; Böcker, Möhring *et al.* 2019; Ye, Wu *et al.* 2021).

The ban on Glyphosate caused economic losses for consumers

Consumer losses can take place with prices simultaneously driven up with the supply shrinks, with a fixed demand curve in the commodity industry (Szmedra 1997).

The ban on Glyphosate caused economic losses for the whole industry

According to Burton and Martin (1987) herbicide bans can possibly lead to a net loss to the society because of the utilization of extra scarce resources to replace the herbicides for the production process.

3.12 Summary

In this chapter, important aspects in the study including weed management and approaches involved in weed control in tea cultivations in Sri Lanka as a field activity, Glyphosate use trends and policies in other countries and Sri Lanka and finally the impacts of a ban on Glyphosate, and methods involved in those studies are presented in a literature review.

Weed management in tea cultivations is an economically important activity as weeds can lead to economic losses in tea producing entities. There are several approaches adapted in tea cultivations to control weeds, mainly non-chemical and chemical weed management approaches. Chemical weed management involves the rational use of weedicides. Glyphosate was used as an effective weedicide in many tea cultivations in Sri Lanka before it was banned because of purported association of its use with the CKDu that led to high social costs. In the meantime, Glyphosate was classified as a probable carcinogen for humans by the World Health Organization, and its use was heavily debated around the world with revised Glyphosate use policies in terms of outright bans and gradual phase outs etc.

Economic impacts of a potential ban on Glyphosate studied in literature have shown that increased weeding costs because of the use of expensive alternative approaches that included more labour on mechanical strategies, costly alternative herbicides, narrowed gross margins, economic losses on producers, consumers and the whole industry can be resulted. These key points derived from literature were used as the basis for literature propositions reviewed on this study.

Key outcomes from this chapter were used as inputs to Chapter 4 in designing the method of the study, Chapter 5 in developing the EDM on the tea industry and Chapter 9 in analysing main findings of this study with finding of literature and evaluating the implications of the ban.

Chapter 4 Research Methods

4.1 Introduction

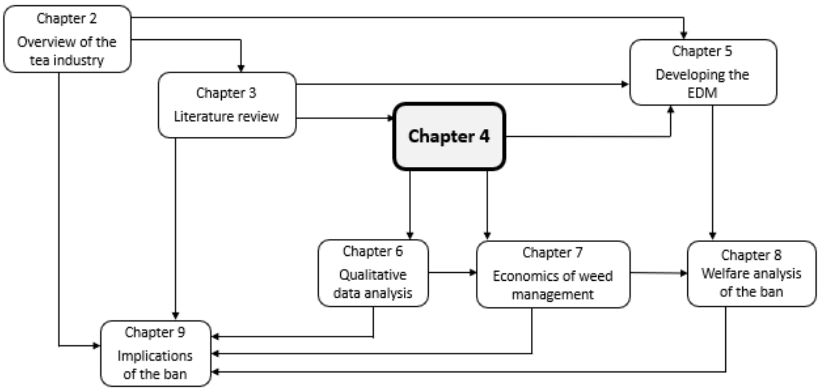


Figure 4.1. Flow of chapters in the thesis

In this chapter, the methods used to assess the economic impact of the Glyphosate ban on the Sri Lankan tea industry are presented. The chapter contains two main sections. First, alternate approaches to designing and undertaking applied research projects are reviewed and discussed, with a summary subsection outlining the methods chosen for this study. Second, the process by which the research was conducted is outlined, with an emphasis on the way different methods are integrated to answer specific research objectives. Results obtained using the methods described in this chapter and key findings with respect to research objectives are presented in Chapters 5, 6, and 7 in EDM development, identifying and study of factors influencing the decision making on weed management approaches in tea grower sectors and issues faced by them following the ban and budget analysis of representative landholdings from the tea smallholder and estate sector with different weed management combinations, respectively as presented in Figure 4.1.

4.2 Deciding on the research approach

The broad framework of a research design consists of three main components:

(i) philosophical worldview
(ii) research design
(iii) research methods.

4.2.1 Philosophical worldview

The philosophical worldview (Guba and Lincoln 2005) selected by a researcher simply refers to how they perceive orientations of research and plan to incorporate them in a study. Four philosophical worldviews have been widely discussed in the literature as post positivism (Phillips and Burbules 2000), constructivism (Mertens 2010; Lincoln *et al.* 2011), transformative (Neuman 2009; Mertens 2010) and pragmatism (Murphy 1990; Cherryholmes 1992).

Post positivism usually deals with quantitative approaches and is often found in experiments for theory verification. Constructivism on the other hand leads to theory generation by associating qualitative approaches. Transformative worldview deals with politics and political change agendas for achieving justice for the society and human rights. It is the pragmatic worldview that associates with the problem, question/s in research with all approaches possible for better understanding the context. These different types of beliefs underpinning each type of worldview eventually support and lead the researcher to line up with one of the three main types of research designs in their research study, namely quantitative, qualitative and mixed method designs.

This study aligns with the pragmatic worldview that does not focus on the method itself, but rather focuses on highlighting the research problem and questions using any type of approach available that is the most appropriate (Creswell and Creswell 2018). The pragmatism worldview is frequently chosen in parallel with mixed method designs in research to facilitate freedom to choose techniques and approaches that help understand the problem and serve the aim of the study. Therefore, researchers who conduct research within a pragmatic worldview attempt to address 'what' and 'how' questions depending on the anticipated outcomes (Creswell and Creswell 2018).

4.2.2 Research design

A research design provides explicit direction and focus on a study by identifying procedures, strategies and lines of inquiry that help address the research questions. Accordingly, there are quantitative, qualitative and mixed method designs that can be adopted when conducting research. Quantitative data is associated with describing and predicting variables or phenomena of interest using numerical data collection and analysis (Gay *et al.* 2009). Alternatively, qualitative designs offer non-numerical approaches including inquiry and observation into comprehensive understanding of the research context (Maxwell 2012). Mixed method designs combine at least one element from both quantitative and qualitative approaches in research (Creswell and Clark 2017). Furthermore, each main design consists of several other complex designs that are appropriate for different types of research from various disciplines.

The research approach implemented in a study must be defined by paying attention to three criteria. Responses provided for those three criteria will assist in developing the method and designing the research strategies to be implemented in the study. These are the three conditions stated by Yin (2017) that help researchers to determine the most suitable research approach for their study:

(i) the type of research question being addressed

(ii) the extent of control an investigator has over actual behavioral events, and

(iii) the degree of focus on contemporary as opposed to historical events.

Addressing these conditions requires proper understanding of the research methodology pertaining to the study that supports the selection of the best method for a systematic solution of the research problem.

Moreover, there are five major research strategies used in social science research namely experiments, case studies, surveys, history and archival analysis (Yin 2017). Experiments in research methods involve manipulating one or more variables usually in a controlled environment to test hypotheses in the research (Webster and Sell 2014; Creswell and Creswell 2018). Surveys are usually associated with collecting data from a sample of the population of interest when providing quantitative descriptions about a population (Creswell and Creswell 2018). Case studies are empirical inquiries that explore contemporary situations in real life contexts (Yin 2003). History as a research method relies on primary and secondary documents, cultural and physical artifacts as the main source of evidence where no relevant person is alive to report whereas, archival analysis studies information and evidence from historical sources such as documents, records etc. (Yin 2017).

Each strategy has its own way of being applied to studies depending on the responses given for the above criteria. In addition, three types of research approaches can be identified based on the purpose served by undertaking the particular research as exploratory, descriptive and explanatory studies (Yin 2003). Exploratory studies are conducted at initial stages of a researchable area by investigating research questions that have not been examined in detail, while explanatory studies usually describe reasons for phenomena in terms of causes and effects of it (Strydom 2013). Descriptive studies describe and/or define phenomenon of interest (Strydom 2013). Each research strategy can be applied to each of these three types of research approaches.

Types of research questions being addressed

As comprehensively explained by Yin (2003), the types of question forms that a researcher usually comes across in research questions are ‘what’, ‘who’, ‘where’, ‘how’ and ‘why’. Research questions focusing on ‘what’ type of questions can also indicate ‘how much’ and ‘how many’ lines of inquiry.

Types of 'what' questions that directly imply the research question can be conducted as exploratory studies using any of major research strategies (for example, exploratory survey, exploratory case study and exploratory experiments). Other types of 'what' questions that suggest 'how much' and 'how many' forms deal with identifying outcomes of the research problem of interest, plus 'who' and 'where' forms of questions. All of these types of questions fall either under exploratory or descriptive research approaches and are more likely to take survey and archival strategies than others. On the other hand, addressing 'how' and 'why' questions is possible using case study, experimental and historical analysis types of strategies rather than survey or archival record analysis since such questions need more clarification of the identified problem.

Accordingly, 'what' (also in the form of 'how much'), and 'how' questions that have been used in research questions describe the nature of the research as a study undertaken combining descriptive, exploratory and explanatory approaches. Specifically, the question that looks at 'how much is the economic impact of the ban' calls for a descriptive type of a study using survey or archival strategies. Therefore, research questions allow using all five research strategies, but including an explanatory approach works best in addressing questions that try to explain the effect of the ban on the landholdings and the industry through 'how' (and 'what') question forms. The latter approach favors case study, historical and experimental strategies.

However, for further refinement of the research strategy to be used in the study, the other two conditions that are mentioned earlier must be taken into consideration. This will help in isolating the potential research method that must be implemented in order to achieve set objectives in addressing research questions.

The extent of control over actual behavioral events and the degree of focus on contemporary as opposed to historical events

With regard to the extent of the investigator's control over and access to actual behavioral events, this study has access to, but lacks control over the manipulation of behavioral events. This eliminates the need for a historical approach in research. The experimental approach that permits the ability to manipulate the behavior of the subject precisely and systematically, also can be excluded because of its irrelevance in this study. This makes the case study approach the most appropriate strategy in dealing with 'how' questions, allows better explanation of the research problems and subjects of interest through close examination of data within a specific context. In terms of 'what' types of research questions the researcher is left with the choice between survey and archival strategy.

Selection of a strategy from survey or archives depends on the need for data and availability of data in each source.

Addressing the three conditions specified by Yin (2017) in relation to this study confirms that both survey or archival strategies and case study approaches are equally attractive and essential in determining the research strategy to be used. This simply reflects the need to follow both qualitative and quantitative methods, confirming mixed method research over a single method. This allows a better understanding and design of the research problem that will be incomplete with only one type of data.

4.2.3 Type of the research design and the rationale for choosing it

With respect to the present study, the primary research question that is being addressed is 'How has the ban on Glyphosate affected the tea industry in Sri Lanka?'. Secondary research questions devised in order to address the primary research question are 'What have been the impacts of the ban on Glyphosate on the farm sector of the tea industry during the period of the ban?' and 'What have been the effects of the ban on Glyphosate on participants in the tea value chain?'. The first secondary research question particularly focuses on the farm sector whereas the second question broadly considers the tea value chain and its participants.

In summary, the above-mentioned research questions cannot be answered fully with either quantitative or qualitative data. Assessing the impacts of the ban as consequences at the farm sector of the tea industry requires in depth exploring and understanding of the explanations ascribed by individuals, plus the complexity of the situation, aligned more with qualitative data. On the other hand, quantifying the economic effects of the ban mainly deals with quantitative data applied at a whole of industry level of aggregation.

Given the above discussion, it is clear that this study required a combination of both quantitative and qualitative methods within the same design. Thus, the mixed method single case study design was employed as suggested by (Ritchie *et al.* 2013; Creswell and Creswell 2018). Mixed method in research integrates both qualitative and quantitative data, through in-depth study that none of these two methods can offer individually (Ritchie, Lewis *et al.* 2013; Creswell and Creswell 2018). This approach provides an extended, comprehensive understanding of research questions and objectives by combining two research methods within the same research design.

This design allows using one or more core designs within a single or multiple case design in a deductive approach by identifying case/s at the beginning, eventually using quantitative and qualitative data to study the case/s.

Embedded-single case design

The design primarily being used in this research study as a whole was the single case design as suggested by Yin (2017). Single case designs are applicable where cases are critical, unusual, common, revelatory and longitudinal. These types of single case studies are used to determine if propositions specified in the study are correct or if not, whether some other sets of explanations are more relevant. A longitudinal case study approach studies the same single case at two or more different points of time.

The embedded nature of the single case study design comes with the use of multiple units of analysis (sub-units) that are elements within the case. It is not necessary to select these units all from one level, instead it is usually more than one level. However, they must be a part of the original single case. Such designs are usually applied to instances that evaluate projects or programs by in-depth inquiry about goals, implementation and outcomes.

Hence, this embedded, single case design (Yin 2017) suited best as a preliminary design on the present research because the focus was on the performance of the tea industry and its participants across time periods when the government policy of banning the use of Glyphosate was in place.

A graphical representation of the embedded – single case design as suggested by (Yin 2017) is depicted in Figure 4.2. Accordingly, a given context of interest is studied in detail through a thorough study of embedded units bounded by a case.

The context of the study is the broad setting that is evaluated by conducting research. The actual context of interest complementary to the present study was the economic impact of implementation of the government policy of banning the Glyphosate use in Sri Lanka. The policy decision led to severe consequences in numerous agricultural industries in the country given that Glyphosate has been a widely used weedicide in agricultural lands.

Evaluating economic impacts on all affected industries through a single research study was challenging because of resource limitations. Bounding the case is undoubtedly important in this regard, to narrow down the scope of the study, enabling investigation of the case in depth. Therefore, the focus of this research was only the tea industry, as the case.

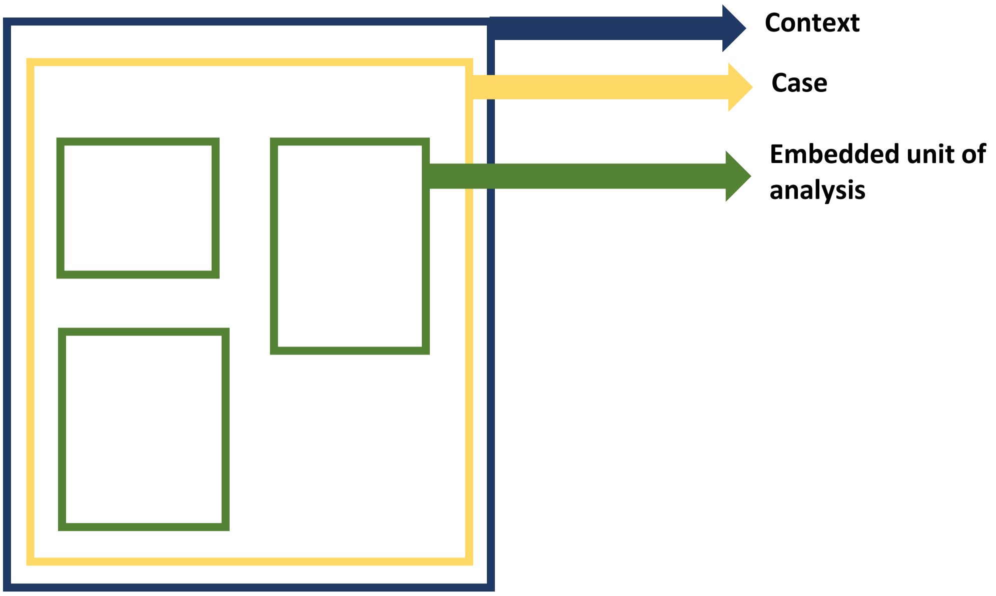


Figure 4.2. Embedded-single case design (Yin 2017). Source: Yin (2017)

While many other agricultural industries were affected by the Glyphosate ban such as coconut, rubber, paddy, maize, sugar cane, chili etc., the tea industry has been selected as the case as it plays a substantial role in generating foreign income as the top export agricultural commodity in Sri Lanka. The repercussion of the government policy on the entire tea industry has been immense (see the discussion in Chapter 2), and it was worth examining the impact thoroughly at each market level.

A study of the entire tea industry implies drawing attention to key participants along the value chain and investigating the impact of the ban on each of them for comprehensive interpretation of the context under interest. The embedded units of analysis in this single case design were therefore the key participants in the tea industry that will be studied in detail. The basis for selection of these embedded units of analysis is explained later in this chapter.

This single case design provides a picture of the research problem, and justification for selecting the tea industry as the entity for research and how research questions are studied within the selected industry.

Convergent mixed method

A separate mixed method research design was selected to explain strategies used within this single case design of the study and achieve research objectives. There are three main types of designs that can be applied on mixed method research as i) convergent design that merges both quantitative and qualitative data, ii) explanatory sequential design where initial quantitative data are explained by a qualitative data collected and analysed subsequently and iii) exploratory sequential design that follows the reverse order of the explanatory sequential design (Creswell and Clark 2017; Creswell and Creswell 2018). These designs differ from each other based on 'when' and 'how' these two research methods are used within the study.

Convergent mixed method design was viewed as the best-suited strategy for the current study because of the applicability of this design to achieving the stated research objectives. The underlying concept behind a convergent mixed method is that data sourced from two methods are converged for corroboration within the single study (Creswell, Plano Clark, et al., 2003). As shown in Figure 4.3, this mixed method design involves two stages, firstly, simultaneous collection and analysis of both quantitative and qualitative data and secondly merging findings for interpretation purposes (Creswell and Clark 2017).

This design has been adopted in the present study as it involved developing an economic model of the tea industry using quantitative data collected from secondary data sources and evaluating the impacts of the ban on the farm sector and key market levels in the value chain using qualitative and quantitative data.

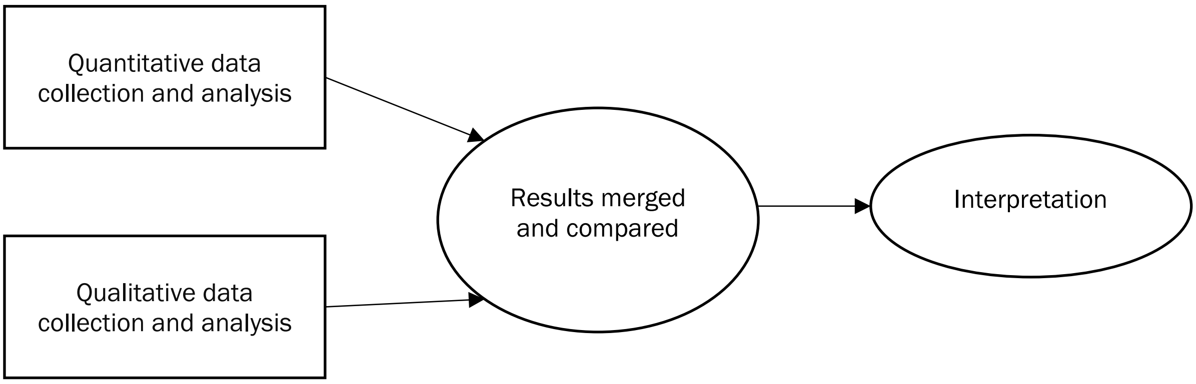


Figure 4.3. Convergent mixed method design. Source Creswell and Clark (2017)

Quantitative and qualitative data are hence required to be collected and analysed at the same time for interpretation and addressing the research questions in the subsequent phase through relevant methods such as budget analysis and using the developed economic model to interpret economic impacts of the ban. These specific methods are discussed in detail in the subsequent sections.

4.3 Research Process

The decision on which methods are used in a research study depends on the design implemented. The methods used in a study involve all of the techniques and processes undertaken in the research for data collection, analysis, and interpretation to finally achieve the objectives and address the research questions.

To recap, the research objectives of this study were 1) to study the factors affecting weed management related decision-making with the ban on Glyphosate and effects of the ban on the farm sector, 2) to quantify changes in weed management practices and tea production budgets in the farm sector, 3) to develop an economic modelling framework for the tea industry in Sri Lanka, 4) to estimate welfare changes of the ban on participants in main market level along the tea value chain and on the industry, and 5) to evaluate implications of the ban on the tea industry. In Figures 4.4 the sequential and inter-related achievement of the above objectives and the main research question are presented.

All research objectives were inter-related that key findings from one research objective provided inputs to achieving the subsequent objective in this study as presented in Figure 4.4.

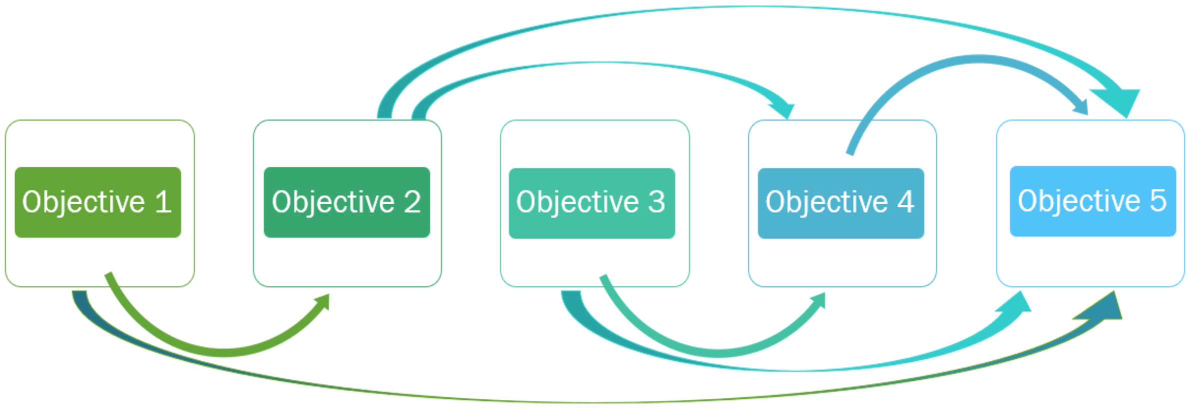


Figure 4.4. Sequential and inter-related achievement of research objectives

Linked to Figure 4.4, a snapshot of the various methods used in achieving each research objective of the study is shown in Table 4.1.

Table 4.1. Methods involved under each research objective

Main research question	Secondary research questions	Objectives	Methods involved
How has the ban on Glyphosate affected the tea industry in Sri Lanka?	What have been the impacts of the ban on Glyphosate on the farm sector of the tea industry during the period of the ban?	To study the factors affecting decisions about weed management as a result of the ban on Glyphosate and the effects of the ban on the farm sector	Primary data collection
		To quantify changes in weed management practices and tea production budgets in the farm sector	Primary data collection Secondary data collection
	What have been the effects of the ban on Glyphosate on participants in the tea value chain?	To develop an economic modelling framework for the tea industry in Sri Lanka	Literature review on the tea value chain in Chapter 2 Secondary data collection Subjective judgements on market parameters
		To estimate welfare changes of the ban on Glyphosate on participants in the main market levels along the tea value chain and the on the industry	Application of results of objective 2 on the economic model developed under objective 3
		To evaluate overall implications of the ban on Glyphosate on the tea industry	Analysis of results from objectives 1, 2,3, and 4

Figure 4.5 is an outline and flow of chapters in the thesis that facilitates a clear understanding of the sequence of achieving research objectives, and their key findings organized in respective chapters.

All methods used under each objective in undertaking the steps are discussed in detail below. The first research question is addressed by Objectives 1 and 2, while Objectives 3, 4, and 5 address the second research question.

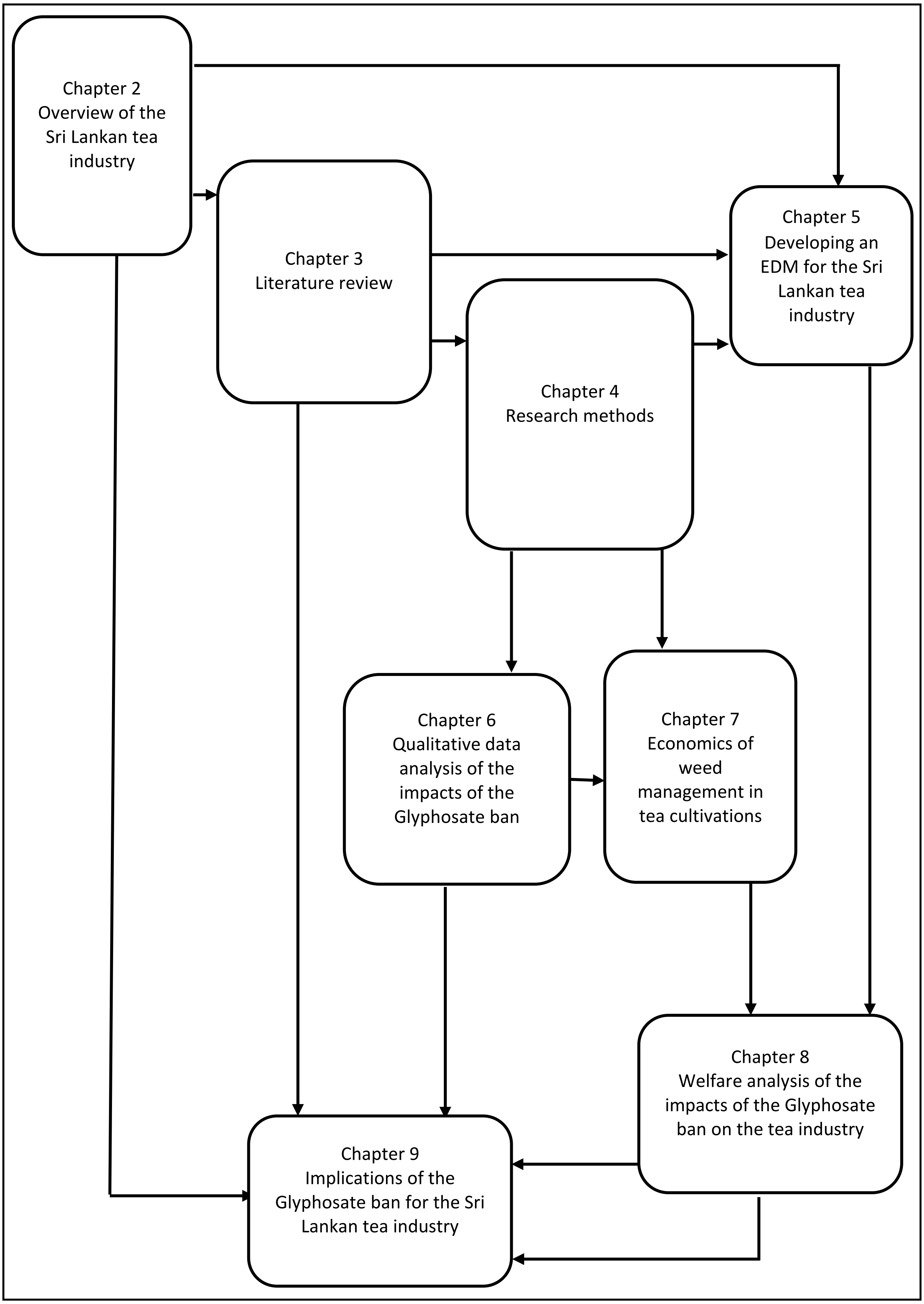


Figure 4.5. Chapter outline of the thesis

4.3.1 Objective 1: To study the factors affecting decisions about weed management as a result of the ban on Glyphosate and the effects of the ban on the farm sector

Primary data collection

The main method of collecting data under this objective was by conducting interviews with tea growers, industry stakeholders and experts in the field. This allowed detailed investigation and data gathering on factors influencing their decision making on choosing weed management approaches before and during the Glyphosate ban and exploring impacts/consequences of the ban on the sector as experienced and viewed by farm sector participants and various stakeholders, more specific than data that could be gathered by a formal survey.

4.3.2 Objective 2: To quantify changes in weed management practices and tea production gross margins in the farm sector of the tea industry

Primary and secondary data collection

Quantitative data gathered during detailed interviews with decisionmakers at the farm level from the smallholder sector and the estate sector on changes taken place in weed management practices and related activities in tea cultivation were mainly used. Findings of the first objective were providing justifications for such changes in weed management parameters. This quantitative data along with secondary data on green leaf prices received by tea growers, and wage rates of labourers, were mainly employed in developing production budgets for the tea grower sectors and deriving budget parameters such as changes in total variable costs and gross margins. Budgets were developed for weed management combinations across the period with respect to the imposition of the ban and analysing budget parameters for representative landholdings from the tea grower sectors.

4.3.3 Objective 3: To develop an economic modelling framework for the tea industry in Sri Lanka

Value chain analysis in the literature review

The formal analysis of the value chain in Chapter 2 is also based on findings from Hettiachchige and Rathnayake (2021) using a performance measurement framework that was done while reviewing the literature. This review and analysis together helped in identifying key participants in the tea industry in Sri Lanka, and thereby providing information required for mapping the key components of the tea industry. The tea value chain analysis facilitated identifying inputs and outputs and specific supply and demand relationships at each market level devising the overall framework of the model on the black tea value chain.

Hence, the EDM was developed for the tea industry in Sri Lanka, particularly on black tea which covers the highest portion of national production. The specification of equations representing black tea value chain in the tea industry is discussed in chapter 5. The model facilitates the quantification of the economic impact of exogenous shocks such as policy decisions, thereby achieving the research objective.

The main inputs required for the technical validation of the model are market data for the industry, such as price and quantity data of products along the value chain of the tea industry and market parameters such as price elasticity values of products used in each market level.

Validating the model required price and quantity data and market parameter values collected by several methods including secondary, expert opinion and theoretical considerations. The model was constructed based on data from the period between 2010 and 2014. Model validation including data collected is discussed in chapter 5.

Secondary data collection

Quantitative data from data sources such as annual reports, performance reports, documents on market updates of government institutes working with the tea industry in Sri Lanka including SLTB, TSHDA, Ministry of Plantation Industries, Department of Census and Statistics and the Central Bank of Sri Lanka were used to gather market data on prices and quantities for the given years.

Expert opinion and theoretical considerations on subjective judgements on market parameters

Market parameters such as price elasticities, product transformation elasticities and input substitution elasticities are not readily available in the published literature. Therefore, alternative sources such as expert opinion and considerations based on theoretical relationships were employed to decide on values for the market parameters.

4.3.4 Objective 4: To estimate welfare changes of the ban on Glyphosate on participants in the main market levels along the tea value chain and the on the industry

Findings from Objective 2 on budget parameters reflecting the direct impact of the ban on the farm sector and another unintended consequence of the ban were used as inputs on the technically validated EDM under Objective 3. Such shocks on exogenous demands and supply on inputs and outputs in the industry were expressed as percentage changes. Results thus obtained from the EDM were interpreted as economic surplus changes on different market levels in the value chain and the total surplus change on the tea industry.

4.3.5 Objective 5: To evaluate overall implications of the ban on Glyphosate on the tea industry

This objective was achieved by analysing key findings derived from all other objectives and analysing to interpret the implications of the ban on Glyphosate on the tea industry and its stakeholders.

4.4 Main research methods involved

Primary data collection using interviews

A series of detailed interviews were conducted during the primary data collection to collect both qualitative and quantitative data from participants and stakeholders of the tea industry in Sri Lanka.

4.4.1 Interviewees

Key participants identified in the tea industry interviewed were tea growers (private tea landholders including small holders and medium-scale growers, and estate management of RPCs), tea factory managers from the black tea manufacturing sector, and secondary processors and exporters. These three sectors represent the key market levels in the tea value chain engaging in product conversions. The latter group is confined mainly in the capital city of Colombo whereas all other sectors are scattered in all tea growing regions. In addition, key informants were also interviewed from a range of tea growing areas.

Selected geographical areas

Interviews were carried out in the main districts in the main tea growing regions; up-country, mid-country, low-country and 'Uva' regions. The official statistics suggested that Nuwara Eliya, Rathnapura, Kandy, Galle and Badulla districts had the highest production and areas of tea cultivation over past years (Sri Lanka Tea Board 2017; Ministry of Plantation Industries & Export Agriculture 2020). Figure

4.6 presents the distribution of districts across the main tea growing regions that were selected for conducting interviews with tea industry participants/ stakeholders.

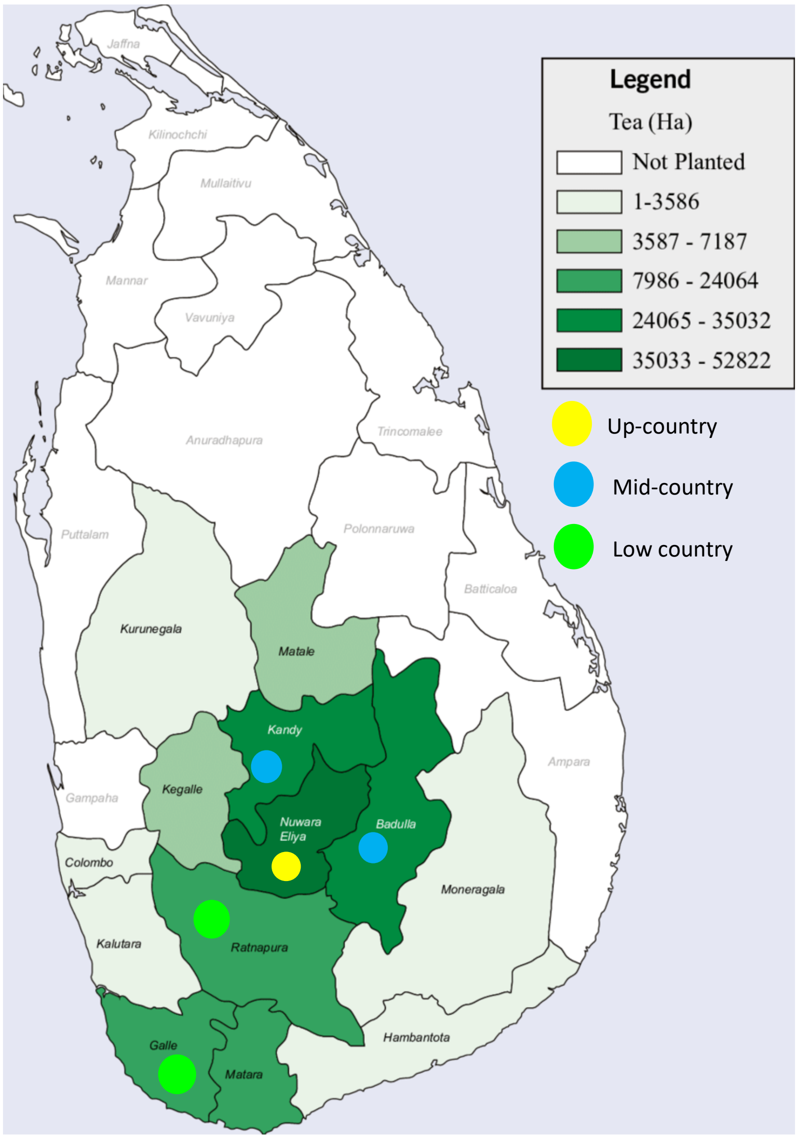


Figure 4.6. Distribution of tea growing regions and districts in Sri Lanka. Source: Adapted from Economic census (2013/14) the Department of Census and Statistics

Types of interviews

Semi-structured interviews were held with the selected participants from the farm sector in the tea value chain. Such interviews allowed collection of both close-ended and open-ended data by exploring the perception, attitudes and personal experiences of individuals on the issue being investigated in more of a private setting.

Interviews were also conducted with several other types of industry stakeholders (in the enabling environment) to examine every possible facet of the issue. These individuals were categorised as key informants in the tea industry. Key informants are people with a deep understanding about the issue or the phenomenon or organization being investigated (Lavrakas 2008). Sometimes they are considered as proxies for the group of individuals they represent or work with. The key informants selected were managers and regional managers of government institutes such as the TSHDA and the SLTB, tea extension officers and office bearers of smallholder tea grower societies who were capable of providing a wide insight and first-hand knowledge of the community they are working with.

Focus group discussions were also held with tea smallholders and labourers in the tea grower sector to explore their perceptions, opinions towards the research problem.

Interviews with experts were also conducted to gain deeper knowledge and different perspectives on the research problem. Accordingly, academics, researchers and senior extension officers were interviewed to obtain their expert knowledge into the study.

Sample selection

Individuals who were key participants in the tea industry were selected by purposive sampling. This enabled the selection of individuals who have knowledge or experience on the context being investigated in the study, and who were willing to participate actively to share their experience and opinions in a more precise and elaborative manner (Creswell *et al.* 2011) . Hence, information-rich sources of data were ensured.

In this case, key informants' opinion provided much useful inputs for the purposeful selection of interviewees from the tea production districts.

Key informants were selected by a snowball sampling technique, where referrals and recommendations provided by key informants contacted in the first place identified other informants. The chain of contacts eventually expanded to identify key informants from each district as well.

Some focus group discussions were held in the presence of 5-8 individuals at a time selected by convenience sampling. Accordingly, focus group discussions with tea smallholders and labourers were organized with the help of extension officers in production areas, and managers of tea estates, respectively.

Experts such as researchers and academics were also selected by snowball sampling.

Sample size

The findings in this study were generalized to the theory/theoretical propositions (analytical generalization), so literal or theoretical replication can be applied. As Yin (2018) explains, 'literal replication helps in predicting similar results across the cases and theoretical replication predicts contrasting results but for anticipatable reasons (p.55)'. Accordingly, to align with theoretical replication, interviews were conducted with more than 6 subunits from each market level.

Table 4.2 provides meta data on interviews conducted with participants and stakeholders in the tea industry as a summary of details discussed so far.

Table 4.2. Meta data on interviews in primary data collection

Type of personal interviews	Data collection tool	Interviewees	Sample size	Sampling technique	Duration of interviews (minutes)
Individual interviews	Semi-structured interviews	Private tea growers Estate managers Tea processing factory managers Secondary processors Tea exporters	35 5 6 3	Purposive sampling	30 – 60
Key informant interviews	Semi-structured interviews	Managers and regional managers of government institutes Extension officers of government institutes Office bearers of tea grower societies	5 5 5	Snowball sampling	20 – 40
Focus group discussions	Semi-structured interviews	Labourers in tea estates Tea smallholders	2 2	Convenient sampling	30
Expert interviews	Unstructured interviews	Academics Researchers	3	Snowball sampling	30

Obtaining consent to participate in interviews and recording of interviews

Upon selection of individuals, verbal consent was obtained from each potential interviewee by explaining the nature of the study, questions asked during the interview and policies regarding data handling to comply with the human ethics[3] and integrity in research in advance to conducting interviews.

Interview guide/schedule

The tool used for data collection was an interview guide/schedule that provided a set of questions for the interviewer to ask during an interview. It facilitated the flow of conversation during the interview keeping track and focus on what is being discussed while raising unanticipated questions for areas of interest that the interviewee brought up ensuring to maintain the natural setting of the interview.

Interview schedules were designed for all types of interviews covering several themes under each interviewee group.

Semi-structured interviews with private tea growers asked questions on aspects covering:

(i) Household and farming information
(ii) Importance of the cashflow from the business in the household
(iii) Weed management and other tea cultivation practices before the ban
(iv) Changes in yield and weed management practices during the ban
(v) Factors affecting the decisions on changes in weed management and other cultivation practices following the ban on Glyphosate
(vi) Effect of changes in yield and weed management on the business budget
(vii) General questions on issues in the tea cultivation

Semi-structured interviews with estate sector growers and estate management asked questions on aspects covering:

(i) General information about the tea estate
(ii) Information about the labour force
(iii) Weed management and other tea cultivation practices before the ban
(iv) Changes in yields and weed management practices during the ban
(v) Factors affecting the decisions on changes in weed management and other cultivation practices following the ban on Glyphosate
(vi) Effect of changes in yield and weed management on the business budget

[3] This study was ethically conducted, that approval was granted for the application submitted with the Ethics ID 1852491.1 from the Human Research Ethics Committee in the University of Melbourne.

(vii) General questions on issues in the tea cultivation

Focus group discussions with estate labourers asked questions on aspects covering:

(i) Changes that took place in weed management and other cultivation practices during the ban with respect to the period before the ban
(ii) Problems encountered while engaging in these cultivation practices

Focus group discussions with tea smallholders asked questions on aspects covering:

(i) Changes that took place in yield and weed management practices during the ban with respect to the period before the ban
(ii) Problems encountered while engaging in weed management practices
(iii) Factors affecting the decisions on changes in weed management practices following the ban on Glyphosate
(iv) Trends in green leaf production, prices received and cost on tea landholdings during the ban
(v) Issues faced by the private tea grower sector

Key informant interviews in the farm production sector asked questions on aspects covering:

(i) General information about the member base of the organization and their demographics
(ii) General practices adopted by members for weed management before the ban
(iii) Changes in weed management practices and issues in tea cultivation during the ban faced by members
(iv) Major trends in green leaf production, prices received, and costs incurred by members during the ban
(v) Issues faced by members over the years

Semi-structured interviews with tea processing factory managers asked questions on aspects covering:

(i) General information about the business
(ii) Demographic information about the client base supplying green leaves
(iii) Performance of the business before the ban
(iv) Changes noticed in the input and output supplies (quantity and quality) of the business
(v) Trends in input supply, costs of production, and prices received during the ban
(vi) Issues faced by tea processors

Semi-structured interviews with tea traders/marketers/exporters asked questions on aspects covering:

(i) General information about the business
(ii) Major buyers of tea
(iii) Performance of the business before the ban
(iv) Changes that took place in major buyers during the ban
(v) Issues faced by traders

Complete interview guides used during the primary data collection are attached in the appendices. (See APPENDIX 1)

4.4.1 Conducting interviews

All interviews were conducted by the researcher herself in a time and place convenient to the interviewee to make it more comfortable for the interviewee to respond to questions. Field notes/written records were taken by the researcher to record responses of interviewees during individual interviews and focus group discussions. Audio recording was not practiced based on the possibility of exposing financial information deemed sensitive and confidential by interviewees. Relying on field notes could be identified as a data collection limitation as it does not capture everything discussed in the interview regardless of how important they are. However, some key informant and expert interviews were audio recorded with their consent.

Most of the interviews were conducted in Sinhala, which is the language most respondents were comfortable with, and some key informant and expert interviews were conducted in English.

All field notes taken during all interviews, including observations on interviewee's reactions to questions and the setting of the interview, were translated and transcribed into an interview transcript after the interview, to be used later for analytical purposes. Hence, an interview transcript was developed for each interview. A sample interview transcript is attached in appendices for reference (See AAPENDIX 2). The rest of the interview transcripts are available as supplementary information from the author.

4.4.2 Data analysis of interviews

Data gathered in the primary data collection through different types of interviews comprised both quantitative and qualitative data. Quantitative data was collected from tea grower groups, mainly on resource use, allocation and changes took place following the ban on Glyphosate on tea cultivation practices. With the information thus collected from private and estate tea growers, variable cost budgets were developed in Excel for representative landholdings to derive different k shifts for weed management combinations and respective scenarios emphasized from qualitative data analysis, that were later applied on the EDM.

Thematic analysis was carried out for the qualitative data in the NVivo software by identifying themes in interview scripts. Further refinement of themes emerged helped studying factors affecting weed management approach related decision making in tea grower sectors and identify potential weed management combinations and related scenarios that were used as inputs on the EDM.

4.5 Secondary data collection

Secondary data collection used data sources from government institutes working with the tea industry in Sri Lanka and also institutes engaged in gathering and processing market information on the industry. In the following Table 4.3 the sources used in secondary data collection are listed.

Table 4.3. Sources used in secondary data collection

Government institute	Document	Years
Central Bank of Sri Lanka	Annual report	2014 – 2019
Sri Lanka Tea Board	Annual report	2014 - 2017
	Tea market updates	2014 -2018
Tea Small Holdings Development Authority	Annual report	2014 – 2018
Ministry of Plantation Industries	Annual performance report	2014 – 2017
Department of Census and Statistics	Cost of production of tea (website)	2014 - 2018

Some information collected from secondary data sources also allowed triangulation of data with other sources such as primary data collected. This also allowed improving the credibility of findings.

4.6 Summary

In this chapter the methods undertaken in addressing the key research objectives of the study evaluating the economic impact of banning the use of Glyphosate on the tea industry of Sri Lanka were discussed.

With respect to the philosophical worldview that categorizes research, this study falls in the category of pragmatism that focusses on understanding and eventually answering the research question and problem using any appropriate means available. Pragmatic worldview therefore favours integration of both quantitative and qualitative approaches to ensure maximum reach to data in any form. Accordingly, the study adopted a more complex version of mixed method design, mixed methods single case design. A convergent mixed method approach was involved in studying the tea industry in Sri Lanka as a single case. Therefore, both quantitative and qualitative data were collected and analysed in the study to evaluate the impact of the ban on the tea industry.

Objectives set in addressing research question were achieved by several modes of data collection and analysis. Study on the value chain of tea by reviewing literature facilitated identifying the key market levels in the tea industry, their interaction and thereby providing inputs to mapping the framework of industry on black tea production and marketing. An EDM was developed to the black tea industry in Sri Lanka using secondary data on prices of quantities of black tea and related products, that will help evaluating the economic impact of the ban in terms of a welfare analysis using real scenarios.

A primary data collection was conducted to gather quantitative and qualitative data at the same time through a series of interviews with participants and stakeholders in the tea industry. These quantitative and qualitative data were used for budget development, analysis and thematic analysis respectively, along with secondary data on market prices and quantities collected from government data sources to develop scenarios as inputs in the EDM. Exogenous shocks as percentages derived from scenarios were applied on the model to measure surplus changes as a result of implementing the ban.

Finally, findings obtained while achieving research objectives were integrated and analysed to evaluate implications of the ban on participants and stakeholders in the tea industry in Sri Lanka.

Chapter 5 Developing an Equilibrium Displacement Model for the Sri Lankan Tea Industry

5.1 Introduction

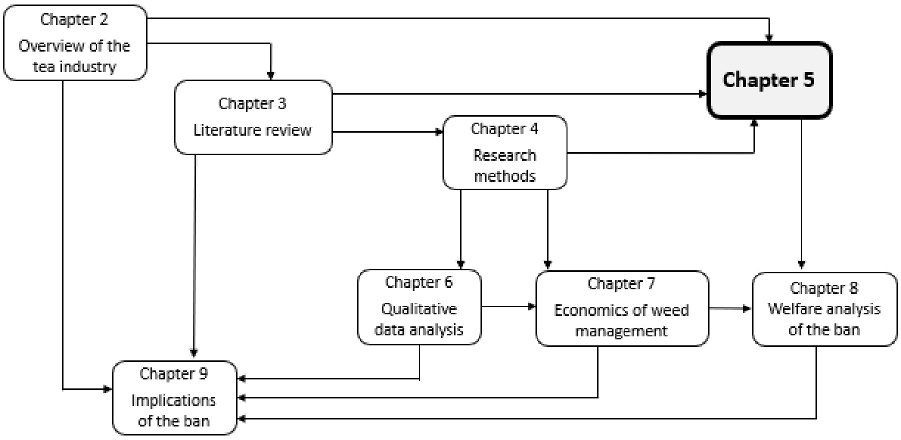


Figure 5.1. Flow of chapters in the thesis

The process of developing the Equilibrium Displacement Model of the tea industry in Sri Lanka is explained in this chapter. Section 5.2 provides a brief literature review on the EDM since it was first introduced and then its applications. The rest of the chapter comprises key sections that lead progressively to the construction of an EDM of Sri Lanka's tea industry. First, the main market levels of the industry are defined by segmenting the tea production, processing and retailing sectors into markets, vertically and horizontally. This defines the industry in terms of a system of demand and supply equations in each market sector, using firm production functions and their derivations and representations of consumer demand. The tea industry thus presented in a series of general functional forms is then translated into equilibrium displacement form. Towards the end of the chapter, input data such as market quantities and price, and elasticity estimates that are used in the model, are defined. Some hypothetical external shocks are imposed on initial supply and demand functions to verify that the model outcomes are consistent with the changes in inputs. Additionally, formulas that were used for measuring changes in consumer, producer, and total economic surplus are explained. The EDM developed in this chapter is used in conducting the welfare in Chapter 8 as shown in Figure 5.1.

5.2 Introduction to the Equilibrium Displacement Model

Equilibrium Displacement Models have been one of the tools used to measure the welfare effects of a policy decision in other countries banning the use of Glyphosate, not only on the producers, but also the whole agricultural industry (see Section 3.9 of Chapter 3).

In the following section, an introduction to the EDM is provided with a brief literature review on its evolution and application by researchers for different purposes with modifications to the basic model.

Econometric models and equilibrium models are frequently used in the analysis of agricultural industries in terms of estimating changes in prices and quantities and hence the economic surplus or welfare changes due to the adoption of new technologies, other research and development, generic promotion investments, and government policy changes related to industries. Econometric models deal with lengthy historical (time series) (Sumner and Wohlgenant 1985; Salhofer and Sinabell 1999) data on variables to quantify values which become difficult with the amount of data gathered.

Due to the data-intensive nature of the econometric modelling approach, equilibrium models have become popular in research undertaken to evaluate the above-mentioned aspects in industries. There are two separate approaches in calculating welfare effects using equilibrium models using demand and supply curves (Just and Hueth 1982) which are general equilibrium models and partial equilibrium models (Mounter *et al.* 2008). The first approach measures the welfare effect of an exogenous change to the industry on a single market on horizontally and vertically related markets rather than calculating the distribution among all the industry participants. The latter, unlike the first approach, measures welfare changes in all related markets in an industry.

Equilibrium displacement modelling (Piggott 1992) is a comparative static approach using a partial equilibrium framework for linear approximation of changes in price and quantities of inputs and outputs in a production system resulting from exogenous shocks to the initial equilibrium using base price and quantity data and elasticity values of supply and demand (Farquharson *et al.* 2003; Mounter, Griffith *et al.* 2008). This enables a welfare analysis of exogenous shocks on participants at different market levels in an industry. Alston *et al.* (1995) discussed comprehensively the applications of the EDM under various circumstances including a multistage production process with multiple products with examples of empirical studies. Hence, the same approach is applicable in the Sri Lankan tea value chain as well, with multiple products and market levels.

The approach of evaluating welfare effects of a technical change on industries was first introduced by Muth (1964) for a two-factor model in a competitive industry. As discussed by Alston, Norton *et al.* (1995), this simple and basic model on a closed economy introduced by Muth (1964) had been modified eventually to accommodate multiple products and production stages in industries by Holloway (1989) for a three-factor case with two marketing stages and distribution for a farm product and then by Mullen *et al.* (1989) for three or more factors.

Subsequently, the EDM was adapted in several studies analysing a wide array of policy scenarios including minimum and maximum pricing schemes, subsidies, taxes or quantitative restrictions on inputs, outputs or trade and exchange rate distortions (Alston, Norton *et al.* 1995). Thus, EDMs have been used often as an effective tool in agricultural policy analysis (Salhofer and Sinabell 1999) to reflect effects of legislation, research and promotion, advertising, labeling, traceability and export subsidies (Ferrier and Zhen 2014). Thus, EDMs engage in evaluating changes in the market equilibrium, assessing the gross revenues received by agricultural producers in various market levels in an industry, social welfare and endogenous variables as well, due the effect of exogenous shocks (Ali *et al.* 2015).

In the Sri Lankan context, an EDM has only been used on the coconut industry by Pathiraja *et al.* (2017) in evaluating the economic impact of climate change on perennial crops.

Specifying the Equilibrium Displacement Model on the tea industry in Sri Lanka

5.3 Industry review

The complete structure of the Sri Lankan tea industry is given in Figure 5.2. More details on the value chain of the tea industry in Sri Lanka are discussed by Hettiachchige and Rathnayake (2021). This representation of the Sri Lankan tea industry as in Figure 5.2 covers most of the forms of final tea products and their flows to market levels along respective channels, expressed as percentages of the total national made tea production.

5.2.1 Vertical structure of tea production and marketing

This industry producing tea can be vertically segmented into sectors that are engaged in tea cultivation, primary processing, secondary processing, and marketing.

Tea cultivation and green leaf production

Tea is commercially cultivated by two entities: the private tea grower sector and the estate sector. Private tea growers are referred to as those with no processing facilities and who rely on private

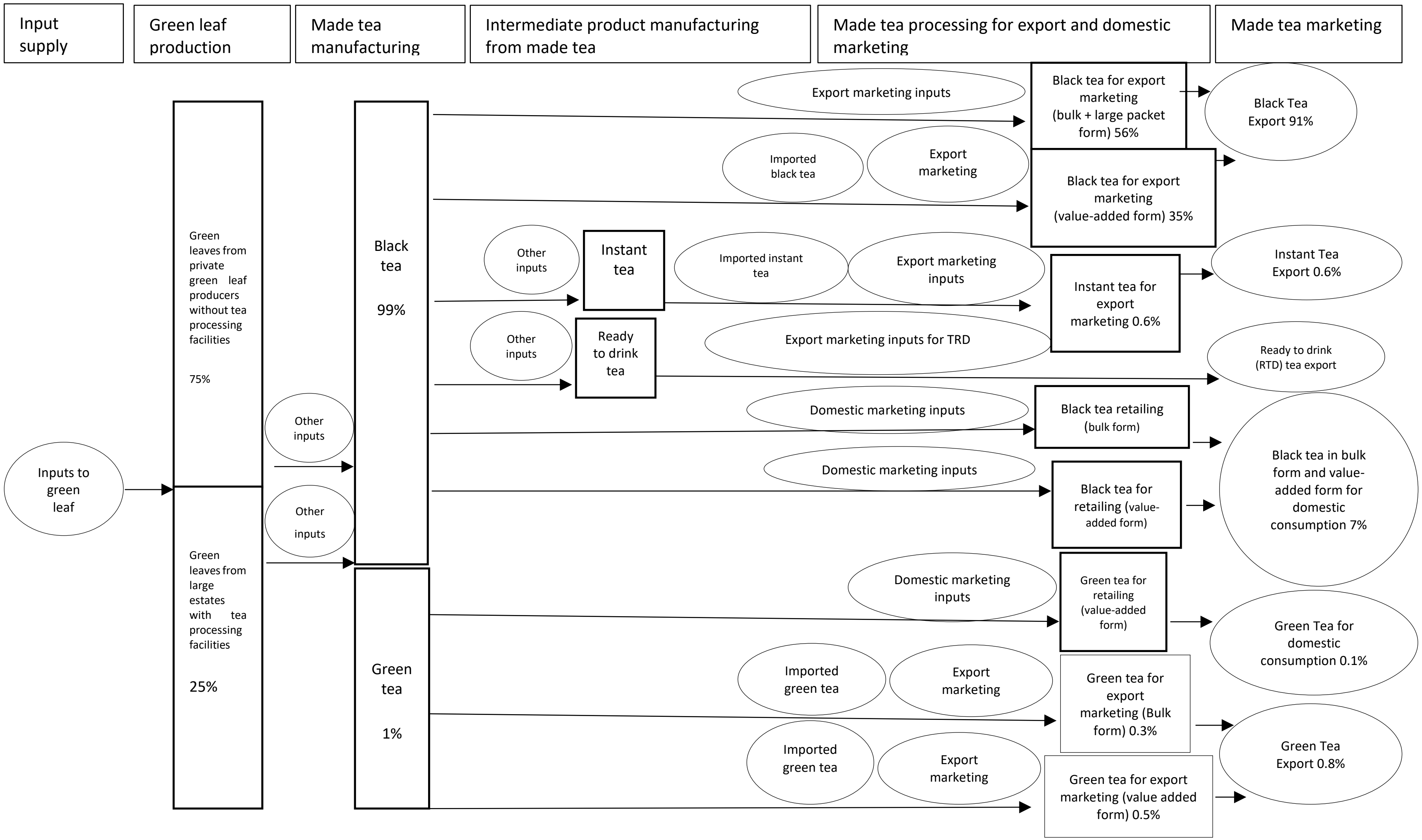


Figure 5.2. Structure of the tea industry in Sri Lanka

processors to sell their harvest. This sector comprises smallholder tea growers in addition to medium scale growers without their own tea factories. All other entities except private tea growers without green leaf processing facilities are aggregated and considered as the estate/plantation sector. The largest proportion of this group is 23 RCPs. It is considered that this sector can represent RPCs and contributes to 29 per cent of the total national made tea production.

As described in earlier chapters, the production systems of these two sectors differ in several main ways (Shyamalie 2015b). They differ in scale of operation, management structure, input use, labour allocation, fixed and variable costs, input purchasing prices (bulk form in estate sector) and so on. Therefore, the cost of production of green leaves across these two sectors is different.

Further information about the farm sector of the tea industry in Sri Lanka are discussed by Rathnayake, Malcolm *et al.* (2021).

Primary processing to produce bulk tea

Harvested green leaves from the tea grower sector are delivered to tea manufacturing factories for primary processing of green leaves to produce made tea. There are two groups engaging in green leaf processing: private processors operating with bought leaves mostly from tea smallholders, and estate sector processors with their own processing factories in estates. However, both these groups are aggregated and considered as one unit since the made tea production processes are similar.

The two main tea products manufactured are black tea and green tea. These are less differentiated compared to the final consumable product - made tea in terms of the quality and value addition. Made tea produced in tea manufacturing factories in tea growing areas are transported to the warehouses in the capital city to be sold to tea traders. The Colombo Tea Auction provides the platform for the sale of made tea, while the selling process is facilitated by tea brokers by linking tea manufacturers with traders who engage in secondary processing.

Secondary processing of tea for marketing

Secondary processing and packaging of tea are performed by tea traders to transform the undifferentiated, bulk commodity into a differentiated and consumable form. Secondary processing involves value addition to tea by blending, flavouring, and packing tea into consumer packets, small bags, gift packs and other types of packaging with branding (Ariyawardana 2001). Bulk tea undergoes some value adding by blending and marketed in large packets with volumes more than 10 kg as defined by the Sri Lanka Tea Board (2017). Consequently, tea products are marketed internationally and domestically.

Some factories have their own branded tea products in retail sizes sold in their factory or sales outlets as direct sales in small quantities. However, the idea is all primarily processed tea should be sold via the Colombo tea auction and reach secondary processors. Companies whose tea cultivation, primary and secondary processing are vertically integrated have their own made tea brands that might not necessarily consist of tea from their own estates and factories.

5.2.2 Horizontal market segments and product specifications

Final products of black tea and green tea produced along the supply/value chain can be segmented horizontally into two differentiated products as bulk tea and value-added tea produced by secondary processing to be marketed internationally and domestically.

Export market

Sri Lankan tea production is heavily export-oriented, and the country is best known as a black tea exporter. Around 90 per cent of the total national production of made tea is exported annually. The main types of tea marketed internationally are black and green tea, instant tea, and ready-to-drink (RTD) tea that account for nearly 93 per cent of the national made tea production as in Figure 5.2. The latter two products are secondary processed products of black tea, targeting export markets. Both black tea and green tea are exported in bulk form and value-added form in different packaging sizes as tea bags and packets with loose tea.

Turkey, Russia, Iraq, and Iran are the top Sri Lankan tea importers over recent years. The United Kingdom was the largest tea importer of Sri Lanka for many years. With emerging tea producers and exporters to the global tea market, Sri Lanka now faces tight competition from Kenya, Indonesia, and India for exporting tea to the United Kingdom (Kasturiratne 2008). Black tea covers around 98 per cent of total exports, while green tea and instant tea exports are less than 1 per cent.

More than 50 per cent of black tea exports are in the value-added form, while more than 40 per cent of exports are in bulk form. Bulk black tea is also known as commodity tea, and is processed into value-added forms; tea bags, packets in processing plants of the importing country to be sold domestically or exported. Russia is the number one bulk tea importer of Sri Lanka, with Iran being the second in recent years (Sri Lanka Tea Board 2017). This is because of the discriminative tea import tariffs structure in Russia that impose a tax of 12.5 per cent on prepacked teas and zero per cent tax on bulk teas. In addition, there have been improvements in tea packaging industries recently that has led to more bulk tea imports (Sri Lanka Tea Board 2017). Iran imports bulk tea and packs it for consumption, meeting their specific quality standards (Hilal and Mubarak 2016). There is an increasing trend of exports of Sri Lankan bulk tea to the Middle Eastern region as using tea bags has grown in popularity.

International exports of black tea and green tea in value-added forms are marketed as tea bags and tea packets ranging from 1 kg – 3 kg, as well as RTDs and instant tea. At the same time, Sri Lanka imports black tea, green tea, and instant tea from other producer countries to supplement value added processes by blending teas. Sri Lanka exports tea bags mainly to Russia, Syria, and Jordan from the value-added tea export sector (Hilal and Mubarak 2016). The main value-added tea importers in the world tea market are the United Kingdom, United States of America, and the United Arab Emirates, but Sri Lanka does not sell to them. In significant quantities.

Domestic market

Domestic consumption of tea in Sri Lanka is a low share of total production, hence the export-oriented trade of the country. The per capita consumption of tea in Sri Lanka has been steady over decades; 1.29kg/year in 1998 (Ariyawardana 2001) and nearly 1.4kg/year in 2016 (Food and Agriculture Organization of the United Nations 2018). Black tea is the most popular and commonly found tea in the retail market. It is available in retail packages and loose leaf/dust form. Green tea is not as popular as black tea and is found in lesser amounts in the retail market in packaged form. The total domestic consumption of green tea has not been accurately assessed in Sri Lanka because of the lack of data available on the inventory holding and direct factory sales each year.

Local packers and dealers purchase black tea from the tea auction mainly and also from tea factories and reclaimed processors. They then add net value to made tea by cleaning, blending and packaging bulk tea to deliver to the local market for retail marketing in packaged and loose form.

Colombo tea auction is the main channel for local packers and dealers to purchase primarily processed tea, while there could be other sources such as direct sales from tea manufacturing factories and reclaimed processors. Local tea marketers do further value addition by cleaning, blending and packaging bulk tea to deliver to the local market for retail marketing in packaged and loose form.

Only 8 per cent of the total made tea production remains within the country after exports, while 7 per cent and 1 per cent of this national production is black tea and green tea respectively, available for domestic consumption. Of the two main types of tea available in domestic markets, commercially packaged retail packets of loose tea and tea bags are the most popular form of tea consumed in most parts of the country. These forms of tea account for more tea than loose tea products that are not commercially packed.

The framework in Figure 5.3 that maps the tea industry is based on several assumptions.

Production of green leaves by the farm sector in different tea growing regions is aggregated and considered under each grower sector regardless of the tea growing region. It is assumed that the tea cultivation across growing regions is homogenous neglecting differences in yield and frequencies of field operations due to variations in the geography and climate.

Black tea, green tea, instant tea, and Ready to Drink (RTD) tea are considered as final products, while the small share of Oolong tea production is neglected. Only the final black tea produce is considered in the framework regardless of the processing methods CTC and orthodox. The quality of black tea made from both orthodox and CTC processing methods is assumed to be homogenous.

RTDs made of only black tea are considered in the framework but can be made from green tea as well.

Bulk tea and large packets of volume above 3 kg are aggregated and collectively known as bulk tea.

Imported black, green and instant teas are only re-exported and not used for domestic consumption.

The structure of the tea industry shown in Figure 5.3 provides a simplified version of Figure 5.2 based on some further assumptions on final products and sizes of channels as given below. Figure 5.3 was used as input in conceptualizing the structure of the tea industry for EDM development. In Figure 5.3, only black tea production is considered, excluding green tea, instant tea and RTD production. The black tea manufacturing sector is assumed to be a single sector, aggregating the produce from both private and estate tea manufacturers.

Green leaves produced and harvested from any grower sector can finally end up in any of the final tea products stated in the model based on the assumption that they all have a homogenous quality.

Exports of black tea are only provided from national black tea production and exclude black tea imports/re-exports.

Although there are quality variations in these graded intermediate products based on the particle size, the same quality is assumed across intermediate and final products to avoid complications in the model.

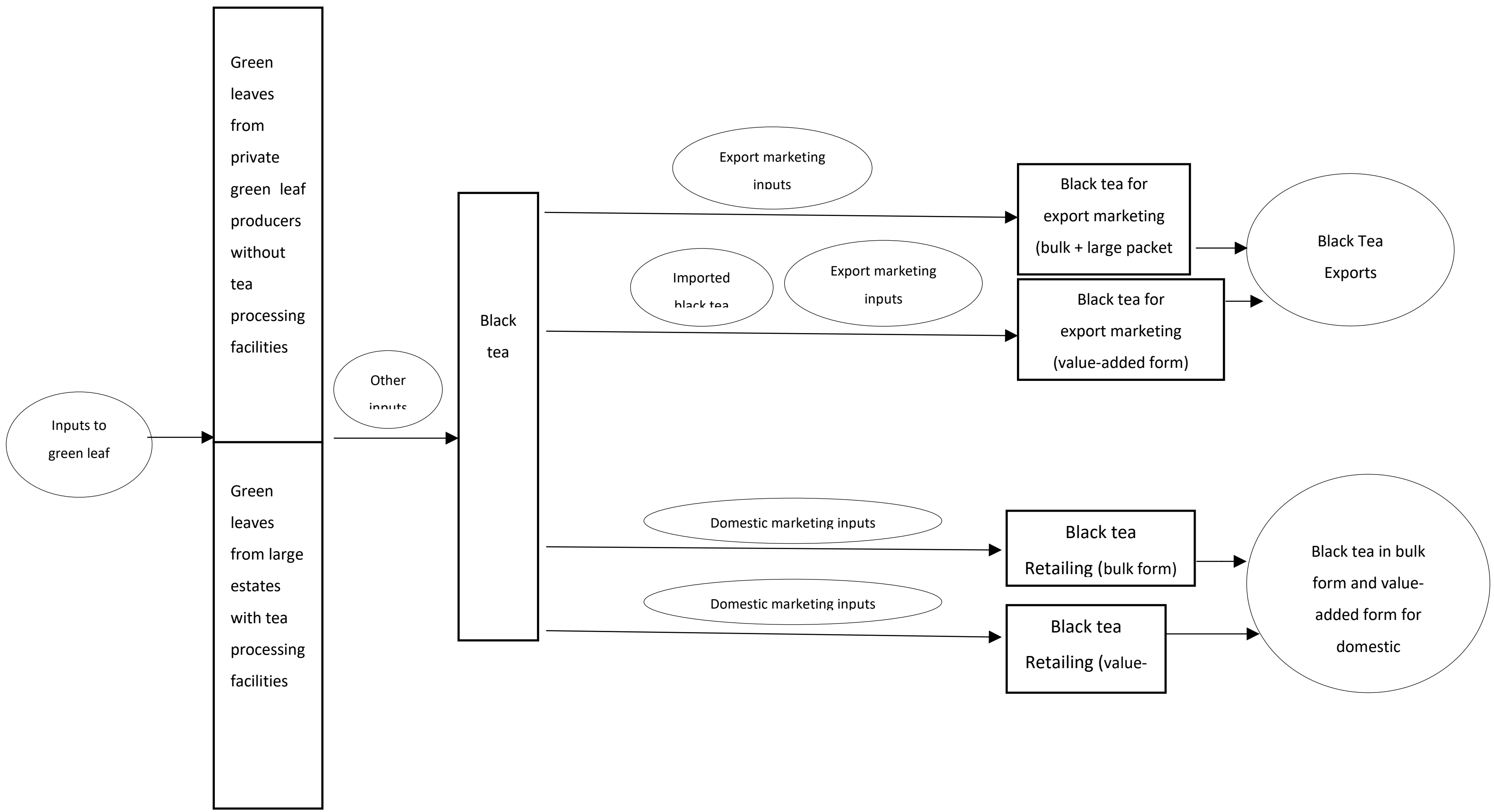


Figure 5.3. Simplified structure of the tea industry

5.3 Structure of the model

The structure of EDM used in the tea industry is adapted from Figure 5.3, which is a simplified version of the complete framework in Figure 5.2.

As demonstrated in Figure 5.4, each production function is shown by a rectangle, while input/factor supplies, and product demands are shown by ovals where exogenous shifts are possible. Arrows depict demand and supply relationships, where the arrowhead and the arrow shaft represent the demand for the product and supply of the product, respectively.

The conceptual structure of the industry can be disaggregated horizontally and vertically into segments as explained below. This disaggregation is required in examining the welfare distribution of different exogenous shocks on the industry and across various sectors.

Main product groups in the industry are represented in horizontal market segments of the framework. Accordingly, horizontal market segments given by the framework in Figure 5.4 are black tea in bulk form and value-added form for both domestic and export markets.

The vertical disaggregation represents key sectors in the value/supply chain of the industry as green leaf production, made tea manufacturing, intermediate product manufacturing, secondary processing of made tea for retail and export marketing, and made tea marketing locally and internationally.

Therefore, channels of black tea manufactured across different tea-growing regions merge at the point of tea trading at the Colombo Tea Auction that can end up in either domestic or international markets. Production processes of green leaves, black tea, and final products are homogenous with several variations in terms of quality.

5.3.1 Inputs and outputs in the model

It is assumed that production functions used in the model are multi-output, separable in inputs and outputs. Usually, outputs of the tea production process consist of the primary/main output that is mostly a form of made tea and secondary/potential outputs. These potential outputs can be any kind of outputs in production processes such as externalities in the form of energy waste and/or product waste. However, these secondary outputs are not taken into consideration in the model as there is no evidence that secondary outputs from black tea manufacturing are monitored or recorded.

The main input of an industry sector is a variable input that flows through market levels along the value chain of the industry. The main/primary output of one market level is the input for the next market

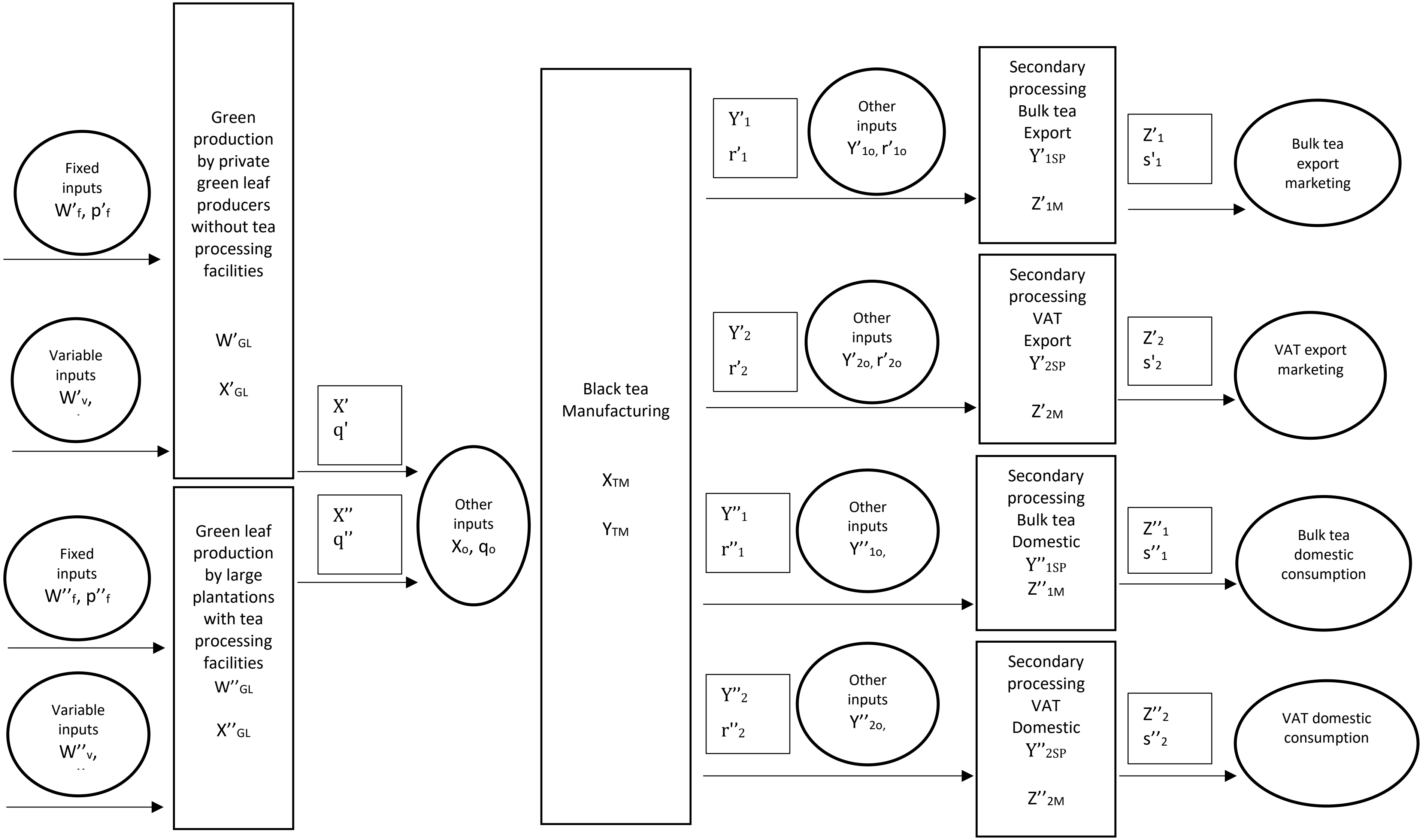


Figure 5.4. Structure of the equilibrium displacement model of the black tea industry

level. The main/primary inputs and outputs in most market levels are made tea either in bulk or value-added form.

Other inputs at a market level are either variable or fixed. Other inputs are water, chemicals, packaging material, labour, machinery, factories, and warehouses that can be classified into variable and fixed inputs into labour, capital, etc. at most market levels. Only the inputs in the green leaf production sector are classified as fixed and variable inputs, while inputs other than the main input in every other market sector are aggregated and categorized as other inputs.

Inputs

The main input in the green leaf production sector is the tea bush stand which is a fixed input complementary to land in factors of production. A constant tea bush cover is assumed in the medium run; therefore, it is assumed that pruning is done every 5 years. Additionally, all other sectors including the tea production sector generally use labour, water, energy, auxiliary material as variable inputs and machinery, storage buildings, staff, and vehicles as to fixed inputs. As in Table 5.1, variable and fixed inputs used in key market sectors are categorized.

Table 5.1. Inputs of main market levels in tea industry

Market level	Variable inputs	Fixed inputs
Tea cultivation sector	Fertilizer	Tea bush stand/ land
	Agrochemicals (weedicides, pesticides and fungicides)	Chemical spraying machinery
	Labour	Weeding equipment - Grass cutters if used
	Water	Shade tree lopping equipment if used
	Other material	Vehicles
Made tea manufacturing (Taulo and Sebitosi 2016)	Green leaves	Machinery
	Labour wages	Storage and warehousing
	Water	Staff
	Energy (electricity, firewood, diesel)	Vehicles
	Auxiliary material (bulk tea packaging material)	
	Other material	
	Transportation	
Secondary tea processing for export marketing	Made tea	Machinery
	Labour wages	Storage and warehousing
	Water	Staff
	Energy (electricity, firewood, diesel)	Vehicles
	Auxiliary material (value-added and bulk tea packaging material)	
	Flavours/chemicals/additives	
	Other material	
	Transportation	
	Made tea	Machinery

Secondary tea processing for domestic marketing	Labour wages	Storage and warehousing
	Water	Staff
	Energy (electricity, firewood, diesel)	Vehicles
	Auxiliary material (value-added and bulk tea packaging material)	
	Flavours/chemicals/additives	
	Other material	
	Transportation	

5.4 Specification of production functions and decision-making problems

Developing an EDM for the tea industry requires specifying production functions for each market level engaging in production and decision-making problems. Equations must be specified using notations with reference to parameters such as market prices, quantities, elasticities, and external shocks in the industry. In the sections that follow, parameters are defined in terms of notations and specified production functions: together, these form the tea industry EDM.

5.4.1 Defining variables and parameters in the model

In this section all notations for variables and parameters used in the EDM are defined and listed. Variables and market parameters along with a brief description are shown in Table 5.2. Quantity variables are denoted by W, X, Y, and Z for green leaf production, black tea manufacturing, and black tea secondary processing and tea marketing sectors, respectively. Price variables are given by p, q, r, and s for green leaf production, black tea manufacturing, and black tea secondary processing and tea marketing sectors, respectively. Subscripts and superscripts are mostly used to differentiate between comparable variables.

Superscripts ‘and ‘’ indicate the private tea landholding sector and estate sector respectively in the green leaf production sector, and export and domestic marketing respectively in the black tea marketing sector.

The list of subscripts used is given below.

f – fixed inputs in green leaf production
v – variable inputs in green leaf production
o – other inputs in production processes
1 – black tea in bulk and large packet form (commonly as bulk)
2 – black tea in value-added form
GL – green leaf production
TM – tea manufacturing
M – export or domestic marketing

Table 5.2. Definition of variables and parameters in the tea industry model

Endogenous variables	
W'_v, W'_f	Quantity of variable and fixed inputs used in green leaf production private landholding sector respectively
W''_v, W''_f	Quantity of variable and fixed inputs used in green leaf production estate sector respectively
p'_v, p'_f	Price of variable and fixed inputs used in green leaf production private landholding sector
p''_v, p''_f	Price of variable and fixed inputs used in green leaf production estate sector
W'_{GL}	Aggregate input index of green leaf production private landholding sector
W''_{GL}	Aggregate input index of green leaf production estate sector
X'	Quantity of green leaves supplied from the green leaf production private landholding sector to the black tea manufacturing sector
X''	Quantity of green leaves supplied from the green leaf production estate sector to the black tea manufacturing sector
X	Quantity of total green leaves supplied from the tea grower sector to black tea manufacturing sector
q'	Price per kg of green leaves received by private tea grower sector from the manufacturing sector
q''	Price per kg of green leaves received by estate tea grower sector from the manufacturing sector (internal transfer price of green leaf by vertically integrated processors)
q	Price per kg of green leaves paid by the black tea manufacturing sector
X'_{GL}	Aggregate output index of the green leaf production from the private landholding sector
X''_{GL}	Aggregate output index of the green leaf production from the estate sector
X_o	Quantity of other inputs used in black tea manufacturing
q_o	Price of other inputs used in black tea manufacturing
X_{TM}	Aggregate input index of black tea manufacturing
Y'_1, Y'_2	Quantity of black tea from the manufacturing sector to the export marketing sector for secondary processing (bulk and value-added forms respectively)
Y''_1, Y''_2	Quantity of black tea from the manufacturing sector to the domestic marketing sector for secondary processing (bulk and value-added forms respectively)
r'_1, r'_2, r''_1, r''_2	Price of black tea from the manufacturing sector to the secondary processing sector
Y_{TM}	Aggregate output index of back tea manufacturing
Y'_{1o}	Quantity of other inputs used in secondary processing of black tea for exports in bulk form
r'_{1o}	Price of other inputs used in secondary processing of black tea exports in bulk form
Y'_{1SP}	Aggregate input index of secondary processing of black tea for bulk tea exports
Z'_1	Quantity of bulk black tea from secondary processing to export market
s'_1	Price of bulk black tea to export market
Z'_{1M}	Aggregate output index of bulk black tea to export markets
Y'_{2o}	Quantity of other inputs used in secondary processing of black tea for exports in value-added form
r'_{2o}	Price of other inputs used in secondary processing of black tea exports in value-added form
Y'_{2SP}	Aggregate input index of secondary processing of black tea for value added tea exports
Z'_2	Quantity of value-added black tea from secondary processing to export market
s'_2	Price of value-added black tea to export market
Z'_{2M}	Aggregate output index of value-added form of black tea to export markets
Y''_{1o}	Quantity of other inputs used in secondary processing of black tea for domestic marketing in bulk form
r''_{1o}	Price of other inputs used in secondary processing of black tea for domestic marketing in bulk form
Y''_{1SP}	Aggregate input index of secondary processing of black tea for bulk tea domestic marketing
Z''_1	Quantity of bulk black tea from secondary processing to domestic market
s''_1	Price of bulk black tea to domestic market

Z''_{1M}	Aggregate output index of bulk black tea for domestic markets
Y''_{2o}	Quantity of other inputs used in secondary processing of black tea for domestic market in value-added form
r''_{2o}	Price of other inputs used in secondary processing of black tea for domestic market in value-added form
Y''_{2SP}	Aggregate input index of secondary processing of value-added tea black tea for domestic market
Z''_{2}	Quantity of value-added black tea from secondary processing to domestic market
s''_{2}	Price of value-added black tea to domestic market
Z''_{2M}	Aggregate output index of value-added black tea for domestic markets
	Exogenous variables
T_X	Supply shifter shifting up the supply curves vertically
t_X	Amount of shift as a percentage of price of green leaves
N_X	Demand shifter shifting up demand curves vertically
n_X	Amount of shift as a percentage of price of green leaves
	Parameters
$\eta_{i,j}$	Demand elasticity of input i with respect to price j
$\varepsilon_{i,j}$	Supply elasticity of input i with respect to price j
$\tilde{\eta}_{i,j}$	Constant- output input demand elasticity of input i with respect to price j
$\tilde{\varepsilon}_{i,j}$	Constant-input output supply elasticity of input i with respect to price j
$\sigma_{i,j}$	Elasticity of substitution between inputs i and j
$\tau_{i,j}$	Elasticity of transformation between outputs i and j
κ_i	Cost share of input i
λ_i	Revenue share of output j
$\rho x'$, $\rho x''$	Quantity shares of X' and X'', ie. $\rho x' = X'/(X'+X'')$, $\rho x'' = X''/(X'+X'')$

5.4.2 Model specification in general functional forms

According to Figure 5.4, seven industry sectors can be identified in the model, thus multi-output production functions and decision-making problems can be specified within themselves. All general functional forms specified here according to the model structure follow previous work done by Zhao *et al.* (2000) and Mounter *et al.* (2005).

Equations are specified based on assumptions that

(i) all production functions exhibit constant returns to scale,

(ii) all multi-output production functions are separable in inputs and outputs; and

(iii) each market level in the model operates with the objective of profit maximization and perfect competition in firms.

These assumptions are applied to all market levels in the EDM.

The assumption of constant returns to scale reflects that the total cost and total revenue are equal in each market level in the industry; assuming zero pure profits under equilibrium conditions. Although it is assumed on every market level, some levels operate in circumstances close to the conditions of perfect competition. Both tea grower and manufacturing sectors have many firms, and there are many different options for private tea growers to choose from estate-owned or many privately operating tea manufacturing factories, while plantations have their own tea factories, all reflecting that there is a relatively competitive market, i.e., perfect competition or monopolistic competition. The Colombo tea auction where buyers and sellers of primarily processed made tea meet with prices decided on a bidding system closely approximates a perfectly competitive market. In contrast, in the black tea secondary processing and marketing sectors, there is some evidence of oligopoly and oligopsony power (Weerahewa 2003).

Sectors in the tea industry specified under equilibrium conditions are green leaf production, black tea manufacturing, secondary processing of black tea for export marketing and domestic retail marketing.

(5.4.2.1)	$\sum_{i=f,v} p'_i W'_i = X'q'$	Green leaf production equilibrium by private landholding sector
(5.4.2.2)	$\sum_{i=f,v} p''_i W''_i = X''q''$	Green leaf production equilibrium by estate sector
(5.4.2.3)	$q X + q_o X_o = r Y$	Black tea manufacturing equilibrium
(5.4.2.4)	$r Y'_1 + r'_{1o} Y'_{1o} = s'_1 Z'_1$	Secondary processing equilibrium of made tea for export marketing in bulk form
(5.4.2.5)	$r Y'_2 + r'_{2o} Y'_{2o} = s'_2 Z'_2$	Secondary processing equilibrium of made tea for export marketing in value-added form
(5.4.2.6)	$r Y''_1 + r''_{1o} Y''_{1o} = s''_1 Z''_1$	Secondary processing equilibrium of made tea for domestic marketing in bulk form
(5.4.2.7)	$r Y''_2 + r''_{2o} Y''_{2o} = s''_2 Z''_2$	Secondary processing equilibrium of made tea for domestic retail marketing in value-added form

In all these equilibrium conditions, total costs are given on the left-hand side while the right-hand side gives the total revenue. The cost shares of other inputs in each market level (W'_f, W'_v, W''_f, W''_v, Xo, Y'_{1o}, Y'_{2o}, Y''_{1o}, and Y''_{2o}) are calculated as the residual for each equilibrium condition stated.

5.4.3 Production function and decision-making problem specification

All production sectors are characterized by multi-output technologies/production functions. All production functions are assumed to show constant returns to scale, profit maximizing behavior, perfect competition across all sectors and multi- output production functions separable in inputs and outputs.

The general forms of multi-output production functions have been written in accordance with Zhao, Mullen *et al.* (2000).

(5.4.3.1) $F(x, y) = 0$

x – vector of inputs
y – vector of outputs

This is the product transformation function that is assumed to be twice-continuously differentiable, which means that the second derivative of general forms $\partial^2 f/\partial x^2$, $\partial^2 f/\partial x \partial y$ and $\partial^2 f/\partial y^2$ exist and are continuous.

For an example, in the green leaf production sector, $x = (W_v, W_f)$ and $y = (X)$.

Accordingly, the above equation of general form of production functions can be written as follows equating the scalar output index[4] based on the assumption of output separability (Chambers, 1998, p.286).

(5.4.3.2) $X'_{GL}(X') = W'_{GL}(W')$

(5.4.3.3) $X'_{GL} = X'_{GL}(X')$; scalar output index

(5.4.3.4) $W'_{GL} = W'_{GL}(W')$; scalar input index

This can be used in specifying the product transformation functions for the seven sectors of the tea industry considered in the model.

(5.4.3.5)	$X'_{GL}(X') = W'_{GL}(W'_v, W'_f)$	Green leaf production in tea by private landholding sector
(5.4.3.6)	$X''_{GL}(X'') = W''_{GL}(W''_v, W''_f)$	Green leaf production in tea by estate sector
(5.4.3.7)	$Y_{TM}(Y', Y'') = X_{TM}(X, X_o)$	Black tea manufacturing

[4] An output index to be utilized as the output variable. When an index of output and a set technology exists, the technology is separable in outputs. For a twice continuously differentiable product transformation function, output separability and input separability are equivalent.

(5.4.3.8)	$Z'_{1M}(Z'_1) = Y'_{1SP}(Y'_1, Y'_{1o})$	Secondary processing of made tea for export marketing in bulk form
(5.4.3.9)	$Z'_{2M}(Z'_2) = Y'_{2SP}(Y'_2, Y'_{2o})$	Secondary processing of made tea for export marketing in value-added form
(5.4.3.10)	$Z''_{1M}(Z''_1) = Y''_{1SP}(Y''_1, Y''_{1o})$	Secondary processing of made tea for domestic marketing in bulk form
(5.4.3.11)	$Z''_{2M}(Z''_2) = Y''_{2SP}(Y''_2, Y''_{2o})$	Secondary processing of made tea for domestic retail marketing in value-added form

In the above set of product transformation functions, the left-hand side of the equations defines the outputs for each sector, and the right-hand side defines the inputs.

5.4.4 Cost functions and derived demand schedules

The profit maximizing behavior in firms consists of two components: cost minimization for a given level of output and revenue maximization for a given input mix (see Zhao, Mullen *et al.* (2000)).

As an example, the cost function in the farm sector can be specified under the cost minimization for a given level of output vector.

(5.4.4.1) $C_X(p, X) = \min_w \{p^* W: X\}$

Where $p = (p_f, p_v)^*$ are the input prices for (W_f, W_v),

According to Chambers (1988) and Zhao, Mullen *et al.* (2000) the multi-output cost function can be simplified to a single-output cost function based on the assumption that the technology is output separable[5]. Output separability helps represent the technology in single-product terms.

$$(5.4.4.2)\ C_X(p, X) = \min_w \{p^* W; X\} = \min_w \{p^* W: X_{GL} = X_{GL}(X)\} = C_X(p, X_{GL})$$

Where, $C_X(p, X_{GL})$ is the cost function for the single-output technology $X_{GL} = W_{GL}(W)$.

As per the assumption of constant returns to scale, that also indicates the input and output separable technology, $W_{GL}(\lambda W) = \lambda X_{GL}$ and $X_{GL}(\lambda X) = \lambda W_{GL}$ for any $\lambda>0$.

[5] Output separability makes it convenient for representing the technology in single-product terms

Hence, the cost function can be written as:

(5.4.4.3) $C_X(p, X_{GL}) = \min_w \{p^* W: W_{GL}(W) = X_{GL}\}$

$= \min_w \{p^* W: W_{GL}(\lambda W) = \lambda X_{GL}\}$

$= \min_w \{p^* W: W_{GL}(W/X_{GL}) = 1\}$ (When $\lambda = 1/X_{GL}$)

$= X_{GL} \min_w \{p^* (W/X_{GL}): W_{GL}(W/X_{GL}) = 1\} = X_{GL}C_X(p, 1) = X_{GL}\, c_X(p)$

Where $c_X(p)$ is the unit cost function for the minimum cost of producing one unit of X_{GL}.

Cost functions related to all production functions can be derived using the general format of the above equation, as below.

(5.4.4.4) $C_{X'GL} = X'_{GL} * c_{X'GL}(p'_f, p'_v)$	Green leaf production in tea by private landholding sector
(5.4.4.5) $C_{X''GL} = X''_{GL} * c_{X''GL}(p''_f, p''_v)$	Green leaf production in tea by estate sector
(5.4.4.6) $C_{YTM} = Y_{TM} * c_{YTM}(q, q_o)$	Black tea manufacturing
(5.4.4.7) $C_{Z'1M} = Z'_{1M} * c_{Z'1M}(r, r'_{1o})$	Secondary processing of made tea for export marketing in bulk form
(5.4.4.8) $C_{Z'2M} = Z'_{2M} * c_{Z'2M}(r, r'_{2o})$	Secondary processing of made tea for export marketing in value-added form
(5.4.4.9) $C_{Z''1M} = Z''_{1M} * c_{Z''1M}(r, r''_{1o})$	Secondary processing of made tea for domestic marketing in bulk form
(5.4.4.10) $C_{Z''2M} = Z''_{2M} * c_{Z''2M}(r, r''_{2o})$	Secondary processing of made tea for domestic retail marketing in value-added form

Were,

C_X - total cost of producing output index X

c_X - unit cost function

$x = X'_{GL}, X''_{GL}, Y_{TM}, Z'_{1M}, Z'_{2M}, Z''_{1M},$ and Z''_{2M}

Quantities and prices are represented in capital and simple letters respectively in the above equations.

By assuming that c_X (p) can be differentiated with respect to p, Shephard's Lemma is applied to cost functions to derive output-constrained input demand functions (Chambers 1988).

$$(5.4.4.11)\ \partial C_X (p, X)/ \partial p_i = X\ c_X{'}_i (p) \qquad (i = 1,2,3\ldots, k)$$

Where $c_X{'}_i$ (p), (i = 1,2,3…., k) are the partial derivatives of the unit cost function c_X (p).

The above equation is used to derive the output constrained input demand functions for all sectors in the model in Section.

5.4.5 Revenue functions and derived supply schedules

The second section of the profit maximization behavior in firms is revenue maximization for a given input mix.

The revenue function for the green leaf production sector as an example can be specified as given in Zhao, Mullen *et al.* (2000).

$$(5.4.5.1)\ R_W (q, W) = \max_X \{q^* X: W\}$$

Where q = q* is the output price of X.

According to Zhao, Mullen *et al.* (2000), the revenue function can be simplified to a single input revenue function based on the assumptions of input separability.

$$(5.4.5.2)\ R_W (q, W) = \max_X \{q^* X: W\} = \max_X \{q^* X: W = W_{GL}(W)\} = R_W (q, W_{GL})$$

Where $R_W (q, W_{GL})$ is the revenue function for the single input technology $W_{GL} = X_{GL}(X)$.

The constant returns to scale assumption denotes that the revenue function can be written as (Zhao, Mullen *et al.* 2000) follows.

$$(5.4.5.3)\ R_W (q, W_{GL}) = \max_X \{q^* X: X_{GL} (X) = W_{GL}\}$$

$$= \max_X \{q^* X: X_{GL} (nX) = nW_{GL}\}$$

$$= \max_X \{q^* X: X_{GL} (X/W_{GL}) = 1\} \qquad (\text{When } n = 1/W_{GL})$$

$$= W_{GL} \max_X \{q^* (X/W_{GL}): X_{GL} (X/W_{GL}) = 1\} = W_{GL}\ R_W (q, 1) = W\ r_W (q)$$

Where $r_W(q)$ is the unit revenue function associated with the maximum revenue from one unit of input index W_{GL}.

Revenue functions for a given input mix related to the sectors in the industry can be presented as follows.

(5.4.5.4)	$R_{W'GL} = W' * r_{w'}(q')$	Green leaf production in tea by private landholding sector
(5.4.5.5)	$R_{W''GL} = W'' * r_{w''}(q'')$	Green leaf production in tea by estate sector
(5.4.5.6)	$R_{XTM} = X * r_X(r)$	Black tea manufacturing
(5.4.5.7)	$R_{Z'1M} = Z'_1 * r_{Z'1}(s'_1)$	Secondary processing of made tea for export marketing in bulk form
(5.4.5.8)	$R_{Z'2M} = Z'_2 * r_{Z'2}(s'_2)$	Secondary processing of made tea for export marketing in value-added form
(5.4.5.9)	$R_{Z''1M} = Z''_1 * r_{Z''1}(s''_1)$	Secondary processing of made tea for domestic marketing in bulk form
(5.4.5.10)	$R_{WZ''2M} = Z''_2 * r_{Z''2}(s''_2)$	Secondary processing of made tea for domestic retail marketing in value-added form

Where,

R_X – total revenue earned from fixed input index x

r_X – unit revenue function

quantities and prices are represented in capital and simple letters, respectively.

Partial derivatives of the unit revenue functions of the above revenue function can be obtained using the Samuelson – McFadden Lemma (Chambers 1988) by differentiating the unit revenue function; $r_w(q)$ with respect to all output prices.

$$(5.4.5.11)\ \partial R_W(q, W_{GL})/\partial q_j = W_{GL}\, r_{w}{}'_j(q) \qquad (j = 1, 2, \ldots m)$$

Where $r_{w}{}'_j(q)$, (j = 1, 2, ….m) are the partial derivatives of the unit revenue function $r_w(q)$.

The equation above is used to derive the input constrained output supply functions for all the relevant sectors in the model in section.

5.4.6 Profit functions and exogenous factor supply

The set of inputs that are exogenous to the EDM system are given below.

W'_f, W'_v, W''_f, W''_v, X_o, Y'_{1o}, Y'_{2o}, Y''_{1o}, Y''_{2o}

The supply schedules for these factors are exogenous to the model. The decision variables associated with their supplies cannot be specified within the model.

The logic used by Zhao, Mullen *et al.* (2000) is used to derive the supply relationships of these exogenous inputs.

By considering x as any of the exogenous inputs to the model ie. x = W'_f, W'_v, W''_f, W''_v, X_o, Y'_{1o}, Y'_{2o}, Y''_{1o}, Y''_{2o}, the related production function can be specified as:

(5.4.6.1) $F(x, O) = 0$

O – vector of all inputs and other outputs of the production function.

The respective profit function according to Zhao, Mullen *et al.* (2000) is:

(5.4.6.2) $\pi = \max_{x,o} \{w_x x + W' O: F(x,O) = 0\} = \pi(w_x, W)$

w_x – price of x

W – price vector of O

According to Varian (1992), price vectors are negative and positive for an input and output, respectively.

Hotelling's Lemma is used in deriving the supply of x.

(5.4.6.3) $X = \frac{\partial}{\partial wx} \pi\ (w_x, W) = \pi'_{wx}\ (w_x, W) = x\ (w_x, W)$

Where, π_{wx}' (w_x, W) is the partial derivative of π (w_x, W) with respect to w_x.

The supply of each exogenous input x can be derived using the above equation.

5.4.7 Utility functions and exogenous demand

The following demands for the final products of black tea are considered exogenous to the model:

Demands for exports in bulk form, exports in value-added form, domestic retails in bulk form and domestic retails in value-added form are given by Z'_1, Z'_2, Z''_1, Z''_2 respectively.

The quality of the bulk and value-added black tea is different in terms of the packaging sizes and degree of blending with other constituents and reaching different consumer markets. Most of the value-added tea in the form of tea bags are exported to Russia, Syria, and Jordan (Hilal and Mubarak 2016). Russia and Iran are the top two countries importing Sri Lankan tea in bulk form for further value-addition and selling (Sri Lanka Tea Board 2017). The highest proportion of black tea exported to foreign markets is in the bulk form and averages 60 per cent of total exports between 2010 to 2014.

Therefore, the demand for black tea exports in bulk and in value-added tea form are assumed to be independent and reflect preferences of different consumers.

The logic used by Zhao, Mullen *et al.* (2000) is used to derive the demand relationships of these exogenous final products.

The indirect utility function (v) for a given income level of m for a consumer of Z'_i (i = 1,2), can be specified as given by Varian (1992) and Zhao, Mullen *et al.* (2000). An indirect utility function gives the maximum level of utility from a given set of prices and income, consistent with the consumer's constrained optimization problem.

(5.4.7.1) $v(r'_i, P, m) = \max_{Z'i, Q} \{u(Z'_i, Q): r'_i Z'_i + P'Q = m\}$

Where,

r_i – price of Z'_i (i = 1,2)

Q – vector of all the quantities of other commodities consumed

P – price vector of Q

u(.) – consumer's utility function

The Marshallian demand equation for a good can be derived by applying Roy's identity (Jehle and Reny 2011); using the indirect utility function by forming the following ratio of partial derivatives. Roy's identity states that the Marshallian demand for the good Z'_i is the ratio between the partial derivative of the indirect utility function with respect to the price of Z'_i and income level after a sign change.

(5.4.7.2) $Z'_i(r'_i, P, m) = -\frac{\partial v(r'i,P,m)/\partial r'i}{\partial v(r'i,P,m)/\partial m}$ (i = 1,2)

Marshallian demand at an income of m is Hicksian demand at utility v(p,m).

The above equation can be used in deriving exogenous demand equations.

That is, the demand for each of Z'_1 and Z'_2; black tea exports in bulk and value-added form are independent of the rest of the model and is only related to own price. Simply, the demand for Z'_1 is not affected by the price of Z'_2, and vice versa.

With respect to domestic demands of black tea products, bulk and value-added forms are substitutes for Sri Lankan consumers. Bulk tea comes without brands, while value-added tea products in the domestic market are available in a wide array of brands in different package sizes convenient for consumers' use. Consumers purchase bulk and VAT depending on the relative prices of the two tea products and on other available beverages such as coffee, and soft drinks. Therefore, there are two variables (Z''_1 and Z''_2) found within the model related to domestic consumers' decision-making problems.

The indirect utility function for given income m for domestic consumers is assumed according to Varian 1992.

(5.4.7.3) $v(r''_1, r''_2, P, m) = \max_{r''1,\, r''2,\, Q} \{u(Z''_1, Z''_2, Q): r''_1 Z''_1 + r''_2 Z''_2 + P'Q = m\}$

Where,

r''_1, r''_2 – price of Z''_1 and Z''_2 respectively

Q – vector of all the quantities of other commodities consumed

P – price vector of Q

u(.) – consumer's utility function

The Marshallian demand equation for a good can be derived by applying Roy's identity (Jehle and Reny 2011); using the indirect utility function by forming the following ratio of partial derivatives as explained above.

(5.4.7.4) $Z''_1(r''_1, r''_2, P, m) = -\frac{\partial v(r"1,r"2,P,m)/\partial r"1}{\partial v(r"1,r"2,P,m)/\partial m}$

(5.4.7.5) $Z''_2(r''_1, r''_2, P, m) = -\frac{\partial v(r''1, r''2, P, m)/\partial r''2}{\partial v(r''1, r''2, P, m)/\partial m}$

5.5 The Equilibrium Displacement Model

5.5.1 Structural/ general functional form

The demand and supply relationships between all variables are explained through the structural model that is derived through partial derivatives of the decision-making problems specified above. The next step is to apply comparative statics on the structural model in yielding the relationships between changes in all variables; changes in prices and quantities because of exogenous shocks and estimating welfare implications of those changes.

This section provides the series of general functional forms of equations that represent the EDM of the tea industry in Sri Lanka. There is a pair of supply and demand functions for each product and a pair of equilibrium conditions in each industry level that sums up to a total of 52 equations. There are also exogenous variables which are either supply or demand shifters that reflect the impact of cost changes, technology changes or demand changes. It is assumed that respective shifts resulted by exogenous changes in variables are parallel shifts in supply and demand curves.

The system of equations specified in general forms are as below.

Input supply functions are obtained by the partial derivation of respective profit functions. Price vector for all other inputs and outputs; W specified in equations are assumed exogenously constant and therefore, are not included in supply equations.

Output demand functions are partial derivatives of utility functions using Shephard's lemma.

Green leaf production

Input supply to private tea grower sector

(5.5.1.1) $W'_v = W'_v(p'_v, T_{W'v})$ variable input supply

(5.5.1.2) $W'_f = W'_f(p'_f, T_{W'f})$ fixed input supply

Input supply to estate tea grower sector

(5.5.1.3) $W''_v = W''_v(p''_v, T_{W''v})$ variable input supply

(5.5.1.4) $W''_f = W''_f (p''_f, T_{W''f})$ fixed input supply

These equations that specify the input supply to the green leaf production sectors; private and estate sectors include the aggregated price of variable and fixed inputs of green leaf production and shifters of their supply. Supply shifters are exogenous changes; technologies that increase the cost of production, and increased input prices.

Output-constrained input demand of private green leaf production sector

(5.5.1.5) $W'_v = X'_{GL} * c'_{X'GL, p'v} (p'_f, p'_v)$ demand for variable inputs for green leaf production

(5.5.1.6) $W'_f = X'_{GL} * c'_{X'GL, p'f} (p'_f, p'_v)$ demand for fixed inputs for green leaf production

Output-constrained input demand of private green leaf production sector

(5.5.1.7) $W''_v = X''_{GL} * c'_{X''GL, p''v} (p''_f, p''_v)$ demand for variable inputs for green leaf production

(5.5.1.8) $W''_f = X''_{GL} * c'_{X''GL, p''f} (p''_f, p''_v)$ demand for variable inputs for green leaf production

$c'_{X, pv} (p_f, p_v)$ and $c'_{X, pf} (p_f, p_v)$ are the partial derivatives of the unit cost functions of variable and fixed inputs in private and estate green leaf production with respect to price of variable and fixed inputs. Hence, the demands for inputs in green leaf production by both sectors are given by the respective partial derivative unit cost function with respect to input prices given above and aggregate output index of green leaves supplied for made tea manufacturing.

Input-constrained output supply of private green leaf production

(5.5.1.9) $X' = W'_{GL} * r'_{w'GL, q'} (q')$ green leaf supply from private tea grower sector

Input-constrained output supply of estate green leaf production

(5.5.1.10) $X'' = W''_{GL} * r'_{w''GL, q''} (q'')$ green leaf supply from estate tea grower sector

$r'_{w'GL, q'} (q')$ and $r'_{w'GL', q''} (q'')$ are the partial derivatives of the unit revenue functions of aggregate input indices in private and estate green leaf production respectively with respect to other secondary outputs. Hence, the supply for output in green leaf production by both sectors are given by the respective partial derivative unit revenue function with respect to the output prices as given above and quantity of green leaves supplied for made tea manufacturing.

Given below is the relationship for the aggregated output supply of green leaf production sector. The total production of green leaves produced in the industry is the summation of quantities produced by both private and estate sectors.

Input-constrained output supply equality

(5.5.1.11) $X = X' + X''$ green leaf supply equality in the tea grower sector

Equilibrium conditions of private green leaf production

(5.5.1.12) $W'_{GL} (W'_{v}, W'_{f}) = X'_{GL} (X')$

(5.5.1.13) $c_{X'GL} (p'_{v}, p'_{f}) = r_{W'GL} (q')$

Equilibrium conditions of estate green leaf production

(5.5.1.14) $W''_{GL} (W''_{v}, W''_{f}) = X''_{GL} (X'')$

(5.5.1.15) $C_{X''GL} (p''_{v}, p''_{f}) = r_{W''GL} (q'')$

These equations depict the quantity and value equilibrium conditions by equations 13 and 14 respectively. Aggregated inputs and aggregated outputs in quantity are equalized in quantity equilibrium, while the unit cost of production incurred per unit of aggregated outputs and unit revenue earned per unit of aggregated inputs are equalized in value equilibrium.

Black tea manufacturing

Other input supply to black tea manufacturing

(5.5.1.16) $X_o = X_o (q_o, T_{Xo})$

Supply function of other inputs to made tea manufacturing is a function of own price of black tea manufacturing other inputs and supply shifters.

Output-constrained input demand of black tea manufacturing

(5.5.1.17) $X = Y_{TM} * c'_{YTM, q} (q, q_o)$

(5.5.1.18) $X_o = Y_{TM} * c'_{YTM, qo} (q, q_o)$

These two equations depict the demand functions of black tea manufacturing inputs; green leaves supplied for black tea manufacturing and other inputs used in the manufacturing process.

$c'_{Y,q}$ (q, q_o) and $c'_{Y,qo}$ (q, q_o) are the partial derivatives of the unit cost functions of green leaves supplied for black tea manufacturing and other inputs in the manufacturing process with respect to price of green leaves and price of other inputs. Hence, demand for inputs in black tea manufacturing are given by the corresponding partial derivative of the unit cost function with respect to input prices given above, and quantity of black tea supply for secondary processing for exports and domestic retails.

Input-constrained output supply of black tea manufacturing

(5.5.1.19) $Y'_1 = X_{TM} * r'_{XTM, r'1} (r'_1, r'_2, r''_1, r''_2)$

(5.5.1.20) $Y'_2 = X_{TM} * r'_{XTM, r'2} (r'_1, r'_2, r''_1, r''_2)$

(5.5.1.21) $Y''_1 = X_{TM} * r'_{XTM, r''1} (r'_1, r'_2, r''_1, r''_2)$

(5.5.1.22) $Y''_2 = X_{TM} * r'_{XTM, r''2} (r'_1, r'_2, r''_1, r''_2)$

Equilibrium conditions of black tea manufacturing

(5.5.1.23) $X_{TM} (X, X_o) = Y_{TM} (Y'_1, Y'_2, Y''_1, Y''_2)$

(5.5.1.24) $c_{YTM} (q, q_o) = r_{XTM} (r'_1, r'_2, r''_1, r''_2)$

Secondary processing of made tea for export marketing in bulk form

Other input supply to secondary processing of made tea for export marketing in bulk form

(5.5.1.25) $Y'_{1o} = Y'_{1o} (r'_{1o}, T_{Y'1o})$

The supply of black tea for secondary processing of black tea exports in bulk form is a function of the price of other inputs used in secondary processing and supply shifters.

Output-constrained input demand of secondary processing of made tea for export marketing in bulk form:

(5.5.1.26) $Y'_1 = Z'_{1M} * c'_{Z'1M, r'1} (r'_1, r'_{1o})$

(5.5.1.27) $Y'_{1o} = Z'_{1M} * c'_{Z'1M, r'1o} (r'_1, r'_{1o})$

These two equations depict the demand functions for inputs of secondary processing of black tea in bulk and large packet form for exports; black tea from the auction and other inputs used in the secondary processing.

$c'_{Z'1M, r'1}(r'_1, r'_{1o})$ and $c'_{Z'1M, r'1o}(r'_1, r'_{1o})$ are the partial derivatives of the unit cost functions of black tea supplied for secondary processing and other inputs used with respect to price of black tea supplied at the auction and price of other inputs. Therefore, demands for inputs in secondary processing of black tea for bulk exports are given by the corresponding partial derivative of the unit cost function with respect to input prices given above and quantity of black tea demand for export markets in bulk and large packet form (Z'_1).

Input-constrained output supply of secondary processing of made tea for export marketing in bulk form

(5.5.1.28) $Z'_1 = Y'_{1SP} * r'_{Y'1SP, s'1}(s'_1)$

Equilibrium condition of secondary processing of made tea for export marketing in bulk form

(5.5.1.29) $Y'_{1SP}(Y'_1, Y'_{1o}) = Z'_{1M}(Z'_1)$

(5.5.1.30) $c_{Z'1M}(r'_1, r'_{1o}) = r_{Y'1SP}(s'_1)$

Export demand for tea in bulk form

(5.5.1.31) $Z'_1 = Z'_1(s'_1, N_{Z'1})$

The demand for black tea exports in the bulk and large packet form is a function of its own price supplied for export marketing and demand shifter.

Secondary processing of made tea for export marketing in value-added form

Other input supply to secondary processing of made tea for export marketing in value-added form

(5.5.1.32) $Y'_{2o} = Y'_{2o}(r'_{2o}, T_{Y'2o})$

Output-constrained input demand of secondary processing of made tea for export marketing in value-added form

(5.5.1.33) $Y'_2 = Z'_{2M} * c'_{Z'2M, r'2}(r'_2, r'_{2o})$

(5.5.1.34) $Y'_{2o} = Z'_{2M} * c'_{Z'2M, r'2o} (r'_2, r'_{2o})$

Input-constrained output supply of secondary processing of made tea for export marketing in value-added form

(5.5.1.35) $Z'_2 = Y'_{2SP} * r'_{Y'2SP, s'2} (s'_2)$

Equilibrium condition of secondary processing of made tea for export marketing in value-added form

(5.5.1.36) $Y'_{2SP} (Y'_2, Y'_{2o}) = Z'_{2M} (Z'_2)$

(5.5.1.37) $c_{Z'2M} (r'_2, r'_{2o}) = r_{Y'2SP} (s'_2)$

Export demand for tea in value-added form

(5.5.1.38) $Z'_2 = Z'_2 (s'_2, N_{Z'2})$

Secondary processing of made tea for domestic marketing in bulk form

Other input supply to secondary processing of made tea for domestic marketing in bulk form

(5.5.1.39) $Y''_{1o} = Y''_{1o} (r''_{1o}, T_{Y''1o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in bulk form

(5.5.1.40) $Y''_1 = Z''_{1M} * c'_{Z''1M, r''1} (r''_1, r''_{1o})$

(5.5.1.41) $Y''_{1o} = Z''_{1M} * c'_{Z''1M, r''1o} (r''_1, r''_{1o})$

Input-constrained output supply of secondary processing of made tea for domestic marketing in bulk form

(5.5.1.42) $Z''_1 = Y''_{1SP} * r'_{Y''1SP, s''1} (s''_1)$

Equilibrium condition of secondary processing of made tea for domestic marketing in bulk form

(5.5.1.43) $Y''_{1SP} (Y''_1, Y''_{1o}) = Z''_{1M} (Z''_1)$

(5.5.1.44) $c_{Z''1M} (r''_1, r''_{1o}) = r_{Y''1SP} (s''_1)$

Domestic demand for tea in bulk form

(5.5.1.45) $Z''_1 = Z''_1 (s''_1, s''_2, N_{Z''1}, N_{Z''2})$

Secondary processing of made tea for domestic marketing in value-added form

Other input supply to secondary processing of made tea for domestic marketing in value-added form

(5.5.1.46) $Y''_{2o} = Y''_{2o} (r''_{2o}, T_{Y''2o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in value-added form

(5.5.1.47) $Y''_2 = Z''_{2M} * c'_{Z''2M, r''2} (r''_2, r''_{2o})$

(5.5.1.48) $Y''_{2o} = Z''_{2M} * c'_{Z''2M, r''2o} (r''_2, r''_{2o})$

Input-constrained output supply of secondary processing of made tea for domestic marketing in value-added form

(5.5.1.49) $Z''_2 = Y''_{2SP} * r'_{Y''2SP, s''2} (s''_2)$

Equilibrium condition of secondary processing of made tea for domestic marketing in value-added form

(5.5.1.50) $Y''_{2SP} (Y''_2, Y''_{2o}) = Z''_{2M} (Z''_2)$

(5.5.1.51) $c_{Z''2M} (r''_2, r''_{2o}) = r_{Y''2SP} (s''_2)$

Domestic demand for tea in value-added form

(5.5.1.52) $Z''_2 = Z''_2 (s''_2, s''_1, N_{Z''1}, N_{Z''2})$

The structural equilibrium model of the Sri Lankan black tea industry is represented by equations from (1) to (52) in their general functional form. As shown in Figure 5.4, the model consists of 52 endogenous variables expressed in 52 equations in the system. There are altogether 38 price and quantity variables from 19 factor/product markets involved and 14 aggregated input and output index variables representing the seven multi-output markets in the black tea industry. The exogenous shifters are the 13 shifters of demand and supply products. These shifters allow measures of the impact of a change in the cost of production, a change in yield or a change in consumer willingness to pay.

5.5.2 The model in equilibrium displacement form

General functional forms of the model specify the equilibrium status in all markets involved in the industry. Once these equilibriums are converted to displaced forms which facilitate the study of impacts of exogenous shocks on the industry that lead to shifts from the base equilibrium. Total differentiation of the set of equations specifying endogenous price and quantity variables at the initial equilibrium points provides the respective displaced form as a percentage change. This method of differentiating equations to reflect a percentage change helps obtain informative estimations of quantity and price changes resulting from exogenous shocks, even without the functional forms of demand and supply based on the assumption that exogenous shifts cause small and parallel shifts.

In APPENDIX 3 - A, the model in equilibrium displaced form is specified.

5.5.3 Integrability conditions (for market parameters)

The next step after specifying the EDM in the displaced form is to specify values for the market parameters. Market parameters are decided based on realistic values specified through satisfying integrability conditions. There are two integral parts in integrability namely economic integrability and mathematical integrability.

Zhao, Mullen *et al.* (2000) and Mounter, Griffith *et al.* (2008), explained that integrability conditions are imposed on market parameters to make sure;

(a) the underlying decision-making preference functions in equations (5.4.2.1) to (5.4.2.7), (5.4.4.4) to (5.4.4.10), (5.4.5.4) to (5.4.5.10), (5.4.6.2) and (5.4.7.1) can be recovered from the demand and supply functions in equations from (5.5.1.1) to (5.5.1.52) - mathematical integrability.

(b) the underlying decision-making preference functions satisfy the regularity condition to be actual cost, revenue, profit and utility functions – economic integrability.

Satisfying integrability conditions is key to estimating the change in total economic benefits/costs or welfare changes resulting from a shift in demand and/or supply because of an exogenous shock on the system.

There are two methods used in quantifying the change in total economic surplus of a system.

(a) Summing up the changes in economic surplus across all affected market levels as reflected in the partial demand and supply curves. The distribution of total economic benefits/costs can be evaluated using this method, facilitating a welfare analysis of the operation of the system.

(b) The second method involves general equilibrium demand and supply functions and estimates the change in total economic surplus of the system resulting from an external shock at a market level.

These two methods that directly measure the change in total economic benefits/costs are solvable by satisfying integrability conditions.

5.5.4 Output-constrained input demand

According to Zhao, Mullen *et al.* (2000), and Mounter, Griffith *et al.* (2008), there are three integrability conditions that must be satisfied to relate input demand functions to their respective cost functions. They are homogeneity, symmetry, and concavity. The input demand function must be homogenous of the degree zero in input prices for the homogeneity condition to be met. Symmetric Allen-Uzawa input substitution elasticities and negative semi-definite Hessian matrix of input substitution elasticities are required to satisfy the symmetry and concavity conditions respectively. The following equations show these three conditions.

(5.5.4.1) $\Sigma^{k}_{j=1} \eta^{\sim}_{ij} (p, x) = 0$ (homogeneity)

Where $\eta^{\sim}_{ij} (p, x)$ – constant- output input demand elasticity of w_i with respect to a change in input price p_j, for (I,j = 1, ……, k).

(5.5.4.2) $s_i (p, x)\ \eta^{\sim}_{ij} (p, x) = s_j (p, x)\ \eta^{\sim}_{ji} (p, x)$ (i,j = 1, ….., k) (symmetry)

where $s_i (.) = (p_i w_i/C)$ – total cost share of the i^{th} input in total cost (i = 1, …., k).

The following shows how the Hessian matrix $H_\eta = (\eta^{\sim}_{ij} (p, x))_{k\,x\,k}$ must be negative semi-definite to meet the concavity requirement.

(5.5.4.3)

$$(-1)^m H_{\eta m} = (-1)^m \begin{vmatrix} \eta^{\sim}_{11} & \eta^{\sim}_{12} \dots & \eta^{\sim}_{1m} \\ \eta^{\sim}_{21} & \eta^{\sim}_{22} \dots & \eta^{\sim}_{2m} \\ . & . \quad . & . \\ . & . \quad . & . \\ . & . & . \\ \eta^{\sim}_{m1} & \eta^{\sim}_{m2} \dots & \eta^{\sim}_{mm} \end{vmatrix} \geq 0 \ (m = 1, \dots, k) \quad \text{(concavity)}$$

Where $H_{\eta m} = | (\eta\sim_{ij} (p, x))_{m \times m} |$ (m = 1, …., k) is the m^{th} principal minor of H_η. Therefore, H_η; the principal minors of the input demand elasticity matrix can take either sign between non-positive or non-negative when k is odd and even respectively (Zhao, Mullen *et al.* 2000).

Definitions provided by McFadden (1978, pp.79-80) must be used in introducing elasticities of input substitution in the conditions stated above (Zhao, Mullen *et al.* 2000).

(5.5.4.4) $\eta\sim_{ij} (p, x) = s_j (p, x)\ \sigma_{ij} (p, x)$ (i,j = 1, ….., k)

$\sigma_{ij} (p, x)$ – Allen-Uzawa elasticity of substitution between the i^{th} and j^{th} inputs.

The above equation can be used in re-writing the integrability conditions stated above as follows (Zhao, Mullen *et al.* 2000).

(5.5.4.5) $\Sigma^k_{j=1} s_j (p, x)\ \sigma_{ij} (p, x) = 0$ (homogeneity)

(5.5.4.6) $\sigma_{ij} (p, x) = \sigma_{ji} (p, x)$ for (i,j = 1, ….., k) (symmetry)

This implies that Allen-Uzawa substitution elasticities are symmetric, with respect to input substitution.

(5.5.4.7)

$$(-1)^m H_{\sigma m} = (-1)^m \begin{vmatrix} \sigma_{11} & \sigma_{12} \ldots & \sigma_{1m} \\ \sigma_{21} & \sigma_{22} \ldots & \sigma_{2m} \\ \vdots & \vdots & \vdots \\ \sigma_{m1} & \sigma_{m2} \ldots & \sigma_{mm} \end{vmatrix} \geq 0 \ (m = 1, \ldots, k) \qquad \text{(concavity)}$$

As a summary, for the output-constrained input demand functions in the model to be integrable, they must satisfy the conditions stated in the equations (5.5.4.1) – (5.5.4.3) or equivalently (5.5.4.5) – (5.5.4.7).

5.5.5 Input- constrained output supply

The set of integrability conditions that apply to the output supply functions on their respective revenue functions as in output-constrained input demands are homogeneity, symmetry and convexity. The output supply function must be homogenous of the degree zero in output prices, in order to satisfy the homogeneity condition. Symmetry in the Allen-Uzawa product transformation elasticities is required to satisfy the symmetry condition. The convexity condition is gained by ensuring the Hessian Matrix to be positive semi-definite.

(5.5.5.1) $\Sigma^n_{j=1} \tilde{\varepsilon}_{ij}(q, w) = 0$ (homogeneity)

$\tilde{\varepsilon}_{ij}(q, w)$ – constant-input output supply elasticity of x_i with respect to a change in output price q_j, for (i = 1, ……, n).

(5.5.5.2) $\lambda_i(q, w)\, \tilde{\varepsilon}_{ij}(q, w) = \lambda_j(q, w)\, \tilde{\varepsilon}_{ji}(q, w)$ (i,j = 1, ….., n) (symmetry)

Where $\lambda_j(.) = (q_j x_j/R)$ is the revenue share of the j[th] output in total revenue or (j = 1, ..., k).

The following shows how the Hessian matrix $H_\varepsilon = (\tilde{\varepsilon}_{ij}(q, w))_{n \times n}$ must be positive semi-definite to meet the convexity requirement.

(5.5.5.3)

$$(-1)^m H_{\varepsilon m} = (-1)^m \begin{vmatrix} \tilde{\varepsilon}_{11} & \tilde{\varepsilon}_{12} \ldots & \tilde{\varepsilon}_{1m} \\ \tilde{\varepsilon}_{21} & \tilde{\varepsilon}_{22} \ldots & \tilde{\varepsilon}_{2m} \\ . & . & . \\ . & . & . \\ \tilde{\varepsilon}_{m1} & \tilde{\varepsilon}_{m2} \ldots & \tilde{\varepsilon}_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \ldots, n) \text{ (convexity)}$$

Where $H_{\varepsilon m} = |(\tilde{\varepsilon}_{ij}(q, w)_{n \times n}|$ (m = 1, …., n) is the m[th] principal minor of H_ε. Therefore, H_ε; all principal minors of the output supply elasticity matrix are non-negative (Zhao, Mullen *et al.* 2000).

Definitions provided by McFadden (1978, pp.79-80) must be used in introducing elasticities of input substitution in the conditions stated above (Zhao, Mullen *et al.* 2000).

(5.5.5.4) $\tilde{\varepsilon}_{ij}(q, w) = \lambda_j(q, w)\, \tau_{ij}(q, w)$ (i,j = 1, ….., n)

Where $\tau_{ij}(q, w)$ is the Allen-Uzawa elasticity of transformation between the i[th] and j[th] outputs.

The above equation can be used in re-writing the integrability conditions stated above as follows (Zhao, Mullen *et al.* 2000).

(5.5.5.5) $\Sigma^n_{j=1} \lambda_j(q, w)\, \tau_{ij}(q, w) = 0$ for (i = 1, …., n) (homogeneity)

(5.5.5.6) $\tau_{ij}(q, w) = \tau_{ji}(q, w)$ for (i,j = 1, ….., n) (symmetry)

(5.5.5.7)

$$H_{\tau m} = \begin{vmatrix} \tau_{11} & \tau_{12} & \ldots & \tau_{1m} \\ \tau_{21} & \tau_{22} & \ldots & \tau_{2m} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ \tau_{m1} & \tau_{m2} & \ldots & \tau_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \ldots, n) \text{ (convexity)}$$

Simply, equations (5.5.5.1) – (5.5.5.3) or their equivalent equations (5.5.5.4) – (5.5.5.7) present the homogeneity, convexity and symmetry conditions satisfied; integrable conditions of output supply equations in the model.

5.5.6 Exogenous Input Supplies

Convexity is the integrability condition that must be required for exogenous input supply functions. The reason for this is that the relevant profit function in equation 5.4.2.1 derives each exogenous supply equation as the only variable. Every other variable is assumed as exogenous, which can influence the factor supply. Under these circumstances the other two integrability conditions; homogeneity and symmetry are considered not applicable. Therefore, the own-price supply elasticities of input supply functions must be positive to satisfy the convexity integrability condition (Zhao, Mullen *et al.* 2000).

(5.5.6.1) $\varepsilon_x \geq 0$

Where;

x: = W_f, W_v, X_o, Y'_{1o}, Y'_{2o}, Y''_{1o}, Y''_{2o}

5.5.7 Exogenous Output Demands

The assumption of exogenous product demand functions means that the export market for bulk and value-added tea is commodity specific for a group of consumers, and therefore they are non-substitutable (as discussed above). The demand for each product traded into the export market Z'_1 and Z'_2 must be integrable with the demand for other products that are not in the model. Therefore, the only requirement that must be satisfied in this case for demand elasticities of export commodities is the concavity or own-price demand elasticities of Z'_1 and Z'_2 being non-positive.

(5.5.7.1) $\eta\ (Z'_i, r'_i) \leq 0$ (i = 1, 2).

Since the domestic black tea commodities in the bulk form and VAT are considered substitutes, they must be integrable with the demand of both commodities and the demands for other commodities in the budget of domestic consumers. In this case, Marshallian economic surplus areas will be used to measure welfare based on the assumptions that hold the marginal utility function of income constant and ignore the income effect. This situation implied the need to satisfy the two integrability conditions of symmetry and concavity, negative semi-definite Marshallian substitution matrix.

(5.5.7.2) $\eta ij = (\lambda j/\lambda i)\ \eta ji$ $(i, j = Z''_1, Z''_2)$ (symmetry)

$\lambda j/\lambda i$ - relative budget shares of the two commodities

(5.5.7.3) $\eta ii \leq 0$ and $\begin{vmatrix} \eta ii & \eta ij \\ \eta ji & \eta jj \end{vmatrix} \geq 0$ (concavity)

The choice of sensible values for demand elasticities helps avoid violation of the integrability conditions homogeneity and concavity (Zhao, Mullen *et al.* 2000).

5.5.8 Imposing the Integrability Conditions on the Model

The integrability conditions; symmetry and homogeneity are applied on the equations specified from (A) 5.5.1.1 to 5.5.1.52 in the EDM. These equations are re-written in (B) 1 to 51 subsequently by including the said integrability conditions and elasticities of input substitution ($\sigma_{i\ j}$) and output transformation ($\tau_{i\,j}$). As discussed in detail, appropriate values are used for exogenous input supply and output demand elasticities in order to satisfy concavity and convexity integrability conditions.

Using a linear demand and supply system that meets integrability conditions at the base equilibrium tends to minimize associated errors for small displacements considered (Zhao, Mullen *et al.* 2000).

In APPENDIX 3 - B, the Equilibrium Displacement Model with integrability conditions imposed in specified.

5.6 Input data, exogenous shifts and welfare measurements

5.6.1 Input data

5.6.1.1 Base Equilibrium Price and Quantity Values

Price and quantity data for each sector of the tea industry were obtained from several sources such as publicly available secondary data sources. Published sources of secondary data included annual reports, annual market updates and performance reports from institutions that work closely with the tea industry in Sri Lanka such as SLTB, TRI of Sri Lanka, TSHDA, Ministry of Plantation Industries, Export Development Board and the Central Bank of Sri Lanka.

The five-year interval from 2010 to 2014 was used in specifying base equilibrium average quantities and prices as reported by the annual reports of the Sri Lanka Tea Board. These years were selected to avoid years with direct and indirect impacts on prices and quantities in markets because of the ban on

Glyphosate. Considering a medium run with average values over five years ensures that effects of unusual values present in single years will be evened out.

All quantities and prices are calibrated in terms of black tea equivalent million kilograms and Rs/kg respectively. The Sri Lanka Tea Board (2017) uses the out-turn ratio of 21.5 per cent between green leaves and made tea. Thus, the ratio 4.65 is used as the conversion ratio in converting made tea into green leaf quantities and prices. In other words, only 21.5 per cent of an amount of green leaves are converted to black tea, or 4.65 kilograms of green leaves are required to manufacture one kilogram of black tea. This conversion factor depends on the manufacturing process and other factors including the quality of green leaf harvest.

Quantity data

Quantities of black tea produced by the two tea grower sectors

Annual reports of the TSHDA provide percentage contribution of different tea growing sectors to the national made tea production, while the Sri Lanka Tea Board gives proportions of total national made tea produced based on the processing method. Breakdown of the total national made tea production by processing method includes black tea produced by the orthodox and CTC methods and green tea. Hence, the summation of black tea produced by these two methods are defined as the total national black tea production. It is assumed that the quality of black tea produced by either method are the same to avoid complexity of the model. Black tea covers almost 99 per cent of the total national production attesting Sri Lanka as a major black tea producer in the world. Of the total national made tea production, on average 73 per cent and 27 per cent were contributed by the smallholder/ private and estate/plantation sector respectively within the five years under consideration. These details are used in deriving the average annual contribution to the total national black tea production by the two grower sectors.

Black tea outputs from made tea manufacturing and secondary processing

The output in the primary manufacturing process that converts fresh green leaves to black tea is in the bulk form. This bulk black tea output is graded based on the particle size and categorized into several types, as explained by Hettiachchige and Rathnayake (2021). Therefore, it is the same set of inputs that are used to produce these intermediate products of final black tea products in different grades. The same quality is assumed across made tea products to avoid complications in the model, although there are quality variations in these graded intermediate products in the actual context. These tea grades in bulk form end up in the secondary processing for either export or domestic marketing in bulk or value-added form.

After primary processing the amounts of bulk black tea that are absorbed into each category of final products are not decided at the same processing level, but at the auction and secondary processing stage. There are no published statistics on quantities of these intermediate stage of final black tea products sold from processing factories to traders in the tea auction for secondary processing. Instead, statistics are available in the aggregated form as the total volume of made tea marketed in the Colombo tea auction on a monthly and annual basis.

For convenience in designing the model, it is assumed that secondary processing does not affect the weight of the main product. Therefore, quantities of the input (black tea in the primarily processed form) and the output (final black tea product from secondary processing) are the same.

Information on quantities of black tea exported from Sri Lanka in different product forms; bulk, tea bags, packets are published annually by the Sri Lanka Tea Board. Therefore, based on the above assumption, the same quantities are assumed for the intermediate stages of final black tea products.

Defining bulk and value-added tea in export and domestic marketing

The main outputs of black tea exports are in bulk and value-added form. As per the definition given by the Sri Lanka Tea Board, value-added tea products exported by the country include products with volumes less than 3 kg in the form of tea packets and tea bags. As explained earlier in this chapter, all other forms of black tea products exported in large packets with volumes ranging from 3 kg up to 10 kg and bulk tea lots of more than 10 kg volumes are collectively considered as bulk tea.

Tea in the bulk form after primary processing is the main input for the secondary processing of tea into packets in many sizes and bags.

Derivation of the domestic marketing/consumption of black tea

There is not sufficient data from the industry on actual domestic consumption within the 5 years under consideration. Information from the literature suggests that tea consumption in the country is considered to be 5 per cent of total production by Ganewatte and Edwards (2000), with estimates of 9 per cent by Ariyawardana (2001) and 10 per cent by several previous studies (Ganewatta *et al.* 2005).

Only 10 per cent of the total made tea production on average during the past years has been held in the country as the remainder after exports, where a part of this has been used for domestic consumption. The balance between the national made tea production and total exports (excluding re-exports) is not a good measurement for domestic consumption of tea, as annual exports and productions are prone to frequent fluctuations given the demand changes in export markets and adverse weather events leading to crop yield changes, respectively. However, considering that the annual national production is more stable than annual export volumes, the domestic consumption can be assumed to be 10 per cent of the total national production. This derivation will yield a more realistic estimation of domestic consumption annually.

In 1994, the most consumed form of tea was black tea in loose bulk form, accounting for 80 per cent of the total domestic consumption while only 20 per cent of consumed tea was in packet form (Ariyawardana 2001). According to Ganewatta, Waschik *et al.* (2005), the domestic demand for tea bags and retail packets was not higher during the early 2000s, and the majority of consumers were using the traditional method of tea preparation with loose tea bought from tea stored in bulk form in retail shops.

However, at the turn of the century, Ariyawardana (2001) saw there was potential to increase the domestic consumption of VAT in the country as a result of advanced food consumption patterns influenced by lifestyle changes and consistently improving per capita income in Sri Lanka; income elasticity of 1.004. As anticipated in the early 2000s, currently, a major share of black tea consumed within the country is in value-added forms in packets ranging in sizes from 50g to 500g and tea bags under different local brands. Supermarkets have only value-added black tea products with a brand while black tea in loose form can be available in retail shops in villages. The share of loose tea consumption domestically must have reduced drastically over years because of the introduction of tea packets in convenient sizes at affordable prices. Therefore, it is assumed that the total black tea consumption in the country comprises 90 per cent of value-added and 10 per cent of loose tea consumption.

Price data

The cost of production of green leaves by private growers vs vertically integrated/estate growers

Variable cost of production per year in tea smallholders for years 2010 – 2014 was taken from the green leaf production cost calculation by the TSHDA annual reports. Cost of production of green leaves by the estate sector was extracted from the made tea production cost information given by the Department of Census and Statistics (2020) for the same years.

The average price received per kilogram of green leaves annually is also provided by the TSHDA annual reports. The price received for the green lea harvest by smallholders is the price paid by black tea manufacturing factories based on the reasonable price formula regulated by the government as specified by the Tea Control Act of the Tea Board. It depends on the monthly net sale average of tea factories. This price also varies across tea growing regions, but an average value across all tea growing regions is used on the model in black tea equivalent terms.

Since green leaf harvest in the estate sector does not receive direct revenue from green leaves, the same green leaf price decided by the Sri Lanka Tea Board was assumed as the opportunity cost for the estate sector green leaves.

Price of made tea produced in processing factories

The intermediate stages of final black tea products in the bulk form receive different prices in the auction as there are differences implicit to final products based on attributes such as the grade and quality variations unique to tea growing elevation/regions. Usually, large particle size teas fetch higher prices while tea dust receives lower prices in the tea auction. There is limited published data on prices received by each final product type in the auction, but average prices are formed based on the elevation. Therefore, while acknowledging quality variations in tea, based on the assumption to disregard/not differentiate the quality of final tea products evaluated in the model, it is considered that all teas in the auction receive the same price. Tea processors are price takers. The average price received at the Colombo tea auction annually was used in this case as given by annual reports of the Sri Lanka Tea Board.

Prices received for secondarily processed tea are the Freight on Board (FOB) prices for exported tea as given in the annual reports of the Sri Lanka Tea Board and retail prices of loose bulk tea and value-added tea in the domestic market given by the Department of Census and Statistics (2010); (2016). Sri Lanka Tea Board gives FOB prices for bulk tea, tea bags, and tea packets separately. Tea bags have the highest FOB price and the price decreases as the volume of the packs increase. The FOB prices for the final black tea products exported, bulk and value-added tea, are calculated using weighted averages of prices of each product category given by the Sri Lanka Tea Board.

The Bulletin of Selected Retail and Producer Prices published by the Department of Census and Statistics (2010); (2016) provide prices of unbranded loose tea leaves per kg and price of a 100 g of a branded tea packet (this was converted to per kilogram price).

5.6.1.2 Cost and Revenue Shares

Equilibrium quantity and price values as explained above are used in deriving the cost and revenue shares needed in the model for all market sectors. The cost share of 'other inputs' variable of all market sectors is calculated as residuals using equilibrium conditions.

Table 5.3 is a summary of total value, cost shares of inputs and revenue shares of outputs of each market level for the period 2010 to 2014.

Table 5.3. Base Equilibrium Prices, Quantities and Cost and Revenue Shares (average of 2010-2014)

Market sector	Quantity			Prices			Total value (million Rs)	Cost share		Revenue share	
	Notation	Definition	Value (million kg)	Notation	Definition	Value (Rs. /kg)		Notation	Value	Notation	Value
Green leaf production											
Private growers	X'	Quantity of green leaves supplied from the green leaf production private landholding sector to the black tea manufacturing sector	1,110.6	q	Price per kg of green leaves received by private tea grower sector from the manufacturing sector	59.31	65,867.23	$\kappa_{W'v}$	0.80	λX'	1
								$\kappa_{W'f}$	0.20		
Estate growers	X''	Quantity of green leaves supplied from the green leaf production estate sector to the black tea manufacturing sector	423.2	q	Price per kg of green leaves received by estate tea grower sector from the manufacturing sector (internal transfer price of green leaf by vertically integrated processors)	59.31	25,099.70	$\kappa_{W''v}$	0.86	λX''	1
								$\kappa_{W''f}$	0.14		
	X	Total national green leaf production from both sectors	1,533.8	q	Average price paid for green leaves as decided by the green leaf price formula	59.31	90,966.94				
Black tea manufacturing											

For secondary processing into bulk tea exports	Y'1	Quantity of black tea from the manufacturing sector to secondary processing for bulk tea exports	178.9	r'1	Price of black tea from the manufacturing sector to the marketing sector (auction price)	405.68	72,593.92	κ_X	0.70	$\lambda_{Y'1}$	0.5586
For secondary processing into VAT exports	Y'2	Quantity of black tea from the manufacturing sector to secondary processing for VAT exports	118.3	r'2	Price of black tea from the manufacturing sector to the marketing sector (auction price)	405.68	47,988.53	κ_{Xo}	0.30	$\lambda_{Y'2}$	0.3693
For secondary processing into loose tea domestic markets	Y''1	Quantity of black tea from the manufacturing sector to secondary processing for bulk tea in domestic markets	2.3	r''1	Price of black tea from the manufacturing sector to the marketing sector (auction price)	405.68	936.71			$\lambda_{Y''1}$	0.0072
For secondary processing into VAT domestic markets	Y''2	Quantity of black tea from the manufacturing sector to secondary processing for VAT in domestic markets	20.8	r''2	Price of black tea from the manufacturing sector to the marketing sector (auction price)	405.68	8,430.35			$\lambda_{Y''2}$	0.0649
Secondary processing of black tea for marketing											
Secondary processing of made tea for export marketing	Z'1	Quantity of bulk black tea from secondary processing to export market	178.9	s'1	Price per kg of bulk black tea to export market	498.75	89,246.66	$\kappa_{Y'1}$	0.81	$\lambda_{Z'1}$	1

in bulk form											
								$\kappa_{Y'1o}$	0.19		
Secondary processing of made tea for export marketing in VAT form	Z'2	Quantity of value-added black tea from secondary processing to export market	118.3	s'2	Price per kg of value-added black tea to export market	624.48	73,870.41	$\kappa_{Y'2}$	0.65	λZ'2	1
								$\kappa_{Y'2o}$	0.35		
Secondary processing of made tea for domestic marketing in loose form	Z''1	Quantity of loose black tea from secondary processing to domestic market	2.3	s''1	Price per kg of loose black tea to domestic market	674.23	1,556.77	$\kappa_{Y''1}$	0.60	λZ''1	1
								$\kappa_{Y''1o}$	0.40		
Secondary processing of made tea for domestic marketing in VAT form	Z''2	Quantity of value-added black tea from secondary processing to domestic market	20.8	s''2	Price per kg of value-added black tea to domestic market	960.43	19,958.37	$\kappa_{Y''2}$	0.42	λZ''2	1
								$\kappa_{Y''2o}$	0.58		

5.6.1.3 Market Parameters

Market parameters are needed for every market level in the EDM. These parameters include elasticities of demand, supply, input substitution and product transformation of intermediate and final black tea products, farm and other inputs. Price elasticity values provide a numerical estimation of the responsiveness of quantity variables to price changes.

Elasticity estimates play a critical role in the EDM. Magnitudes of price elasticities of demand and supply can be obtained from existing econometric estimations or estimated by the use of economic theory and subjective judgement. Since many of the price elasticities are not readily available from prior research, it is hard to obtain robust estimates of them. Elasticity estimates tend to vary based on several factors such as functional forms, estimation methods, and model specification, and over time with changes in the external environment (Griffith *et al.* 2001). In such instances, most studies rely on expert opinion and subjective judgment that help arrive at best guesses of elasticity values. These magnitudes of supply and demand elasticities also vary based on the point in the value chain where the elasticity is being measured. Additionally, subsequent results obtained from the model can be overly sensitive to the elasticity estimates used, thus could lead to different inferences.

Furthermore, price elasticities of demand and supply can take different magnitudes across the value chain of the industry owing to varying responses to price changes and production technologies at each market level. For an instance, price elasticities at the farm gate are usually lower than those at the retail market levels, because of factors including perishability of agricultural produce and lower degrees of substitutability. However, finding elasticity estimates for all market levels along the value chain is a challenge as there is not sufficient information about those values.

It is essential for market elasticity estimates to meet integrability for all demand and supply functions in the model in terms of concavity and convexity conditions. This study follows the approach taken by Zhao, Mullen *et al.* (2000) in obtaining elasticity values.

Exogenous demand elasticities

Demand for black tea products in markets of the EDM can be explained using own-price and cross-price elasticities of demand. Own-price elasticity of demand for a tea product describes the responsiveness of tea buyers/consumers' buying quantities to changes in price of the same product, while cross-price elasticity of demand measures the responsiveness of tea buyers to price changes in a related good. A movement along the demand curve represents changes in the quantity demanded to own-price changes.

Studies have found that demand for tea in most of the tea consuming countries is price inelastic throughout an extended period (Broster 1939; Ramanujam 1984; Weerahewa 2003; Ganewatta, Waschik *et al.* 2005; Food and Agriculture Organization of the United Nations 2012; Chang 2015). The recent study by Chang (2015) has stated that price elasticity estimates for black tea vary between 0.32 and 0.8, while many factors including demographic variables such as age, education, occupation, cultural background, health benefits can influence the demand in addition to traditional variables such as price and income. Additionally, demand elasticities can vary in the long run across types of economies with 0.07, 0.14, and 0.48 as estimates from developed, developing, and centrally planned economies (Ganewatta, Waschik *et al.* 2005).

Exogenous demand elasticities in the EDM of the study are required at domestic and export market levels of black tea products.

Domestic marketing

Products of black tea available in the domestic market are branded value-added tea and unbranded bulk/loose tea as explained earlier. Although tea is the mostly consumed beverage in Sri Lanka, its domestic demand is not well-specialized, yet domestic prices of tea products and the income are considered as factors determining the country's demand (Ariyawardana 2001). However, the price elasticities of demand for tea domestically were calculated in a few past studies as shown in the following Table 5.4.

Table 5.4. Price elasticity of demand estimations in previous studies

Study	Price elasticity of demand
Yuliando and Akira 2006	0.588
Ariyawardana 2001	0.4209
Ramanujam 1984	0.2596 (short run) 0.9058 (long run)
Tyler 1976	0.54

Although the recent consumption patterns of black tea have diverted towards value-added tea products as mentioned above, there is no separate information on elasticity estimates on value-added tea and bulk/loose tea consumed domestically. Since there is growing demand for VAT, it is logically assumed that the price elasticity of demand for unbranded loose/bulk tea would be more elastic than that of VATs as the preference would be more towards the latter. Hence, based on estimates from past studies, 0.4 and 0.8 were chosen as price elasticities of demand for VAT and bulk/loose tea respectively.

Export marketing

A major share of annual tea exports is traded by a few exporters; mainly multinational companies (Wijayasiri 2013). Sri Lankan black tea reaches international tea market destinations in the form of value added and bulk teas. As already explained earlier, bulk tea is mainly purchased by secondary processors in importing countries to be re-packed and sold in their own marketing channels, while VAT reach either retail markets or companies that re-distribute them under different brands. Demand for tea by importing countries mainly depends on consumption patterns and economic conditions of those countries. Additionally, prevailing market conditions, cost for importation, marketing, packaging and distribution also influence the demand for tea. Currently, the global preference is changing to value added tea products.

There are a very limited number of studies on export demand elasticities for Sri Lankan black tea products of Sri Lanka separately, but there is general agreement that export demand elasticities are elastic. Since bulk tea is an intermediate product traded in the export market, derived demand elasticities are used. Herath and Weersink (2007) have pointed out that the derived demand for bulk black teas by processors in importing countries is elastic because of the ability of tea consumers in the United Kingdom to substitute Sri Lankan tea with other origin teas from India and China (Weerahewa *et al.* 1997). The top black tea export destinations of Sri Lanka in recent years according to the Sri Lanka Tea Board (2017) were Turkey, Russia and the CIS region, Iran and Iraq in the Middle East, the Oceania region including Japan and China, Australia, the European Union region, and the United States.

Studies that examined export demand elasticities of VAT in Sri Lanka are scarce. Therefore, it is assumed that VATs are elastic with respect to bulk tea because of the availability of many substitutes and differentiated products for VAT in the global market from value addition by both producing and non-producing countries. Furthermore, bulk tea being a raw material in the value addition process of VAT tend to have an inelastic demand. Based on these arguments, export demand elasticities for bulk tea and VAT are estimated as 4.0 and 5.0, respectively.

Input supply elasticities

Input supply elasticities are defined for exogenous inputs used in each market level of production in the EDM. Since own price elasticities of input supplies were used mostly in the model, cross-price elasticities have not been reviewed. Elasticity of input supply explains the responsiveness of factor supplies to changes in its own price. Inputs used in production processes can be categorized under land, labour and capital and further elaborating them as fertilizer, agro-chemicals, energy sources, machinery, packaging material etc. These inputs are aggregated in each market level to one category as other inputs that are specified exogenous to the model.

Given the limited evidence on supply elasticity estimations on inputs, earlier studies by Zhao *et al.* have classified inputs into two as fixed capital, human capital, and other inputs aggregated together and inputs such as labour, chemical, and other inputs under mobile factors with relatively elastic supplies. That study has chosen 0.4 and 5 as the supply elasticity estimates of fixed capital and human capital factor inputs and mobile factor inputs respectively. Fixed capital and human capital have been allocated a relatively inelastic supply elasticity because of the technical aspects of such inputs, while identifying mobile input factors as very much closer to perfect elasticity indicating the non-specific nature.

Applying the same concept on the EDM of the tea industry, in this study farm inputs were classified into fixed and variable inputs as explained in Section 5.3. Elasticity estimates of estate sector farm production found by Roberts (1989) were helpful to be used as inputs in the EDM. Although those market parameters date to 30 years back, it can be assumed that they still apply to the present context. This is because tea production at the farm levels is a labour-intensive activity depending on labour for most of the field activities and there have not been significant advances in the technology of farming systems, especially in labour-saving technology, that has changed the input of labour much since then.

Fixed inputs in the two farm sectors constitute land, capital, and human capital in varying degrees. Tea being a perennial crop tends to have input factors such as land, and capital such as buildings and vehicles fixed over the medium run. Fixed inputs in the estate sector tend to be much more technical and highly specialized than the private grower sector. Additionally, there is the separate human capital - estate management is a fixed input in the estate sector that is not found in private growers. It is assumed that the supply of fixed inputs in the estate sector is inelastic with respect to the other sector. Roberts (1989) has found out that supply elasticities of field labour and vehicles in the estate sector as 0.3 and 0.2, respectively. Taking into account this distribution of fixed inputs across two grower sectors, 0.6 and 0.4 are used as supply elasticities of fixed inputs in private and estate grower sectors, respectively.

On the other hand, a major share of variable inputs in the farm sector is labour as tea cultivation is labour-intensive. The residential labour force in the estate sector is usually specialized for separate field activities than the casual labour hired in the private sector, thus, are relatively inelastic. Supply elasticities of field labour in estates were calculated to be 0.99 by Roberts (1989). Based on this data, variable input supply elasticities for the private and estate sector are assigned 1 and 0.9 respectively.

Furthermore, black tea manufacturing and secondary processing requires highly sophisticated and capital-intensive equipment and machinery in addition to specialized human capital. A value of 1.0 of other input supply elasticity is assumed in all those market levels.

Input substitution elasticities

Input substitution is possible in a production function when there are multiple inputs. The elasticity of input substitution gives an indication of the degree of substitutability between inputs at a market level. The significance of input substitution was discussed by earlier studies and Zhao *et al.* (2003) have pointed out arguments made by Freebairn *et al.* (1982) and Alston and Scobie (1983). Accordingly, elasticities of input substitution are critical in the EDM, where distributions of benefits or costs along market levels from an exogenous shock are dependent on the substitution estimates. In instances when inputs are used in fixed proportions - no substitution between inputs - in a sector, returns would equally be distributed across market levels, whereas with input substitution possible in a market level, with a shock on the sector the same level gets a larger proportion of total returns.

There is no previous work that studied the substitutability of inputs in market levels along the value chain of the tea industry. Depending on the insubstantial degrees of substitution between inputs in the farm and other tea processing sectors, it is assumed that inputs are used in fixed proportions hence there is no substitution.

Product transformation elasticities

According to Powell and Gruen (1968), the elasticity of product transformation is "the responsiveness of a product-mix ratio to changes in the marginal rate of transformation" (p. 315). It describes the degree of substitution between products for a given level of inputs as a response to relative price changes in outputs.

Most of the market levels in the tea value chain have single products except for the black tea manufacturing sector that produces the four black tea product types differentiated based on the final marketing channel after undergoing secondary processing. Rest of the other sectors have one main input. Given the limited flexibility to change the product mix ratio because on the nature of the black tea manufacturing and scarce information on product transformation elasticities, the EDM assumed a fixed ratio in the product mix. Therefore, the elasticity of product transformation is zero.

Market elasticity values for the base equilibrium conditions in each market level are given in the Table 5.5 below.

Table 5.5. Market elasticity values for the base equilibrium condition

		Demand elasticities	Supply elasticities	Input substitution elasticities	Product transformation elasticities
Green leaf production	Private tea growers		$\varepsilon_{W'vp'v} = 2.5$ $\varepsilon_{W'fp'f} = 0.4$	$\sigma_{W'vW'f} = 0$	
	Estate tea growers		$\varepsilon_{W''vp''v} = 1$ $\varepsilon_{W''fp''f} = 0.1$	$\sigma_{W''vW''f} = 0$	
Black tea manufacturing			$\varepsilon_{Xoqo} = 1$	$\sigma_{XXo} = 0$	$\tau_{Y'1Y'2} = 0$ $\tau_{Y'1Y''1} = 0$ $\tau_{Y'1Y''2} = 0$ $\tau_{Y'2Y''1} = 0$ $\tau_{Y'2Y''2} = 0$ $\tau_{Y''2Y''1} = 0$
Secondary processing of made tea for export marketing in bulk form		$\eta_{Z'1s'1} = -4$	$\varepsilon_{Y'1or'1o} = 1$	$\sigma_{Y'1Y'1o} = 0$	
Secondary processing of made tea for export marketing in value-added form		$\eta_{Z'2s'2} = -3$	$\varepsilon_{Y'2or'2o} = 1$	$\sigma_{Y'2Y'2o} = 0$	
Secondary processing of made tea for domestic marketing in bulk form		$\eta_{Z''1s''1} = -0.8$	$\varepsilon_{Y''1or''1o} = 1$	$\sigma_{Y''1Y''1o} = 0$	
Secondary processing of made tea for domestic marketing in value-added form		$\eta_{Z''2s''2} = -0.4$	$\varepsilon_{Y''2or''2o} = 1$	$\sigma_{Y''2Y''2o} = 0$	

A sensitivity analysis will be carried out to test some of the critical assumptions made while assigning elasticity estimates through subjective judgements. The outcomes of the EDM are sensitive to market parameter estimates, thus conducting a sensitivity analysis is important to monitor changes in model outcomes.

5.6.2 Measuring economic surplus changes

Subsequent displacements in quantities and prices from the initial equilibrium of the system of equations in the EDM representing demand and supply of market levels resulting from an external shock can be measured by calculating the economic surplus changes. The section below provides a description on measuring economic surplus changes.

5.6.2.1 Changes in the producer surplus

As already explained earlier in this chapter, factor supplies at each market level are a function of their own price and independent of other variables, so are exogenous to the EDM. Figure 5.5 below is a depiction of the change in the producer surplus of the farm sector as a result of a shock on variable inputs that eventually increased production costs of the market level.

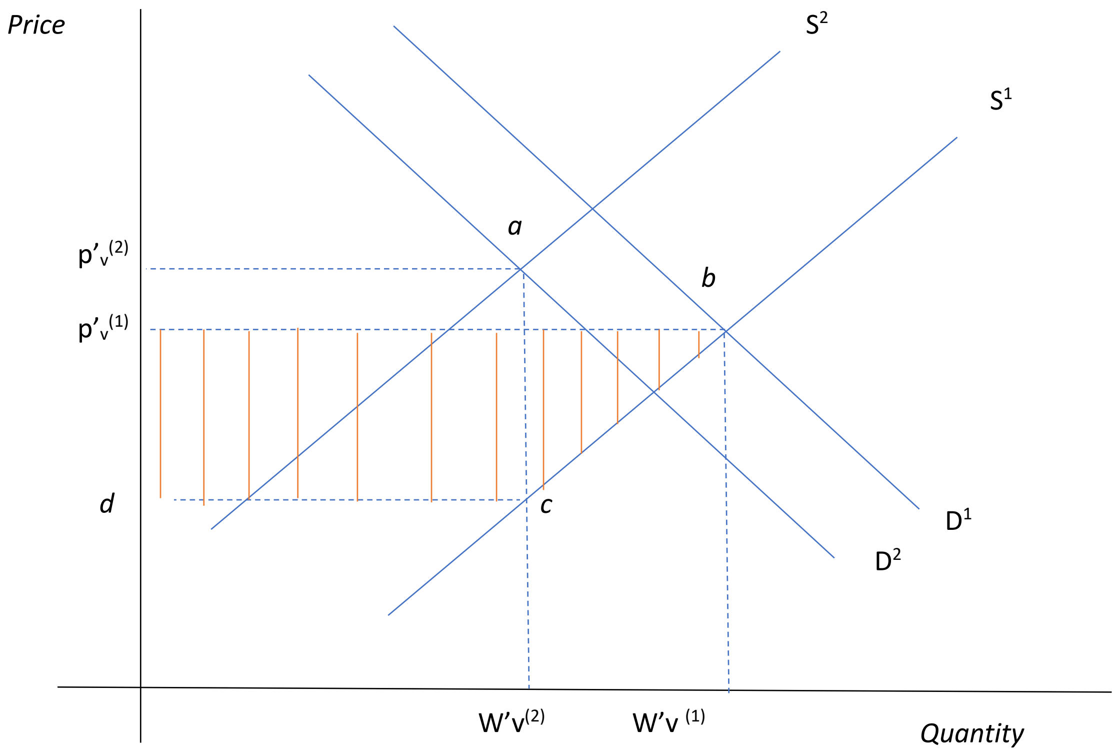


Figure 5.5. Change in producer surplus for a shock in factor supply (tW'v = 0.01). Source Zhao, Mullen et al. (2000) and Mounter, Griffith et al. (2008)

The shock on variable input supply of the private grower sector leads to the initial effect of shifting the supply curve upwards from S^1 to S^2. Since the EDM covers the entire tea industry comprising of all vertically related market levels, the effect of the initial shock does not stop at the private grower sector itself but replicates the effect of the shock on other market levels as well. Therefore, the increase in the green leaf price from $p'_v{}^{(1)}$ to $p'_v{}^{(2)}$ with the upward movement in the private grower supply curve leads to upward shifts in other supply curves of intermediate and final products in all market levels beyond the farm sector, and eventually increasing their prices and decreasing quantities. This is because upstream markets supply inputs to the downstream markets i.e., farm sector supplies green leaves as inputs to primary processing of tea and continues to other upstream market sectors. As prices of final products are increased, the demand decreases, and in turn decreases the demand for intermediate products along with factors of production. Eventually, the demand curve for variable inputs of the sector shifts downwards from D^1 to D^2 while setting up a new equilibrium point shown by *a*. Depending on the assumption that all shifts in supply and demand are parallel, the change in the producer surplus at the private grower sector is obtained by calculating the shaded area ($p'_v{}^{(1)}$bcd) obtained by the formula specified by Zhao, Mullen *et al.* (2000) and Mounter, Griffith *et al.* (2008).

(5.6.2.1) $\Delta PSw'v = p'v^{(1)} W'v^{(1)} (Ep'v - tw'v) (1+0.5EW'v)$

Where $Ep'v = (p'v^{(2)} - p'v^{(1)}/ p'v^{(1)}$ and $EW'v = (W'v^{(2)} - W'v^{(1)})/ W'v^{(1)}$

5.6.2.2 Changes in the consumer surplus

Similar to exogenous factor supplies, demand of final products are a function of own prices and unrelated variables. Change in consumer surplus in the EDM is explained below using Figure 5.6 on export market for bulk black tea. In this case, secondary processors in importing countries are considered as consumers of Sri Lankan Black tea exports.

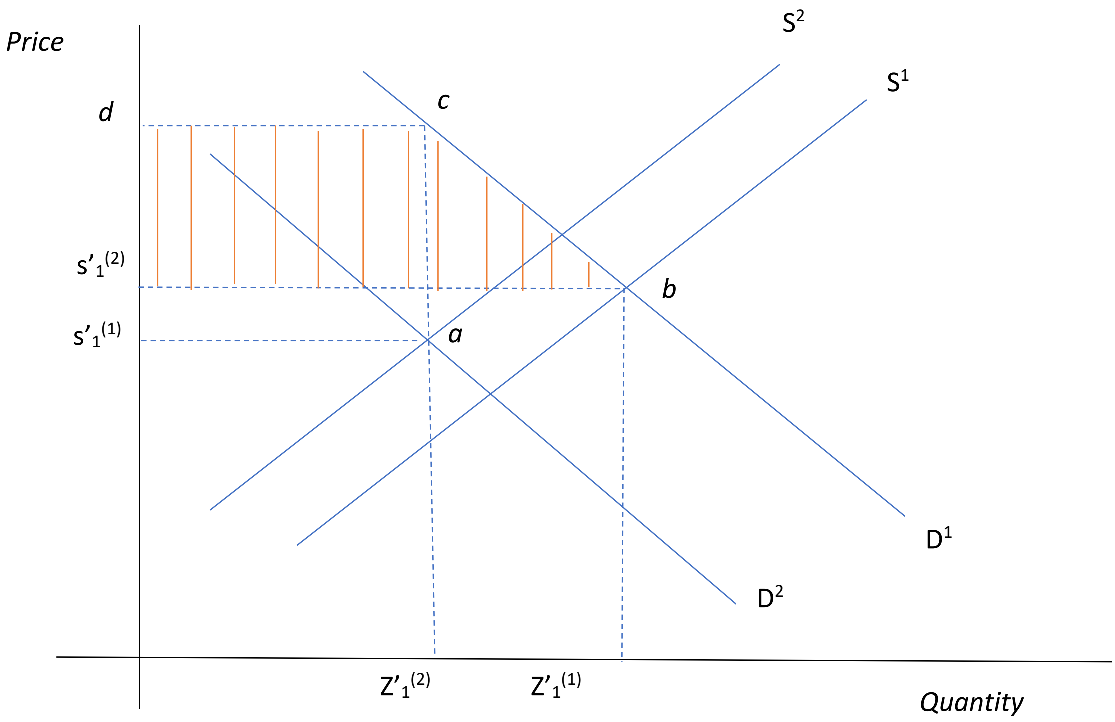


Figure 5.6. Change in consumer surplus for a shock in factor supply (nZ'1 = -0.01). Source Zhao, Mullen et al. (2000) and Mounter, Griffith et al. (2008)

A shock on exogenous demand on bulk black tea exports in terms of a decline in the willingness to pay by overseas processors as is assumed as a result of not satisfying the expected quality of exported teas.

This shock depicted by a downward shift in the demand curve from D^1 to D^2. This leads to reduced demand for export bulk black tea and subsequently replicates to demand declines of outputs in integrated market levels downstream. In turn, reduced demands cause supply curves to shift upwards in all market levels downstream, including the supply curve of bulk black tea exports from S^1 to S^2, shifting the new equilibrium point from *a* to *b*. It is assumed that all demand and supply shifts are parallel, hence the following formula specified by by Zhao, Mullen *et al.* (2000) and Mounter, Griffith *et al.* (2008) calculates the consumer surplus represented by the area,

(5.6.2.2) $\Delta CSz'_1 = s'^{(1)}_1 Z'^{(1)}_1 (Es'_1 - nz'_1)(1+0.5EZ'_1)$

Where $Es'_1 = (s'^{(2)}_1 - s'^{(1)}_1 / s'^{(1)}_1$ and $EZ'_1 = (Z'^{(2)}_1 - Z'^{(1)}_1) / Z'^{(1)}_1$

5.6.2.3 Total surplus change and welfare impacts

Measuring the surplus change of an external demand or supply shock on a multi-market model structure like EDM can be done in two ways. One method is to measure the surplus change from the general equilibrium of demand and supply curves only at the market level that undergoes the external shock, and no information on the distribution of surplus in other market levels can be drawn. In contrast, the other approach sums up individual welfare effects from partial equilibrium demand and supply curves in each market in measuring the total surplus change across all market levels in the EDM. This method provides a greater context of the industry of an external shock by depicting the distribution of surplus in all market levels. However, both methods can be made equivalent by satisfying integrability conditions and the same results can be obtained.

The approach that uses general equilibrium curves in measuring the total surplus change of a shift in supply is depicted in Figure 5.7, equivalent to the scenario described using Figure 5.5. That scenario relates to increased production costs of the farm sector owing to a shock on variable inputs that eventually lead to a change in producer surplus change. In Figure 5.7, the locus that connects the initial and new equilibrium points after the adjustment is shown by the general equilibrium demand curve, D^G.

The summation of the consumer and producer surplus as shown by the areas $p'^{(1)}_v bcd$, and $p'^{(2)}_v ab\ p'^{(1)}_v$, respectively, gives the total surplus bound by the area $p'^{(2)}_v abcd$ calculated using the formula (Zhao, Mullen *et al.* 2000)

(5.6.2.3) $\Delta TS = -\ p'^{(2)}_v\ W'v^{(1)}\ t_{W'v}\,(1+0.5E\ W'v)$

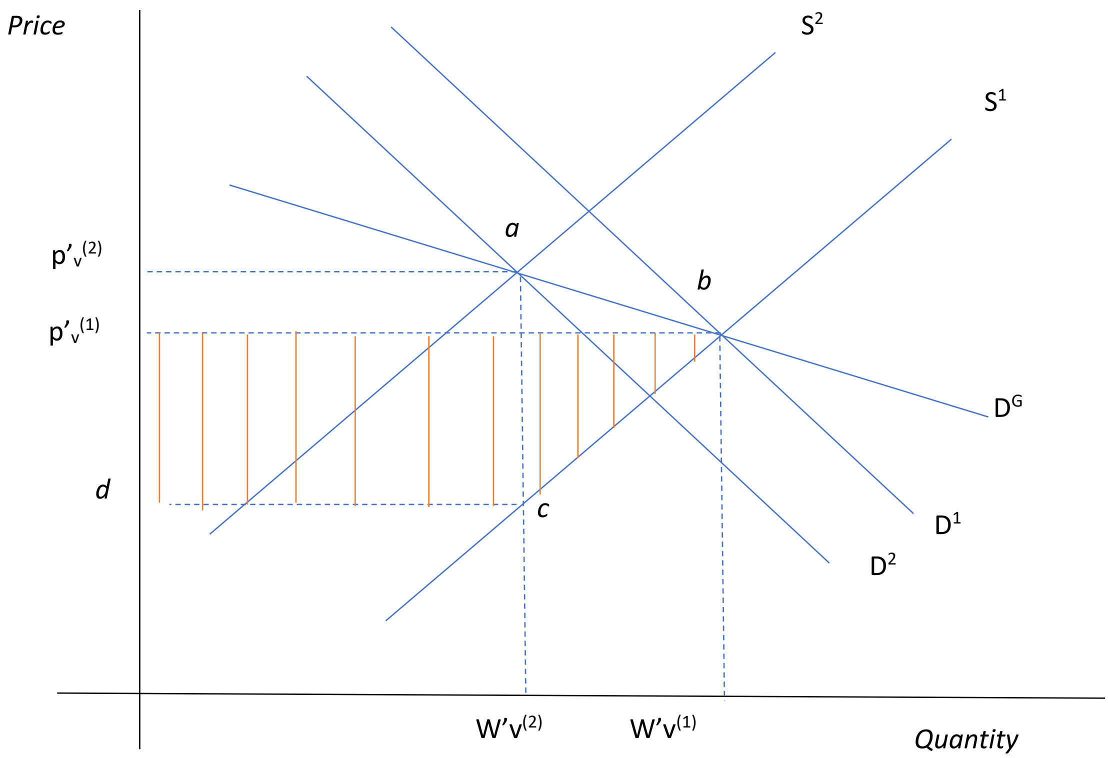


Figure 5.7. Change in total surplus measured from the general equilibrium curve (tW'v = -0.01). Source Zhao, Mullen et al. (2000) and Mounter, Griffith et al. (2008)

Marshallian demand and supply curves as in equations (5.4.6.3) and (5.4.7.2) are used to measure the surplus change. Marshallian demand curves express the relationship between quantity demanded and price while taking income and utility into consideration. On the other hand, Hicksian curves takes into account of income changes while assuming a constant utility. Thus, measuring a welfare change of a policy shock using Hicksian curves allows denoting the change in monetary value by holding the level of utility fixed. This approach is widely used in measuring producer surplus changes of policy decisions as Hicksian curves are considered to yield exact measures, but not for consumer surplus changes (Alston and Larson 1993). However, measures obtained from Marshallian and Hicksian curves are equivalent in producer surplus.

The list of formulas used in calculating producer and consumer surpluses for each market level in the tea industry is given in Table 5.6.

Table 5.6. Formulas for producer and consumer surplus in market levels in the tea industry

Factor producer surplus changes	
Private grower sector variable input suppliers	$\Delta PSw'v = p'v^{(1)}\, W'v^{(1)}\, (Ep'v - tw'v)\, (1+0.5EW'v)$
Private grower sector fixed input suppliers	$\Delta PSw'f = p'f^{(1)}\, W'f^{(1)}\, (Ep'f - tw'f)\, (1+0.5EW'f)$
Estate grower sector variable input suppliers	$\Delta PSw''v = p''v^{(1)}\, W''v^{(1)}\, (Ep''v - tw''v)\, (1+0.5EW''v)$
Estate grower sector fixed input suppliers	$\Delta PSw''f = p''f^{(1)}\, W''f^{(1)}\, (Ep''f - tw''f)\, (1+0.5EW''f)$
Black tea manufacturing other input suppliers	$\Delta PSXo = qo^{(1)}\, Xo^{(1)}\, (Eqo - txo)\, (1+0.5Exo)$
Secondary processing of tea for bulk tea exports to other input suppliers	$\Delta PSY'1o = r'1o^{(1)}\, Y'1o^{(1)}\, (Er'1o - ty'1o)\, (1+0.5Ey'1o)$
Secondary processing of tea for VAT exports other input suppliers	$\Delta PSY'2o = r'2o^{(1)}\, Y'2o^{(1)}\, (Er'2o - ty'2o)\, (1+0.5Ey'2o)$
Secondary processing of tea for bulk tea domestic marketing other input suppliers	$\Delta PSY''1o = r''1o^{(1)}\, Y''1o^{(1)}\, (Er''1o - ty''1o)\, (1+0.5Ey''1o)$
Secondary processing of tea for VAT domestic marketing other input suppliers	$\Delta PSY''2o = r''2o^{(1)}\, Y''2o^{(1)}\, (Er''2o - ty''2o)\, (1+0.5Ey''2o)$
Consumer surplus changes	
Bulk black tea exporters	$\Delta CSz'_1 = s'_1{}^{(1)}\, Z'_1{}^{(1)}\, (Es'_1 - nz'_1)\, (1+0.5EZ'_1)$
VAT exporters	$\Delta CSz'_2 = s'_2{}^{(1)}\, Z'_2{}^{(1)}\, (Es'_2 - nz'_2)\, (1+0.5EZ'_2)$
Bulk black tea domestic consumers	$\Delta CSz''_1 = s''_1{}^{(1)}\, Z''_1{}^{(1)}\, (Es''_1 - nz''_1)\, (1+0.5EZ''_1)$
VAT domestic consumers	$\Delta CSz''_2 = s''_2{}^{(1)}\, Z''_2{}^{(1)}\, (Es''_2 - nz''_2)\, (1+0.5EZ''_2)$

Formulae for total economic surplus changes for hypothetical scenarios described under Section 5.6.2 are listed in Table 5.7 below.

Table 5.7. Formulas for calculating the total economic surplus

Farm sector ($t_{W'v} = -0.01$)	$\Delta TS = -\, p'_v{}^{(2)}\, W'v^{(1)}\, t_{W'v}\, (1+0.5E\, W'v)$
Black tea manufacturing sector ($t_{Xo} = -0.01$)	$\Delta TS = -\, qo^{(2)}\, Xo^{(1)}\, t_{Xo}\, (1+0.5E\, Xo)$
Secondary processing bulk export sector ($t_{Y'1o} = -0.01$)	$\Delta TS = -\, r'1o^{(2)}\, Y'1o^{(1)}\, t_{Y'1o}\, (1+0.5E\, Y'1o)$
Export marketing bulk export sector ($n_{Z'1} = -0.01$)	$\Delta TS = -\, s'1o^{(2)}\, Z'1^{(1)}\, t_{Z'1}\, (1+0.5E\, Z'1)$

5.6.2 Technical validation of the EDM using hypothetical exogenous shifts

The EDM developed on the tea industry in Sri Lanka consists of 13 exogenous shift variables in total with four demand shifters and nine supply shifters. These demand and supply variables help in interpreting the impact of different scenarios in different market levels that can either increase or decrease the economic surplus in the respective sectors.

The model that was set up after specifying its equations and expressed in terms of base equilibrium quantities, prices and market parameters is validated using hypothetical scenarios. They were helpful in technically validating the model using a simple test by checking if it produced the same order of magnitudes corresponding to inputs. Under each scenario, an exogenous demand or supply variable in a market level is shocked by 1 per cent and the respective surplus change reflecting the impact of each shock on the system is investigated. The welfare change (in value terms) of each of these hypothetical scenarios will be proportional to the initial supply or demand shift. For an example, when one percent shocks on variable inputs in both grower sectors are applied on the model, it yielded a change in total economic surplus that was equal to one percent proportion of the gross value relative to the weighted average variable cost share of farm sector inputs. As shifts from external shocks are assumed to be parallel and relatively smaller, distribution of welfare in market levels will be independent of the magnitude of the shift. In Table 5.8 a summary of four hypothetical scenarios with descriptions on exogenous shift variables, magnitudes and direction of shifts is provided.

Table 5.8. Description of hypothetical scenarios and results of welfare changes

Market level undergoing shock	Description of the hypothetical scenario	Result
Farm sector	$t_{W'V}$ = 0.01, $t_{W''V}$ = 0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Cost of production increase in green leaf production resulting from imposition of an input use restriction policy on the tea grower sector	Changes in surplus of Producer surplus = (469.69) Consumer surplus = (253.76) Total surplus = (723.45)
Black tea manufacturing sector	t_{XO} = 0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Cost of production increase in tea manufacturing sector resulting from imposition of an input restriction policy on the sector	Changes in surplus of Producer surplus = (579.42) Consumer surplus = (150.32) Total surplus = (429.10)
Secondary processing bulk export sector	$t_{Y'1O}$ =0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Increase in the cost of production in secondary processing as a result of a government policy	Changes in surplus of Producer surplus = (274.65) Consumer surplus = (58.32) Total surplus = (332.97)
Export marketing bulk export sector	$n_{Z'1}$ = -0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Reduction in the demand for bulk black tea exports by processors in importing countries because of a quality degradation in products	Changes in surplus of Producer surplus = (579.01) Consumer surplus = (312.20) Total surplus = (891.21)

In APPENDIX 4, percentage changes in prices and quantities, economic surplus distributions and probability distributions of the economic surpluses across market levels in the tea industry for the hypothetical shock of increased costs on variable inputs in private and estate tea grower sectors by 1 per cent are specified.

5.7 Summary

In this chapter is presented the key steps in developing an EDM for the tea industry in Sri Lanka. The first section provides a review of the industry and its key market levels that extend from tea cultivation to black tea trading and marketing in export and domestic markets. The explanation regarding vertical and horizontal disaggregation of the industry is demonstrated along with the conceptual frameworks of the model.

The next section provides information about the structure of the tea industry in Sri Lanka in terms of the equilibrium displacement form – by specifying all production, cost and revenue functions of all market levels of the industry in general functional forms. Differentiating the system of equations to displacement form is subsequently explained eventually developing the model; system of equations is justified for integrability conditions to derive the finalized form.

The inputs used for the functioning of the EDM specified by equations (5.5.1.1) – (5.5.1.52) include base equilibrium price and quantity values for all inputs and outputs that outline the equilibrium status of the system, market parameters illustrating the market responsiveness of quantities to changes in prices, and values for all exogenous shift variables for simulated scenarios quantifying the effects of external shocks studied. Unavailability of up-to-date market parameters for most of the market levels, meant that most estimates had to rely upon subjective judgements.

Simulated scenarios with potential shocks leading to 1 per cent shifts of supply or demand curves were assessed to calibrate the EDM. This process is used to partially validate the model structure as a reasonable representation of the tea industry in Sri Lanka.

The EDM on the tea industry is then used in Chapter 8 to quantify corresponding welfare effects of exogenous shocks developed in Chapter 7 that resulted in displacement of supply and demand curves in market levels owing to the Government policy of banning Glyphosate.

Chapter 6 Qualitative Data Analysis of the Impacts of the Glyphosate Ban

6.1 Introduction

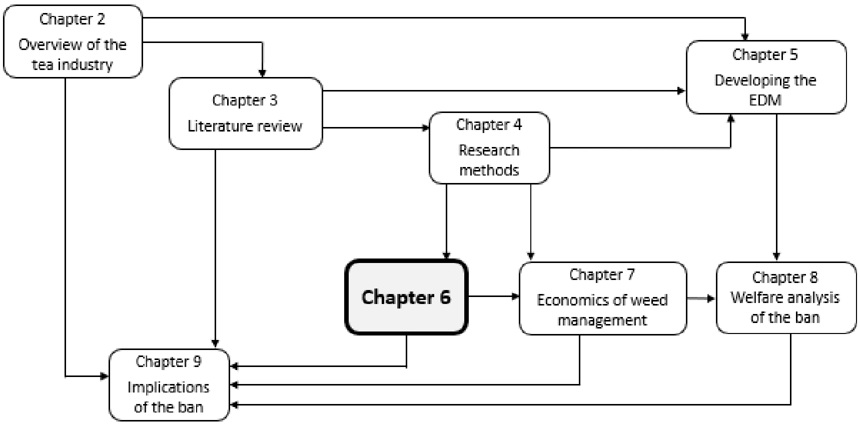


Figure 6.1. Flow of chapters in the thesis

In this chapter, the findings from detailed interviews with participants and stakeholders in the tea industry and information collected from government institutes working with the tea industry as discussed in Chapter 4 are reported. NVivo software was used in thematic analysis of interview data. While discussing qualitative findings from interviews and government documents, quotes from interview transcripts were used in text where necessary. A coding system was used to identify each interview when using extracts as supporting information in the text. The following table provides a guide on the coding system of interviews for easy understanding. Table 6.1 Codes used on interviews

Table 6.1. Codes used on interviews

Districts where participants from tea grower sectors and key informants belong to		Interviews with	
District	Code	Interviewee	Code
Rathnapura	R	Participants from the private grower sector	S
Galle	G	Participants from the estate grower sector	E
Badulla	B	Participants from tea manufacturing sector	M
Kandy	K	Participants from tea export sector	J
Nuwara Eliya	N	Experts	Ex
		Key informants from Sri Lanka Tea Board	SLTB
		Key informants from Tea Small Holdings Development Authority	TSHDA
		Focus group discussions with private growers	FGDS
		Focus group discussions with estate sector participants	FGDE

Except for interviews with experts and tea exporters, every other interview is coded as a combination of the district where the interviewees belong to and the code for the type of interviewee. In all cases, the code of an interviewee is followed by an Arabic numeral to represent that particular interviewee within that district or interviewee category.

Section 6.2 provides demographic information about the participants interviewed from the farm sector, the key market level under interest in the study. The following Section 6.3 describes about weed management approaches used in tea cultivations, followed by factors that affected switching between approaches with the Glyphosate ban in place in Section 6.4. The effects of chemical weed management during the ban are discussed in Section 6.5. Key findings from Sections 6.4 and 6.5 provide supporting information for Chapters 7 and 9 as shown in Figure 6.1. Sections 6.6 to 6.8 present issues faced by participants in key market levels along the value chain of the tea industry during the ban.

6.2 Demographic information about tea grower sectors in the sample interviewed

6.2.1 Size of tea landholdings

The private tea grower sector consists of both smallholders and medium scale tea growers who do not have tea processing facilities, hence rely on external tea manufacturers to process green leaf harvests into made tea. Tea smallholdings (as explained in Chapter 2) are landholdings below 10 ac in extent, whereas medium scale tea landholdings/estates are with tea cultivation extent above 10 ac.

In the primary data collection, the sample of private tea growers interviewed comprised 85 per cent of tea smallholders and 15 per cent of medium scale growers as shown in Figure 6.2.

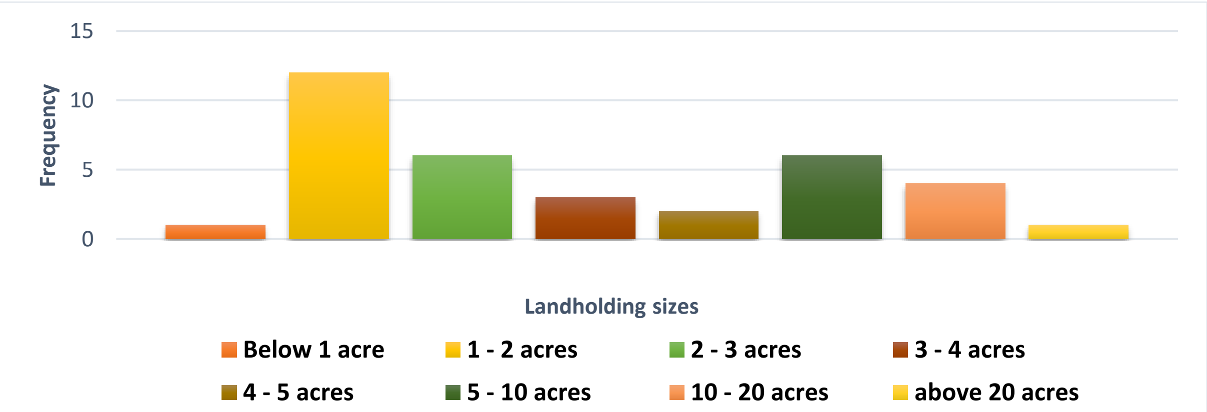


Figure 6.2. The distribution of private tea landholdings, based on the extent under tea cultivation, of interview participants. Source: Field data 2019

The distribution of these private tea landholdings across selected districts is shown in Figure 6.3. The major share of landholdings is from Rathnapura, Galle and Kandy districts.

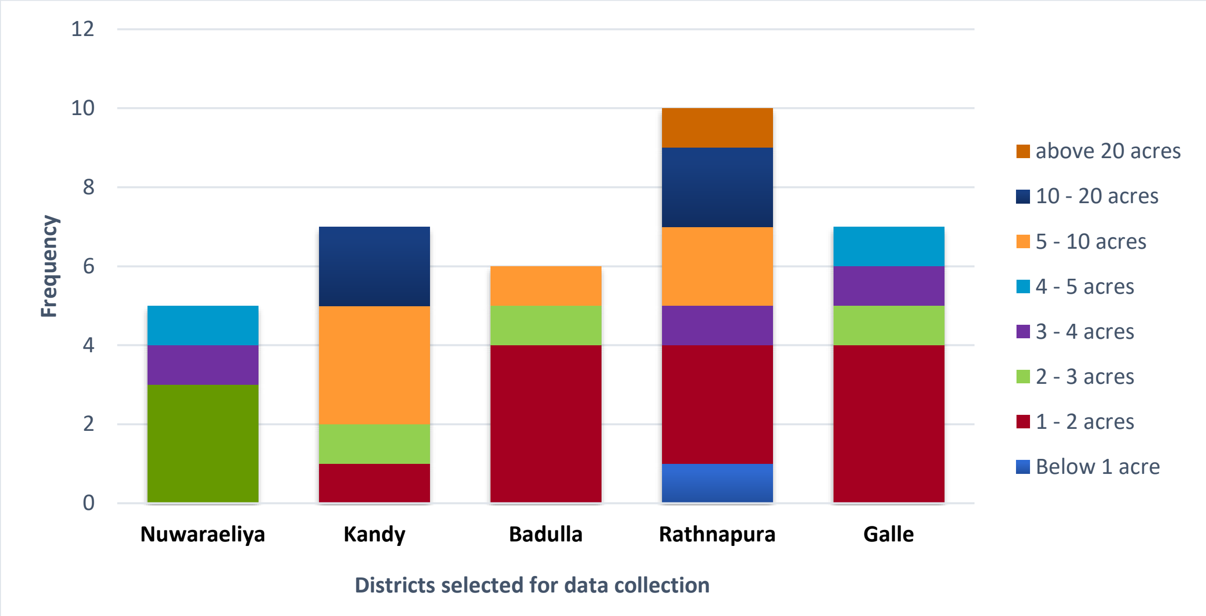


Figure 6.3. Distribution of private tea landholdings within selected districts of interview participants. Source: Field data 2019

Of the selected districts in the sample of tea landholders in the primary data collection, Galle and Rathnapura from the low country tea growing regions and Badulla from the Uva region consisted of the majority of smallholders with smaller cultivation extent below 2 ac, while Kandy from the mid-country tea growing region included the majority of larger land sizes above 5 ac belonging to private tea landholders.

Key informants from different tea growing regions discussed the distribution of private tea landholdings across the country. As highlighted by an expert, "*around 85 per cent of tea smallholders are concentrated in the low country tea growing region and nearly 25 per cent which is the highest proportion of them are reported from Rathnapura*" (Ex1). Referring to the private tea grower sector in Kandy district of the mid-country tea growing region, a key informant mentioned as "*70 per cent of landholders own an extent below 1 ac, 20 per cent own between 2 – 5 ac, while 10 percent own above 5 ac."* (TSHDAK1). A comparable situation was reported by another key informant from Badulla district that belongs to the Uva region in the country as "*a majority of 75 per cent of smallholdings are below 1 ac whereas five per cent are above 5-10 ac*" (TSHDAB2).

The distribution of the sample of interviewees from tea estates is presented in Figure 6.4. Estates were selected from Rathnapura, Badulla and Nuwara Eliya districts from Low-country, Uva region and mainly up-country tea growing regions, respectively.

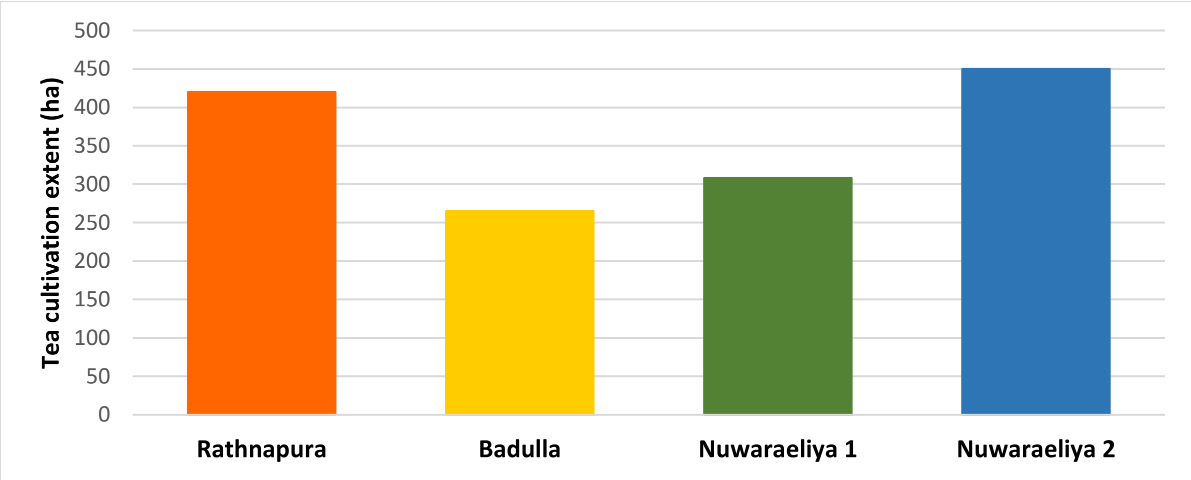


Figure 6.4. Distribution of estate landholdings within selected districts and their extent, of interviewed participants from the estate sector. Source: Field data 2019

Even with respect to the estate sector, the majority of estates from the sample were from Nuwara Eliya district. The sizes of tea cultivations in selected estates of the interviewed sample from the estate sector ranged between 250 – 480 ha as presented in Figure 6.4. In the estate sector, each estate consisting of several blocks of tea cultivations in different plucking stages, and maturity stages owned by a RPC is managed by an Estate manager with an assigned field staff and residential labour force.

As mentioned by tea growers and confirmed by experts interviewed stating "*around 98 per cent of tea smallholders have VP tea fields while 75 per cent of the estate plantations have tea fields cultivated with seedlings*" (Ex4). It was also noted that some low yielding seedling tea fields were being replaced by high-yielding VP tea varieties given that such cultivations were more than 100 years old that have undergone several pruning rounds and had many vacancies.

6.2.2 Engagement in tea cultivation

Tea is a crop that is quite labour intensive on field activities conducted to ensure an economically profitable harvest. Private tea growers interviewed in this study were a mix of full-time growers (54 per cent) and part-time growers (46 per cent). While most of the full-time growers were entirely engaged in tea cultivation related activities, part-time growers were involved in other types of employment. It was found during interviews that these part-time tea growers were engaged in other non-agricultural employment (69 per cent) and agricultural employment (31 per cent). Non-agricultural jobs included government jobs; teaching, businesses; village grocery store, concrete product manufacturing factory, gem cutting, hotel, hardware store. Part-time growers were employed in paddy farming, animal husbandry, vegetable and other crop farming, green leaf dealing, labour work, tea nursery plant sales and spice dealing related to agriculture.

Additionally, tea was intercropped by 80 per cent of private tea landholdings, with other crops such as pepper, cinnamon, coconut, and coffee. Harvests from these crops also have brought an additional income depending on their growth stages. Some estate holdings were also intercropped with other crops such as cinnamon in Rathnapura district and pepper additional to cardamom and mandarin as other crops in Badulla district giving extra income to estates.

Unsurprisingly, of the total private tea landholdings, nearly 90 percent had other sources of income, whereas 10 per cent was entirely dependent on the income from green leaf sales. Almost all part-time growers had other sources of income, and the majority of 43 per cent had their green leaf sales revenue that amounted to half of the household cashflow. Meanwhile, all full-time growers made more than 50 per cent of contribution to the household cashflow from green leaf sales, with a majority of 31 per cent making a contribution between 50-80 per cent.

Interview findings reflected that some full-time tea growers were retired government servants receiving a monthly pension, some had family members earning salaries, family businesses and so on.

Although it is not representative of the sample of farmers itself, key informants made general comments about the engagement of private tea growers in respective districts on other crop cultivations as also observed during the data collection. Hence, some crop cultivations had been unique to districts. For instance, there is a unique "*Kandyan Home Gardening System*" (TSHDAK2) in the mid country where landholdings often involved in cultivating spice crops such as pepper, clove, nutmeg, arecanut, cocoa, coffee etc., in the home garden, animal husbandry and paddy farming along with tea that unfolded the potential to earn an extra income for households in addition to the revenue from green leaf sales. Similarly, most landholdings or home gardens in the low country were either intercropped or cultivated with cinnamon and pepper. Referring to other crop cultivations and secondary income sources to households, a key informant from the low country tea growing region said that "s*ome areas in the Rathnapura district do animal husbandry, Kitul treacle production, floriculture, vegetable farming etc. along with the tea cultivation*" (TSHDAR2). Vegetable cultivation was also popular among growers in the Uva region and up-country tea growing regions as other crops cultivated in addition to tea.

6.2.3 Labour use in tea cultivation activities

Labour plays a critical role in tea cultivation as many of its activities including green leaf harvesting, fertilizer application, weed management are performed manually. The labour requirement in cultivation increases with the area under tea cultivation while the decision to hire casual labour also depends on the availability of family labour and the degree of contribution to the cultivation.

As discussed during interviews, 74 per cent of tea fields of private growers were managed by hired labour, 14 per cent were managed with both family and hired labour and 12 per cent had family labour only. All growers who used family labour only have had tea cultivations below 2 ac in extent, carrying out manual weeding only throughout the period studied. In fact, conducting manual weeding with family labour seems practical only to a smaller extent of cultivation. To manage weeds, the growers who were dependent on hired labour only for conducting tea field activities, 69 per cent had done chemical weed management at least once over the period under consideration while 31 per cent had engaged in manual weed management. Nearly 58 per cent of these landholdings hiring casual labour have extent above 3 ac, hence it is clear that managing the cultivation is difficult with limited family labour engagement.

Although estates were often managed with residential labour force, there were instances when extra labour was hired during some periods of the year, especially during the rush crop season in estates when labour shortage is experienced severely. This was reported in two estates interviewed. The management of the estate sector constitutes of the estate manager, assistant estate manager, field officers and labourers. There is a separate office staff to deal with administrative work in the estate and record keeping.

It was observed in the private tea grower sector that some growers had their cultivations in a different location to where they live. Most of the smallest blocks of tea cultivations of a few perch or below 1 ac were located at the vicinity of the home garden of the landholder. However, there were cultivations with landholdings above 1 or 2 ac which were located within the same household. Usually, cultivations above 1 ac to 20 ac, the owner lived in a different location, ranging from a few kilometers to 40 kilometers from the tea landholding. They were mostly full-time growers who hired casual labour on a daily basis or employed permanent labour to work in such cultivations. It was highlighted during interviews that the role of tea landowners with considerably large land sizes varied across landholdings; they were either engaged in a supervision role only - many part-time growers- or working field activities along with labourers - mostly full-time growers.

On the other hand, the estate sector plantations that had extents more than 200 ha under a single management company consisted of several blocks of cultivations within the estate. In addition to tea cultivations and the estate-owned tea processing factory, a typical RPC owned tea estate is composed of all components a community setting encloses such as housing of the residential labour, estate bungalow of the manager, office, hospital, pre-school, school, religious worship places, post office, grocery stores, road network developed for estate vehicles and public transport services as observed during the data collection. Every aspect of a lifestyle was supplied ensuring proper welfare of the labour force within an estate regardless of the high implicit costs of providing all these facilities.

Interview findings

6.3 Weed management approaches in tea cultivation

Several aspects of weed management in tea cultivation, including how weeds appear, the need for and importance of weed management in fields and approaches involved were discussed with experts and key informants during interviews. As explained by an expert related to weed growth in tea cultivations, "*weeds grow when the ground is exposed to sunlight providing the factor which has been lacking for its growth. Therefore, the basic logic behind minimizing weed growth is avoiding ground exposure as much as possible by maintaining a good canopy*" (Ex4).

The requirement for weed management in tea cultivation arises during times when ground exposure is highest; "... *in new clearings-until first 2 years after uprooting and planting, and after pruning until bush canopies are formed"* (TSHDAR1). Additionally, "t*he productivity of tea bushes reduces after 12 years of age on average and then casualties occur at a higher rate bringing up the need to control weeds*" (Ex1), *"tea bush casualties can take place with pruning due to injuries, improper maintenance etc.*" (Ex2). When causalities are not infilled as a post-pruning practice, it eventually ends up in vacancies in the tea bush stand. Consequently, "*frequent weed management becomes a vital routine practice with increasing vacancies to keep the weed density below the economic threshold level*" (Ex4). They also expressed their knowledge on achieving minimal weed growth by "*avoiding ground exposure as much as possible by maintaining a good canopy*" (E4) through "*in-filling vacancies and proper management of the field*" (TSHDAN1). Economic losses from weeds can be minimized by managing weeds below ETL and avoiding ground exposure to sunlight.

However, vacancies can often be found in tea cultivations in both sectors at varying degrees. According to an expert, "*the problem of vacancies is severe in larger plantations than smallholdings"* (Ex4). While a key informant mentioned that "*many growers do not practice infilling*" (TSHDATIK) referring to the private grower sector, it was revealed during interviews that they also have a considerable number of vacancies in their field.

Another aspect that many respondents mentioned was the importance of weed control in the field. A key informant stated "*if weeds are not managed properly in the field it can lead to severe losses in production and interfere with field activities eventually affecting the overall productivity"* (TSHDAG2). Hence weed management is a crucial activity that should not be neglected in tea cultivation.

Weed controlling approaches that are frequently practiced in tea cultivations by the grower sector were highlighted by an expert as "*manual, chemical and cultural approaches*" (Ex1). Manual and chemical approaches help maintain weeds below the ETL while cultural methods ensure minimal ground exposure and weed growth up to the ETL.

In the following sections the main weed management approaches adapted by the tea grower sectors and reasons for their selections, as explained by interview participants, is identified and outlined. The opinions of respondents were based on their experiences gathered by working in the field with tea grower groups and observations.

6.3.1 Manual weed management

Manual weeding is practiced either as a weed management approach exclusively or combined with weedicide application rounds in chemical weed management. It includes non-chemical weeding methods such as "*hand pulling", "slashing and scraping with hoes [blades, knives and grass cutters/machinery]"* (BE1).

Interview respondents also highlighted methods that were best suited in their cultivations within tea bushes and boundaries. Hence, the approach can involve manual and mechanical methods, and can be undertaken exclusively by one method or as a combination depending on the situation based on availability of vacancies, type of weeds etc., where "*weeds such as Panicum grass must be manually removed either by uprooting while other soft weeds can be scraped or slashed"* (BS1).

A key informant said that "*methods recently practiced by many smallholders under manual weeding were using grass cutters to slash weeds along boundaries, scraping and hand weeding within tea bush rows"* (TSHDAN2). The same view was reflected in practices followed by many private tea growers;

"w*eeds are scraped in between drains and uprooted within tea bushes"* (GS6). In fact, manual weeding that involves uprooting has been widely recommended within tea bushes over other methods, as "*slashing with blades or machinery can damage the tea bush trunk and cause injuries*" (TSHDAK2), while scraping *".... encourages loss of topsoil and lead to soil erosion*" (Ex1) "*especially during the rainy season*" (KS4) and "*leaves stem parts and roots of weeds in the soil that would grow later"* (TSHDAK2). Growers tend to do manual weeding by uprooting entirely in the field including boundaries when there are not many vacancies in the bush stand. This was explained by a grower as *"there is not much of a need for weed controlling within tea bushes as vacancies are minimized, manual weeding is done only along boundaries and drains*" (NS5). However, in cases when there are large patches of exposed land with weeds due to too many vacancies, growers tend to practice weed slashing in fields, whereas both uprooting within tea bushes and slashing along boundaries were also practiced together depending on the situation as mentioned. Boundaries and drains were weeded by scraping or slashing mostly, although they were not recommended.

6.3.2 Chemical weed management

The use of weedicides in tea fields depended on the availability of vacancies, and weeds in the field, within tea bushes and along boundaries as described by tea growers and key informants. Similar views were echoed from a key informant as "w*eedicides must be actually applied not to the tea fields but to the boundaries and roadsides."* (TSHDAR1) and a private tea grower as "w*eedicides are applied only in the cases where necessary; in places with more vacancies etc. otherwise applied to boundaries, roadsides*" (RS10). However, some growers have chosen to apply weedicides within tea bushes in older tea fields with too many vacancies in addition to boundaries, although it is not recommended because of the toxicity of chemicals. In general, the practice is "... to *spray weedicides carefully avoiding tea bushes"* (NE4).

As per the practice of tea growers, chemical weed management could take two approaches that may or may not involve supplementary manual weeding in addition to chemical weeding rounds. Chemical weed management decisions of smallholdings can involve either carrying out only chemical weeding rounds or both chemical and supplementary manual weeding rounds alternatively depending on the choice and situation – type of weeds available in the field, efficiency of weeding methods etc. Referring to using supplementary manual weeding rounds following weedicide applications a grower mentioned "i*n between chemical rounds, sometimes manual weeding was done to remove weeds not destroyed by chemicals*" (KS7).

6.3.3 Cultural and preventive approaches

Cultural and preventive approaches are practices that are often carried out in tea cultivations in addition to manual and chemical weed management approaches. A few growers mentioned some frequently practiced cultural methods included "*placing tree lopping and other plant material as mulch"* (RS4 and BS1), *"planting vacancies with Tithonia (Wild Sunflower) plants or tall grasses*" (NE1) to avoid ground exposure, "*uprooting and scraping weeds before the flowering stage and leaving them in the field which will add green manure to the soil and act as a mulch at the same time*" (NS5), and "*leaving soft weeds in the field during the drought season to helps retain moisture in the soil*" (NE4).

6.3.4 Distribution of private tea landholdings based on weed management approaches before and during the ban of the interview respondents

All private tea landholdings and estates in the study were classified based on two main weed management approaches adopted before and during the ban. Types of weed management approaches found from interview findings were (i) manual weed management and (ii) chemical weed management. Non-chemical weed management will be used interchangeably with manual weed management from here onwards.

A representation of the distribution of private tea landholdings based on weed management approaches adopted before and during the ban on Glyphosate is depicted in Figure 6.5.

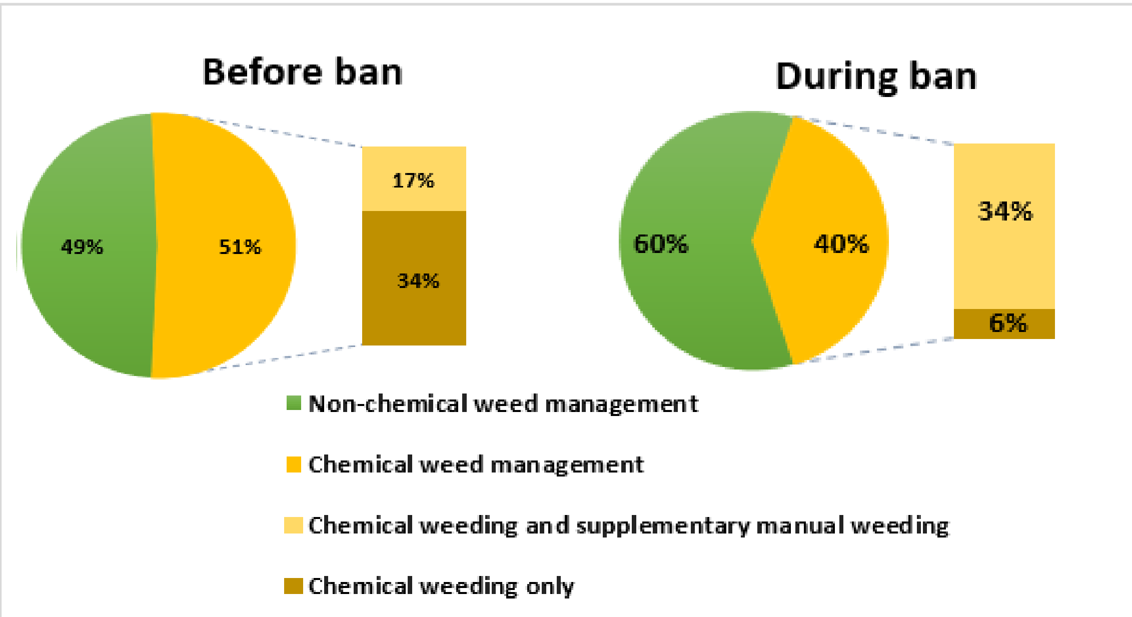


Figure 6.5. Weed management approaches conducted by private tea growers in the interviewed sample before and during the Glyphosate ban. Source: Field data 2019

The sample consisted of nearly equal proportions of private tea landholdings engaged in chemical and manual weed management with respect to the period before the ban on Glyphosate was imposed. Out of the total private tea landholdings 51 per cent have engaged in chemical weed management, which constitutes of 34 per cent that carried out chemical weeding rounds only and 17 per cent of landholdings that used both chemical and manual weeding rounds alternatively within a year. The remaining 49 per cent have not used chemicals for weed management in their tea fields, instead have carried out manual weed management.

During the ban with restrictions on Glyphosate use, the majority of 60 per cent of interview respondents practiced manual weed management, while 34 per cent carried out chemical weeding with supplementary manual weeding and the remaining 6 per cent of growers used chemical weeding rounds only. In general, sample data suggest an increase in landholdings practicing manual weed management and a decline in landholdings engaged in chemical weed management during the ban with respect to prior to ban imposition.

Substantial changes have taken place during the ban with an overall decline of 11 per cent in landholdings practicing chemical weed management approaches before the ban with a reduction and increase in landholdings carrying out chemical weeding only and chemical weeding with supplementary manual weeding, respectively. Further study of data indicates that out of the total 12 landholdings that have used only chemicals for weed controlling before the ban, only two have continued the same approach while six landholdings have continued chemical weed management with supplementary manual weeding throughout the period. Hence, there is a notable fall in the proportion of landholdings that have carried out chemical weeding only by 28 per cent, with almost 50 per cent increase in tea landholdings that have practiced supplementary manual weeding rounds along with chemical weeding rounds during the ban on Glyphosate. This suggests that growers who had been using weedicides only for weed management have incorporated manual weeding rounds to their chemical weed management schedule during the ban.

Turning to the other grower sector, unlike private tea landholdings, those interviewed from the estate sector have adhered to the same weed management approach with the ban in place. All tea estates in the interview sample that consisted of more than 200 ha of tea under cultivation have practiced both chemical and supplementary manual weeding across two periods - with and without the Glyphosate ban. Even though it was not mentioned explicitly, some responses during interviews revealed that almost all of them had used either illicit Glyphosate products and/or other weedicide alternatives to manage weeds with varying degrees of labour engagement on manual weeding.

In the next section, weed management choices of tea growers before and during the ban on Glyphosate by the grower sector and factors that influenced decisions by investigating their demographic data and responses provided during interviews as reasons for such decision making supported by their arguments and perspectives are discussed.

6.4 Choice of weed management approaches in tea cultivation

There are some common factors that decisionmakers in tea cultivations pay attention to when choosing weed management approaches, although *"weeds are different across fields, therefore weed management approach changes*" (BE1). Weather is considered one of the critical factors regarding the decision on the weed management method within a given period. In the integrated approach that combines chemical and manual weeding, "c*hemical weeding rounds are mostly practiced during the rainy season and manual weeding rounds in the dry period*" (KS3). This is because "*weed growth rate is high during the rainy season and low during the drought*" (NE4). Other main factors influencing the decision to adopt weed management approaches in the field such as financial status, labour availability, efficiency etc. are discussed under each approach.

6.4.1 Choice of non-chemical weed management

Data from the sample suggested that 43 per cent of private tea growers practiced non-chemical weed management throughout the period. As per their demographic information about them, 52 per cent were engaged in tea cultivation full time tea, and 70 per cent managed cultivation extent below 3 ac. The majority of 77 per cent have hired labour and the rest 23 per cent depended on family labour for tea field activities. These findings suggest that manual weed management could have been a choice for many full-time growers with smaller cultivation extent. Despite the challenges faced by the grower sector, such as labour shortages and increasing wage rates, such smallholders have hired labour on manual weeding because of the labour intensiveness and not enough contribution from family labour as explained during interviews. An explanation provided for this was that their choice of manual weeding depended on their financial status of them and having no issues with spending more on labour as there were other income sources to the household cashflow, or labour shortage and finding labour was not too difficult for them.

Tea growers' perspectives highlighted during interviews as reasons for choosing manual weeding can be related to information reflected from demographic data. Some tea growers' decision to practice manual weed management was dependent on *"availability of family labour*" (RS2). During a focus group discussion, smallholders agreed on the same view by affirming "*landholders with extents below*

1 ac manage field activities including manual weed management using family labour" (FGDB1). Added to that, "f*ulltime tea growers tend to spend most of their time in the field and engage in weeding and other field activities on a daily basis"* (FGDR2). It seems possible based on growers' opinions that it is reasonable to do manual weeding in small patches of cultivations under fulltime engagement, family labour or less labour units.

Another factor that encouraged manual weed management among growers has been young/new or well-maintained tea fields with fewer vacancies. A smallholder's explanation on conducting manual weed management was "...*there is no need of an intensive weed management in between rows when a good coverage in tea bushes is maintained in the tea fields*" (RS7) as the requirement for weeding within tea bushes is minimal when there are least vacancies. An interesting opinion pointed out by respondents about this factor that "t*here would not be a loss in spending on labour for manual weeding in young and well-maintained, tea fields with less vacancies in as they give a better harvest*" (RS3), which can ensure a favorable income in return.

Many tea growers who practiced manual weeding, avoiding chemicals, explained that their decision was influenced by effects of weedicide application on the environment, soil, and tea bushes. Growers had several arguments such as "... *not spraying weedicides on young tea fields*" (GS4)," trying *to be environmentally friendly by never applying weedicides to the cultivation,*" (BS2), "*not applying chemicals in the tea field because of the concern on the environment, health of the tea bush, health of labourers applying weedicides and destruction of innocent weeds in the tea field that form a good ground cover*" (RS4) that encouraged non-chemical weeding in tea fields.

6.4.2 Choice of chemical weed management

All private growers in the sample who used weedicides in weed management in cultivations, applied Glyphosate before its ban and hired labour for management practices in fields including weeding. The engagement of these growers in tea cultivation was equally distributed within the sample with 50 per cent being full-time growers and the remaining being part-time growers. Nearly 40 per cent of growers' cultivation areas were above 5 ac, while another 40 per cent ranged below 3 ac. Data on the sample of private tea growers suggest that they used chemicals regardless of the area in their tea cultivation. The distribution of areas managed by private tea growers in the sample who used weedicides in weed control ranged between 1 ac and above 20 ac. Of them, 89 per cent depended entirely on hired labour, while the remaining 11 per cent on family labour and hired labour.

Regarding changes in weed management decisions of private landholdings during the ban, 66 per cent of growers continued with chemical weed management while 33 per cent have switched to manual weeding. This is discussed further in Section 6.4.3.

Unlike in private tea landholdings, data from the estate sector showed that all estates in the sample engaged in chemical weed management with supplementary manual weeding throughout the period with Glyphosate before the ban, and alternative chemicals during the ban.

It was found that there was a significant use of Glyphosate on tea cultivation in the grower sector before implementing the policy restricting its use. Similar findings were repeated in interview responses about Glyphosate use from several respondents as *"Glyphosate was the most popular weedicide used in tea fields before the ban was implemented"* (SLTB2) while, "m*ore than 50 per cent of smallholders [private growers] used Glyphosate [in chemical weeding], although it was not reported*" (Ex3).

Chemical weeding that included weedicides such as Glyphosate mainly, and other alternative weedicides have gained much attention and acceptance by tea growers because of several reasons as suggested during interviews. A major argument was cost involved in weeding explained as *"...the use of Glyphosate and other weedicides incurred the low cost with respect to manual weeding with labour*" (FGDR2), such that "*manual weeding is a huge cost for those who hire labour daily*" (K5) and "*growers were using Glyphosate as a cost-effective method"* (RS5). Agreeing with growers' opinion, a key informant described that "*the substitution between chemical and non-chemical approach of weed management in smallholders depends on the cost on labour and the profit most of the time,*" (TSHDAR2). Many respondents believed that weedicides, including Glyphosate, offer better solutions for reducing costs *"decreasing yields from fields, lower prices received for green leaves and eventually the low income and profit have not encouraged manual weeding*" (KS5).

Labour-related issues

Labour use and cost (labour shortage and increasing wage rates) in weed management were highlighted as challenges that influenced weed management decisions of the private grower sectors over years by many respondents during interviews. A key informant mentioned that "l*abour shortage is the biggest challenge faced by the tea industry currently. Because of the same reason, there was a high tendency of smallholders located in tea growing regions to use Glyphosate*" (TSHDAG1). A private grower shared experience as "*many smallholders regardless of the landholding size apply chemicals for weed controlling because of labour shortage, convenience and excessive cost on labour*" (GS5).

Some substantial reasons for labour shortage and wage rate related factors that have influenced less labour-intensive approaches in weed management such as chemical weeding were explained by respondents. A graphical representation developed with the NVivo software on reasons leading to chemical weed management options in tea cultivations is presented in figure 6.6.

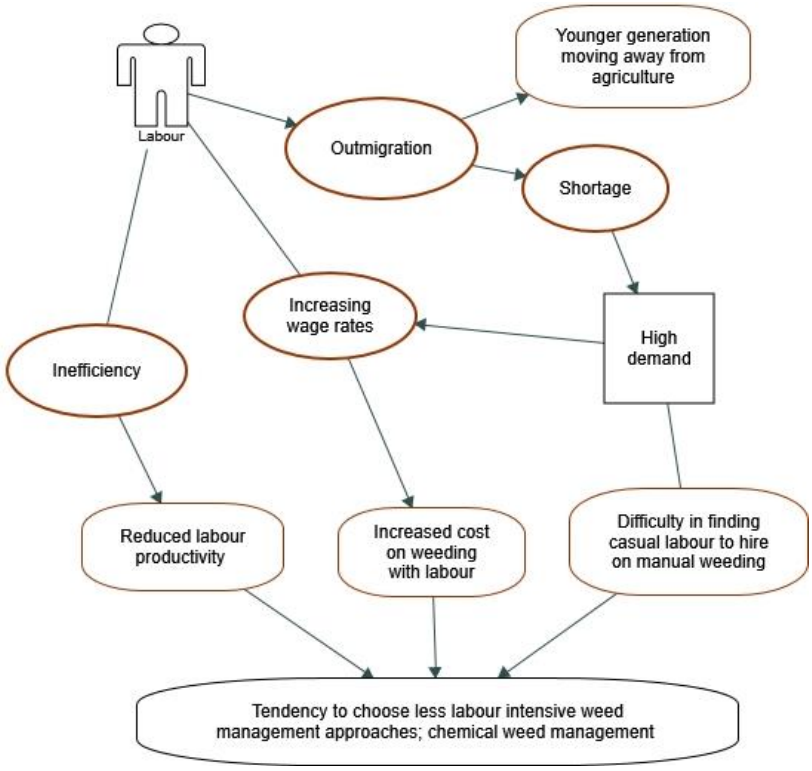


Figure 6.6. Labour related issues affecting the choice of chemical weed management approaches. Source: Field data 2019

As depicted, labour outmigration to non-agricultural sectors has resulted in a severe shortage that has in turn resulted in high demand and increasing wage rates. Owing to inefficiencies in the existing labour force consisting of an older population apparently, this has led to lower labour productivity, while escalating labour wage rates and increased weeding costs forced growers to use less labour-intensive least cost weeding operations.

Decisions about chemical weeding was also influenced by the availability of vacancies in aged and seedling tea cultivations. The view of a grower on this was that "w*eed controlling is problematic in seedling tea than VP tea. Seedling teas can end up in many vacancies in the tea field than VP teas. Weedicides were used since labour costs on manual weeding were unaffordable*" (NS3). Similarly, "*many smallholders tend to use chemicals for weed management as the tea cultivation gets older, with many vacancies eventually leading to production losses"* (GS4) eventually trying to minimize costs. Tea fields with many vacancies and seedling teas can eventually lead to a low harvest and productivity.

An argument raised by tea growers who chose weedicides over other manual methods on weed control was explained by a key informant as "*mechanical methods such as scraping encourage soil erosion by destructing the soil structure. Some growers dig the soil up to a depth of 2 inches or more for weed controlling and with heavy rains, loose soil tends to erode removing the topsoil layer in tea lands*" (TSHDAB1).

The decision on the weed management schedule in tea fields is either to do chemical weeding rounds only or incorporate supplementary manual weeding rounds with chemical weeding rounds. One respondent explained that it depended on the situation as "*the field is left unattended for 1-2 months when hard weeds are manually weeded, and chemical application is done when soft weeds start emerging"* (NE1). It was found that this is the usual practice in chemical weed management although the undergrowth of soft weeds is destroyed adversely affecting the soil microclimate.

The ease of using chemicals over employing labour on weeding was emphasized as an advantage, so that "*there is a demand for weedicides because of the convenience of using them with fewer labour units, while weeding can be completed within a shorter period than manual weeding making chemical weedicides more popular among growers*" (SLTBR2). This has been the case for many growers *"weedicide use became popular and much convenient when wage rates of labour spiked, and labour shortage was severely experienced*" (GS5).

Again, in contrast to the private tea grower sector, the estate sector had no/limited choice between manual and chemical weed management approaches as "*Every estate is allocated with a budget at the beginning of the year by the company management, and estates must operate within that. Decisions on field activities depend on the budget"* (NE2), hence *"weedicide use on weed control is essential in estate plantations because of the limited budget allocation on the tea upkeep. Weed management with only manual weeding using labour is not a sustainable choice on estate budgets as it is not affordable at all*" (RE1). In general, the estate sector is therefore left with only chemical weeding approaches when adhering on to company policies in addition to the large area under cultivation.

6.4.3 Choosing weed management approaches during the ban

Restriction on Glyphosate use in tea cultivations has resulted in several changes in weed management approaches across landholdings. While some growers continued with the same approach throughout, some growers had to shift to other approaches and adjust their practices as discussed in next sections.

A key informant's understanding about weed management strategies adapted during the ban was "...*small extent did manual weeding using family labour, but for considerably large extent including estates, used alternative chemicals or abandoned tea fields without controlling weeds because of unbearable weeding costs with manual labour only*" (SLTBK1).

Non-chemical weeding approaches

Based on the data from interviews, 43 per cent of private tea growers carried out manual weed control throughout the period, regardless of the ban in place. Most of those growers depended on hired labour for field activities and had a significant contribution from the revenue from green leaf sales to the household cashflow (93 per cent had more than 50 per cent contributions to their total incomes). Furthermore, over 60 per cent had smaller cultivation areas which were 3 ac or less, with the majority falling under 1–2 ac category. This implies that in the sample, manual weeding had been practiced to a smaller extent. During interviews with these growers, it was clear that the Glyphosate ban had the least effect on their business because they used minimal to no chemicals. However, all interview respondents were aware of the ban in place and difficulties experienced by other smallholders.

The tea landholders in interviews, who switched from chemical to non-chemical weeding approaches, had several similarities:

- the contribution from income from green leaf sales to the household cashflow in all these growers ranged below 80 per cent, with a majority of 50 per cent contribution.
- the dependence on hired labour for field activities has been common across all those landholdings.
- all these landholdings had area below 10 ac, with almost half of them managing below 3 ac of cultivation. Data suggests that the decision about shifting to manual weeding has been made by those with other income sources and no family labour involvement– ability to afford increasing costs of hired labour, but with manageable extents under cultivation.

According to interview responses, the increase in non-chemical weed management approaches during the ban can be explained, this approach complements the decision to switch between chemical and non-chemical weed management approaches during the ban.

An in depth investigation of responses from tea growers who decided to switch to manual weeding regardless of the cost of escalating labour wage rates and labour shortage over years revealed that main reasons were "*no promising/effective alternative to Glyphosate in the market*" (BS5) or *"... because Glyphosate was available in the market"* (BS2), not having access to chemical alternatives etc., and *"available chemicals being very much harmful on the soil and environment*" (GS1). It was revealed that "*the powder [alternative to Glyphosate] was used for a couple of times, was too strong that weeds did not appear at all. Thereafter, it was not applied, and manual weeding was done instead"* (GS7). Manual weed controlling methods they practiced during the ban in the absence of Glyphosate included manually uprooting weeds, scraping, and slashing as explained already in Section 6.3.1.

Chemical weed management approaches

Data on tea growers' choices on weed management approaches before and during the ban showed that 34 per cent of private growers and all estates continued with chemical weed management approaches throughout the period.

Alternative weedicides

A critical factor that influenced growers' choice on weed management approaches during the period of Glyphosate ban found during interviews was the availability of alternative weedicides. Respondents disclosed that there were alternatives to Glyphosate available from informal sources available in addition to recommended weedicides "t*he market was flooded with illegally imported Glyphosate from Tamil Nādu, India sold under different brand names. and they have not been tested for chemical compositions"* (Ex3). Referring to such informal Glyphosate products, an expert mentioned "t*he weedicide in powder form that has been used by tea growers during the ban period is totally unofficial, has not been tested by the TRI or any responsible authority*" (Ex1). Such imported Glyphosate products were apparently not meeting required standards as described *"*t*he recommended concentration of a registered product of Glyphosate to be sold was 36 per cent formulation, but what was found during the ban was 75 per cent concentrated and highly toxic"* (Ex3). As reported, there had been instances where "*... there were Glyphosate products in the black market at higher prices which have been apparently diluted by distributors*" (TSHDAN2).

Growers who used such illegal Glyphosate products mentioned that *"... products were available both in powder and liquid form. They were expensive; two three times costly than the price of Glyphosate before the ban*" (RS1), and "*most of those products came under several brands did not have a proper label on the bottle/packet with instructions on application*" (KS3). Not all private tea growers had access to such illicit products as *"products were available in local agro-chemical stores where dealers sold them only to their most trusted and regular buyers informally"* (TSHDAK2). Speaking about having access to informal Glyphosate products, an estate manager revealed that "m*any agents introduced different forms of Glyphosate, but they were all adulterated and expensive"* (RE1).

Tea growers interviewed in this study have used several other types of alternative weedicides such as Diuron, MCPA, Glufosinate Ammonium and cocktail mixtures of these chemicals. Their argument was that such alternative weedicides would be toxic, but still more cost-effective than manual weed management "*Basta [Glufosinate Ammonium] which is a red label product was used during the period of the ban as the cost of applying MCPA and Diuron was high, but still was cheaper than manual weeding*" (NE2). Key informants explained about the use of alternative weedicides as "*even during the ban there were Glyphosate supplies and had the highest demand regardless of the quality. Buyers' next choice would be alternatives such as Diuron and MCPA in case if they were not available*" (TSHDAB2) and "w*hen some of the weedicides were not effective, smallholders started mixing other substances and made cocktail mixtures, were very toxic*" (TSHDAR2).

During the interviews, the owners and managers of the estate sector often were not prepared to respond about the use of Glyphosate from informal sources in their estates unlike private tea growers because of confidential nature of their management policies saying *"there were many chemicals in the black-market replacing Glyphosate. Smallholders used such chemicals from informal sources, but RPC did not have permission to buy them"* (NE2). However, some estate sector management admitted that they used illegal Glyphosate along with other chemicals saying "*Some RPC estates might have used illegal Glyphosate coming from the black market. RPC estate budgets must be transparent. In that sense, the management cannot decide to go for illegal Glyphosate or other chemicals beyond the pre-allocated budget. However, some companies might have altered some costs to make the use of illegal modes of chemicals less clear in the budget*" (NE2). An expert also confirmed "*even plantation companies have used such illegal Glyphosate products. They were bought as foliar nutrient, just because they were illegal*" (Ex3). This was further explained as "*many estate holdings too used illegal Glyphosate and it has not been mentioned in their records. Smallholders used illegal Glyphosate informally without others knowing, and it had been easy for them because of not maintaining records as estates did"* (Ex1). It was found that considerable proportions of private tea growers have used illicit Glyphosate products based on findings from growers "*Around 20 – 25 per cent of smallholders in this area must have used illegal Glyphosate during the period of the ban"* (FGDR2).

It was noted that while the estate sector management was aware about types of alternative weedicides used, users in the private grower sector did not have adequate knowledge about the type of chemical they've used in their tea fields. It was revealed that they relied on advice from agrochemical dealers for alternatives, and even the way of using chemicals in the field.

Inefficiency of alternative weedicides relative to Glyphosate

Respondents shared their experiences of using alternative products in cultivations. Their biggest concern was the inefficiency and toxicity of alternative weedicides with respect to previously used Glyphosate. An elaboration to this issue was given by a key informant to this "*the composition or concentrations of these illegal Glyphosate mixtures were unknown. Some of illegal Glyphosate products were of low quality, not as effective as the previous one, while some chemicals caused damages to tea bushes*" (TSHDAK2). Growers explained that as "*During the ban Diuron and MPCA cocktail was also used in the same frequency as Glyphosate. But it did not kill some grasses, while bushes were affected"* (RS9) and "*There were several tea bushes exposed to the drift of alternative chemical sprays and started dying. This did not happen with Glyphosate applied earlier*" (RS10). This has been common in the estate sector also as findings expressed "*during the period of the ban Diuron was used (liquid and powder) according to the correct dose, but it was not as effective as Glyphosate"* (NE4). Respondents revealed that there had been instances when private growers applied higher doses of weedicides, because they were inefficient, despite recommendations. Tea smallholders admitted to using higher than recommended weedicides "*illegal Glyphosate or other alternative chemicals were not effective even though the dose was doubled*" (RS10). The estate sector was found to be following recommendations when applying weedicides as such activities were carried out under frequent supervision.

Even though chemical weed management was the only workable choice for the estate sector, the private sector has had other weeding options to choose from. However, their decisions to continue the chemical use during the ban regardless of the above-mentioned concerns were influenced by critical conditions in the cultivation. During interviews, growers justified their decision to use illegal Glyphosate products stating "*without previously used Glyphosate, the weed density increased to an uncontrollable level. Therefore, had to use illegal Glyphosate bought from the market*" (KS3) and *"illegal Glyphosate coming from India was used to a certain extent because estates could not be managed with the weed pressure, otherwise fertilizing had to be stopped for a while"* (RE1). As explained by a key informant, growers had been desperate on managing their cultivations with no Glyphosate "p*eople who had the access to such informal sources of Glyphosate had bought Glyphosate to save their tea fields from the increasing weed pressure, knowing about this illegal action*" (TSHDAK2).

Findings from interviews showed a large proportion of landholdings that carried out only chemical weeding shifted to integrated weeding with chemical and supplementary manual weeding rounds. It was implied from demographic information about the sample that decisions to include supplementary manual weeding rounds with chemical weeding rounds were mostly made by landholders that hired casual labour for field activities and the majority earned income from green leaf sales that contributed to more than 50 per cent of the household cashflow. The distribution of cultivation area within landholdings was average, ranging within 1-2 ac to 10-20 ac, according to the sample. The main concern of tea growers, which influenced a change in the weed management approach, was the inefficiency of chemicals described as "*such [alternative] chemicals were not as effective as Glyphosate used before the ban*"(GS7). The majority of those who had used alternative weedicides complained about inefficiencies of such chemicals compared to the efficiency of Glyphosate. It was explained as "*Diuron was not highly effective especially on grasses but destroyed some broad-leaved weeds in the field*" (RS3).

Demographic data about private tea landholdings who continued with both chemical and manual weeding revealed that many of them were part-time growers managing areas above 5 ac with hired labour and receiving income from green leaf sales that amounted to above 50 per cent of the household income. Private growers who relied only on weedicides to control weeds before and during ban had smaller areas under cultivation that ranged between 1-2 ac. Interview findings revealed that these growers' decisions were influenced by the threatened situation in tea cultivations with uncontrollable weed growth interfering with other field activities, availability of alternative chemicals in the market and having access to them, reluctance to switch to manual weeding approaches due to excessive cost of labour, and convenience as discussed above.

6.5 Effects of the ban on the farm sector

6.5.1 Effects of continued use of chemical weed management during the ban

Costs associated with chemical weed management during the ban on Glyphosate use and before its ban are graphically depicted in Figure 6.7. As discussed in earlier sections, growers had used high priced illegal Glyphosate products from the black market, other recommended alternative weedicides to Glyphosate that were also expensive, or cocktail mixtures prepared by mixing various chemicals. Tea growers said the use of such chemicals with unknown formulations and concentrations in doses different from the recommended amounts even though they were inefficient and toxic than Glyphosate caused further costs and problems.

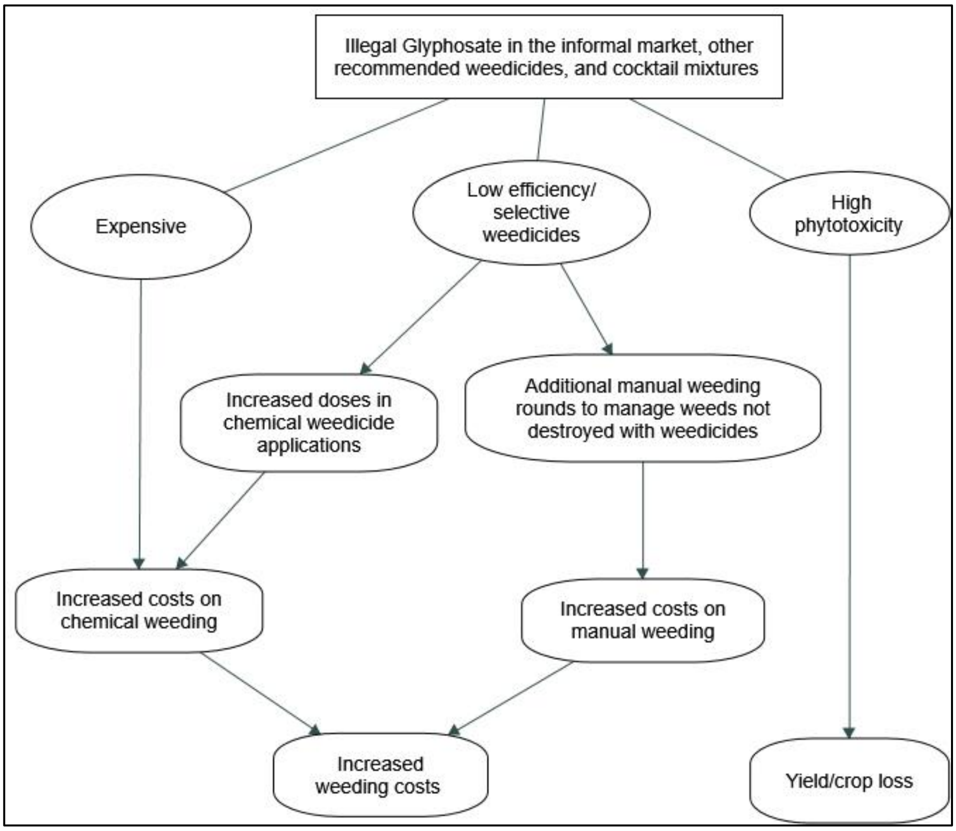


Figure 6.7. Use of weedicides during the ban and its effects. Source: Field data 2019

Alternative weedicides were not as effective as Glyphosate and caused additional weed management measures. Key informants shared their experience about how tea growers coped with the inefficiency as "*during the period of the ban, those who have used illegal Glyphosate have conducted manual weeding rounds also*" (TSHDAN2). It was found that all growers who continued chemical weeding during the ban used illegal Glyphosate products and just over half of them argued that they had to carry out additional rounds of weeding, and employing more labour to compensate the inefficiency and total increasing labour costs on weed management. Many growers explained that they needed to have additional manual weeding to control weeds that were not destroyed "*When alternative chemicals could not be found in the market during some times, slashing and uprooting were practiced in the tea field*" (KS5), "*as those alternatives were not effective, weed density during that time was quite high. Therefore, extra labour was allocated for manual weeding to remove such weeds and for weeding creepers and grasses within tea bushes*" (FGDR1) and *"… because of the inefficiency, about 3 rounds of manual weeding were conducted in between 3 chemical applications*" (GS7), eventually leading to escalated budgets on weeding.

Toxicities of such chemicals was the other major concern experienced by growers. Phytotoxicity developed in tea bushes as effects of continued chemical use was explained by an expert as *"chemical drift, root absorption of such chemicals and resulting in stem cankers. Applying higher doses leads to weakening of tea bushes and being susceptible to pests, diseases and drought. Weak plants when undergo stress conditions tend to die*" (Ex2), "*Diuron which is a quite popular weedicide in large plantations during the ban, can reduce transpiration in tea leaves and influences the performance of the plant*" (Ex5).

Growers described such phytotoxic effects in their cultivations *"there were several tea bushes that were exposed to the drift and eventually died. This did not happen with Glyphosate applied earlier*" (RS10) that could result in production losses in the cultivation, not only in the short-run but also in long-run.

The overall effects of banning Glyphosate on the farm sector are depicted in Figure 6.8. As outlined in the above sections, landholdings including private and estate growers that conducted chemical weed management experienced direct impacts in terms of increased weeding costs and yield losses. As highlighted, the black market supplying unregulated chemical products led to multiple unintended consequences as discussed in section above.

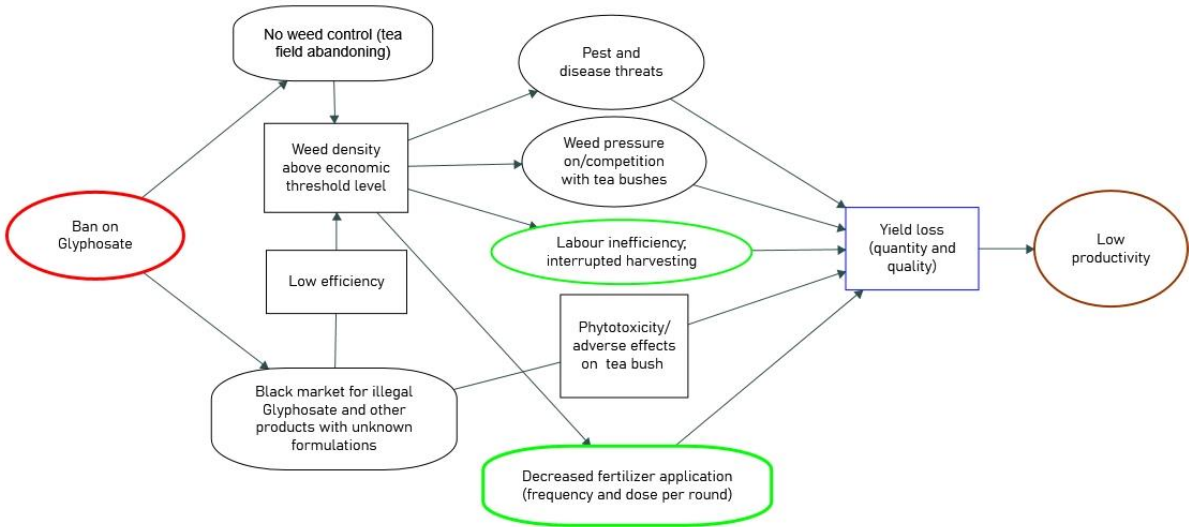


Figure 6.8. Overall effects of the ban on the farm sector. Source: Field data 2019

6.5.2 Other effects of the ban on the farm sector as reported by the respondents

Another issue raised by many tea growers was abandoning marginal tea fields over the ban period. This problem was common across growers with large areas under cultivation and the estate sector as a consequence of surge in weeding costs exacerbated by multiple factors. Growers who practiced chemical weed management were the majority who mentioned ceasing weed management either for a short or extended period. Private tea growers explained "i*n the absence of Glyphosate, it was exceedingly difficult to control tea fields with vacancies. Because of this, many growers abandoned some old and less yielding blocks of tea that had excessive weed densities"* (KS5), *"soon after weeding rounds, weeds grew again, therefore fields were abandoned until the next weeding round*" (KS7), and estate management as well "*most of the marginal tea fields were abandoned. This was severe in seedling tea fields with many vacancies"* (NE2).

The main reasons for abandoning tea cultivations were *"many growers abandoned tea fields because of labour shortage, excessive cost on weeding, and absence of weedicides during the ban*" (RS3). This has been common across both sectors, as "*estate management decided to abandon some marginal tea fields was not being able to bear the cost on labour for manual weeding"* (FGDR2). For the private grower sector with smaller extents *"lands were abandoned by part-time growers with other income sources while full time growers did not, as they had no other choice but to maintain their cultivation*" (TSHDAK2). A few growers mentioned contemplating using abandoned tea fields for growing other perennial crops such as nutmeg, cloves, cinnamon etc., owing to the increasingly unprofitable nature of the tea cultivation.

A considerable number of tea growers as well as key informants, who observed the effects of the ban, commented on "uncontrollable levels" of weed growth in tea fields during the ban. An estate manager described his experience "i*n some neighbouring tea estates, tea fields are still covered with weeds not being able to recover from the absence of chemicals due to the ban"* (NE2). Uncontrolled weed growth has worsened conditions in tea cultivations *"the impact of the absence of Glyphosate was severe because the weed pressure was uncontrollable. Most of the tea fields were covered with weeds if left unweeded*" (NE4), while "s*ome abandoned tea fields had weed growth above the plucking table of the tea bush covering the canopy*" (TSHDAK2). This condition in tea fields in turn affected growers' decision to use illegal Glyphosate or other alternatives, even at a high cost and despite escalated weeding costs and difficulties to employ enough labour and the inefficiency of weedicides as already discussed.

The consequential increased weed growth in tea fields contributed to "*increased leech growth, serpents and other insects"* (GS7) and "s*everal snake bites and victims have been recorded during the period of the ban. Many plantations are bordered by forests, so snakes and serpents started creeping into unweeded tea fields"* (RE1)*.* Additionally, there had been situations as "*each time the weeds/grasses are slashed, the stem enlarges and harden. Therefore, labourers often had injuries in their feet because of stumps"* (RE1). With such hazards in the field, some labourers refused to do routine activities in the field such as harvesting, fertilizer application etc. that involved walking within tea bushes with plucking baskets, or fertilizer sacks. Moreover, *"when weeds grow above the plucking table, pluckers usually remove such creepers manually while green leaf plucking*" (GS7). These impediments in turn severely reduced labour efficiency with under plucking and delayed plucking in tea cultivations leading to production losses.

Fertilizer application, critical in ensuring better yields, was reported to be interrupted with heavy weed densities in tea fields. This is because "*Fertilizer application in the presence of weeds reduces fertilizer use efficiency by tea bushes as nutrients are absorbed by weeds. So, some tea growers either avoided or delayed fertilizer application when weeds could not be cleared in the field"* (Ex4). In practice, growers mentioned such instances "t*here were certain fields had not been fertilized for 6,7 months continuously because fertilizer application had to be stopped because of the high weed growth*" (RE1) and reported yield losses "... *fertilizer could not be applied properly, hence there was a decline in the harvest of green leaves plucked per acre in long term*" (BS5).

Growers highlighted potential risks of pest and disease incidences such as "… *mite attacks with high weed densities"* (NE3) that can reduce the quantity and quality of the harvest. Additionally, uncontrolled weed densities have suppressed the growth of tea bushes because of the weed pressure.

Crop losses, in terms of quantity and quality, were identified as a substantial impact of the ban by almost all respondents, especially tea growers and tea manufacturers. Interruptions on harvesting and fertilizer application individually and altogether have led to extended plucking rounds due to delayed plucking that seemed to have affected both quantity and quality losses. As explained, "t*he plucking interval of 7 days extended to 8, 9 days"* (NE3) where *"delayed/missed fertilizer application reduce the growth in tea buds, thereby plucking rounds get extended"* (TFMR1), while "*some growers tend to delay the plucking interval intentionally, to compensate the cost of labour on harvesting. This has resulted in matured leaves in harvested green leaves"* (TFMG) affecting both the quality and quantity so in low green leaf prices for tea growers. An expert stated "d*elayed plucking can result in a loss of the crop by 25 per cent* "(EXPTRIJM). Concerns of the tea manufacturing sector related to this issue was "*deteriorated quality of made tea produce with increased fiber content in matured leaves"* (NE3).

As mentioned by tea growers and experts as well, production losses occurred from aggregated effects including consequences of the ban, fertilizer policy changes and extreme weather events during the period under consideration in addition to individual variabilities. Hence it is rather difficult to isolate the impact of the ban exclusively on yield.

Many respondents believed that the estate sector and large-scale growers were directly affected by the ban on Glyphosate while *"effects were minimal on tea smallholdings that did not use chemicals for weed management"* (EXPTRISH). Their arguments referring the private grower sector were "s*mallholders have not really felt the issue of Glyphosate unavailability unlike large plantations did"* (NE1) because *".... illegal chemicals were available on and off during the ban even at a higher price, and the extent of the landholding was small"* (K6) so that they could control weeds with available family labour and manage the issue. Apart from having easy access to informal Glyphosate sources, the flexibility in changing input use benefitted private operators unlike the estate sector that needed to maintain transparency in transactions of the estate.

While the majority of growers viewed the ban as having negatively influenced the grower sector and tea production, a few considered it as being helpful by encouraging environment-friendly cultivation and conserving biodiversity. Another respondent explained that "t*he ban produced mixed results, because overdosing and misusing weedicides was reduced to a certain extent with the ban although the use of strong and toxic chemicals was simultaneously increased with the application of illegal chemicals from the black market"* (MK1).

6.5.3 Effects of the ban on the farm sector: secondary data sources

In the following section the focus is on the effects of the ban on the farm sector, as highlighted in secondary data sources such as annual reports, market updates and performance reports from SLTB, TSHDA, Ministry of Plantation Industries, Central bank of Sri Lanka. These sources of information support and corroborate the interview findings and provide insights about the severity of the issue as viewed by institutes working closely with the tea industry in Sri Lanka.

The Sri Lanka Tea Board (2016a) elaborated "*several factors combined to make the beginning of 2016 difficult for the tea industry, including effects of the government's ban on Glyphosate and with Paraquat having been banned already, leaving no viable alternatives other than mechanical weeding*". Hence, the government decision regarding the agriculture sector in the Sri Lanka in mid-2015 to late 2018 were unfavourable for the tea industry as it "h*indered the weed control in large scale estates due to the ban on Glyphosate*" (Ministry of Plantation Industries 2018). According to Sri Lanka Tea Board (2017) "*no alternative weedicides for banned Glyphosate and Glufosinate Ammonium and the unfavorable fertilizer policy are the factors which hindered the growth of the industry in the year 2016"*. Additionally, reports indicate that the weather that prevailed during most years have had adverse effects on tea production. The overall consequences of these outcomes of the ban were identified by the Sri Lanka Tea Board (2016c) as having "... *a 40 per cent drop in the supply of tea leaves. Apart from the drought, removal of the fertilizer subsidy and the drop in tea prices was a double blow to low tea production*".

Overall production declines during 2016 – the year following the Glyphosate ban imposition – were described "*total made tea production in 2016 was 292.36 million kg, registering a drop of 11.1 per cent against 2015, which drop constitutes 9.1 per cent of tea smallholding sector, 16.2 of RPCs and 29.6 per cent of the public sector*" (Ministry of Plantation Industries 2016) and "*Sri Lankan tea production experienced a continuous and drastic fall of green leaf harvest due to the extreme weather patterns with disrupt of routine agriculture practices and government restrictions on fertilizer subsidies to RPCs and small holders*" (Sri Lanka Tea Board 2016e). Similar to yield losses, there have been cost of production increases because of these issues. Disruption of green leaf harvesting was identified by Sri Lanka Tea Board (2016a) "*the issue arisen in the use of weedicides to control weeds in the cultivations under the RPCs have also caused to decrease in the capacity of tea plucking*".

It was reported as "*Sri Lanka's Plantation sector costs are set to rise fairly in 2018, pushed up by higher labour, fertilizer, energy, recommended weedicide prices with low productive aged bushes, escalation of fertilizer prices and crippled supply of fertilizer stocks"* (Sri Lanka Tea Board 2017e).

The severity of the ban experienced by tea growers, especially the estate sector was highlighted with respect to easing the ban by the Sri Lanka Tea Board "*Government's decision to lift the ban on Glyphosate is likely to give much relief to producers and in particular, to the large-scale plantations which would be able to carry-out the required agricultural practices to achieve the full potential of plantations*" (Sri Lanka Tea Board 2018b).

6.6 Additional issues faced by the grower sector during the Glyphosate ban (2015 – 2018)

A concept map generated using key findings from the farm sector, as stated by respondents during the field interviews, is presented in Figure 6.9 while some parts of this have been resented in Figure 6.8 as well. This outlines the underlying issues across main components of the grower sector including effects on weed management because of policy banning Glyphosate, labour related issues, other policies affecting the production, prices and climate changes.

6.6.1 Fertilizer policy change (2016-2017)

There was a change made to the fertilizer subsidy program by the government in 2016 and 2017 shifting from providing fertilizer at a subsidized price to a cash voucher system covering some crops including tea. The Central Bank of Sri Lanka (2016) published this policy decision related to the tea industry as "*The TSHDA implemented the National Fertilizer Subsidy Scheme where Rs. 15,000.00 per hectare was given for tea smallholders who owned between less than 1 ha and over 20 perches of land cultivated for tea*". This was an independent decision made on the agriculture sector that overlapped with the period with the ban on Glyphosate. The cash voucher system was in place from *Yala*[6] 2016 (mid-2016) till *Maha*[7] 2017/2018 (early 2018) *"The removal of the fertilizer subsidy also means that a 50 kilograms fertilizer bag, which was around Rs. 1300.00, has now gone up to more than Rs. 3000.00. Hence, considering of these factors there was really no profit in the industry at these months"* (Sri Lanka Tea Board 2016c).

[6] There are two cultivation seasons in Sri Lanka which are synonymous with two monsoons. *Yala* season is effective from May till August.
[7] Maha season is effective from September to March in the following year when the North-east monsoon operates.

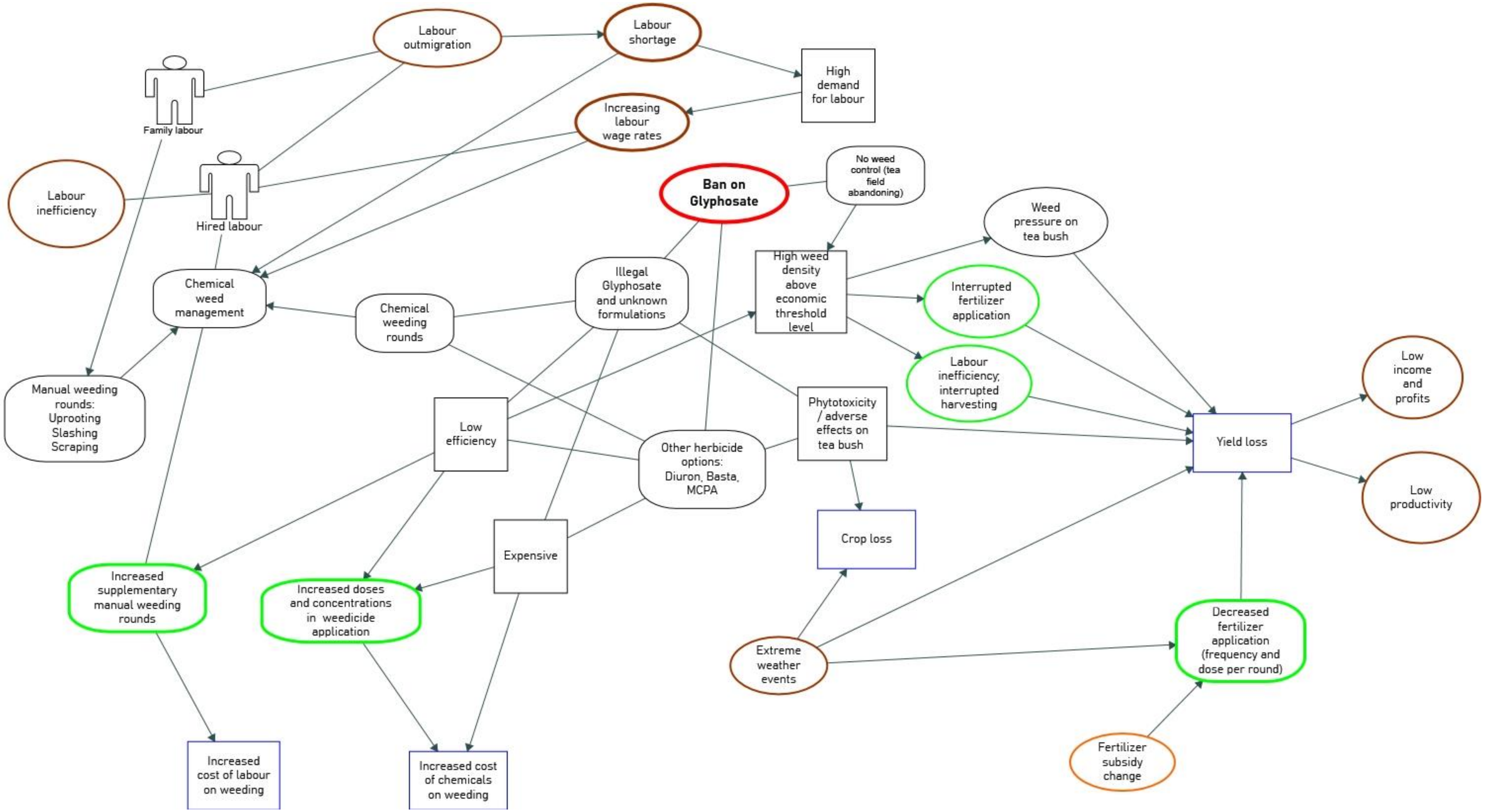


Figure 6.9 Key findings from the farm sector. Source: Field data 2019

This was a major concern for tea growers as it led to serious changes in fertilizer application in tea cultivations and adverse outcomes "... *reduction of fertilizer applications and rising costs of productions affected the total tea production for the quarter to drop by 18.5 per cent*" (Sri Lanka Tea Board 2016d).

Similar information was revealed by respondents during interviews about problems with fertilizer subsidy changes. An expert explained that "*with the increase in fertilizer price during the ban, farmers tend to reduce the amount of fertilizer they applied to the field eventually contributing to the overall yield loss worsened by the ban*" (Ex3). Elaborating on changes in the practice of fertilizer application, growers shared their experience "*on overall there has been a reduction in the amount and timely application of fertilizer because of the increased price of fertilizer. A simultaneous yield reduction could be observed*" (GS6), "*when fertilizer was purchased from the market (2016 for two seasons), the amount applied was largely reduced from five sacks to two sacks per acre"* (GS5), "*Fertilizer was applied three times a year before the ban. During the ban this dropped to once a year leading to 25 per cent decline in yield"* (KS1).

6.6.2 Extreme weather events

Weather prevailing during the ban had adversely affected tea production throughout the country. There had been protracted drought events, landslides and floods that have affected severely tea cultivation regions. Sri Lanka Tea Board reported in annual reports that, "*Finally, a protracted drought in many tea growing districts added to these stresses, which combined to depress production (and arguably quality, too)*" (2016a) and "*tea industry encountered a series of natural disasters. Drought started in January, and it continued till March and April, in late May landslide and floods started and affected over half a million people. The worst affected districts were the tea growing region*" (2017). Hence, the weather influenced tea yields in most cultivation areas.

6.6.3 Fluctuations in green leaf prices received by the private grower sector

Green leaf prices depend on prices fetched by made tea at the Colombo tea auction. Prices are highly sensitive to factors such as local and global tea supplies, demands from importing countries, and local exchange rates and the global economy. According to Sri Lanka Tea Board (2015) " *The contraction in the demand from major tea importers adversely affected tea prices in 2015*", "*Prices at the Colombo auctions have risen in recent weeks after a prolonged slump that was part of the global collapse in commodity prices*" (Sri Lanka Tea Board 2016d) and *"tea prices for all sub districts were significantly improved due to the huge demand generated from exporters*"(Sri Lanka Tea Board 2017b).

Green leaf prices during the first two years of the ban were favorable because of a progressive rise in sale averages of made tea at the Colombo tea auction. Therefore, *"The average price received by tea smallholders for green leaf increased to Rs. 90.69 per kilogram in 2017, from Rs. 68.53 per kilogram in 2016*" (Sri Lanka Tea Board 2017).

6.7 Issues faced by the tea manufacturing sector during the Glyphosate ban

The period with the Glyphosate ban was difficult not only for the grower sector, but also for the manufacturing sector who use the tea harvest as the main input. The Sri Lanka Tea Board reported that "*Low grown manufacturing registered a decreasing pattern of crop intake attributed to dry weather and extended plucking intervals with higher cost of production compared to sales averages*" (Sri Lanka Tea Board 2017b), thus "*many factories halt their manufacture or operate one dryer temporary for existence*" (Sri Lanka Tea Board 2016c).

The following sections discuss findings from interviews with tea industry participants on challenges faced by the black tea manufacturing sector.

6.6.1 Quantity and quality losses of the black tea produce

Tea manufacturers and estate sector management (who also have their own factories) explained that there have been quality losses which was critical to the prices fetched at the tea auction. The effects were explained as *"the manufacturing process of made tea has also been affected by the ban since it gave rise to a higher proportion of coarse leaves in the harvest*" (MR1) because *"with missed fertilizing, tea leaves available for harvesting turned yellowish instead of the bright green colour they should have. A slight fall in yield was also reported by green leaf suppliers"* (MR2) and *"there had been an increase in waste of black tea produce by around 5 to 6 per cent as the fiber content increased. This is because of delayed plucking rounds"* (MB1). Moreover, "*reduced tenderness in tea leaves affected the leaf rolling process in black tea manufacturing. Subsequently, the off-grade percentage in made tea increased at least by 2 – 3 per cent during that period*" (MR1) and *"the blackness of the tea was slightly affected because of the yellowish nature of harvested tea leaves. This was linked with the issue in manuring with the weeds"* (MR2).

Only a few manufacturers indicated some potential incidents that occasionally occurred "t*here were a few instances when weed leaves were mixed with green leaves, it affected the final made tea produce giving a raw taste*" (NE3).

6.7.2 Increased cost of production

Estate managers and factory managers commented about the impact of the ban on budgets and cost management by the tea manufacturing sector during the ban. They highlighted that "t*he ban had either direct or indirect impacts on made tea manufacturing factories"* (MR1) as green leaf is the main input in black tea production and the severity of the impact depended on the supply source of green leaves to the factory. Referring to manufacturing factories owned by RPCs, a manager mentioned that *"company factories had the greatest impact as they were operating mostly with own leaf from the estate*" (MR1), where production declines in the estate directly affected the factory's output. Instead, *"factories operated mainly with bought leaf did not face major issues in the drop of green leaf production much, because new suppliers were found"* (MR2) as "*bought leaf companies do not run at under-capacities*" (NE2), but production declines have been felt by all factories. A common issue often faced by the manufacturing sector was highlighted as *"when the crop was reduced, it lowered the factory capacity with inadequate supply of green leaves and production was done at a cost, with increased cost of production on manufacturing"* (NE2). Hence, increased costs of production were reported by all manufacturers.

There were instances when estate factories tried to buy harvests from private growers to ensure they operated. This caused *"the competition between tea factories increased during the period of the ban. Since the harvest of tea was low, factories had to pay more for green leaves. Therefore, most of the RPC tea factories were shut because of the competition for green leaves and very few tea factories operated with green leaves from neighbouring estates. Some of the factories are still not opened*" (MR1). Increased costs have eventually resulted in higher production cost of made tea *"the cost of production per kilogram of made tea increased by around Rs. 100; so that Rs. 550 rose to Rs. 650, because the cost on labour increased"* (MR2). Manufacturing factories managed to minimize the impact through strategies such as storing made tea produce without selling it until better prices stabilized in the market.

6.8 Issues faced by the black tea export sector during the ban

The black tea export sector also faced unintended consequences from the ban on Glyphosate. The Sri Lankan government reported "*Consequent to banning of Glyphosate by the Government of Sri Lanka, tea growers and large plantations, were forced to use alternative products for the control of weed growth, resulting in MCPA levels higher than permitted for exports to Japan"* thus "*exports to Japan declined"* (Sri Lanka Tea Board 2018b). Contact people from tea export companies shared their experience and opinion on how the ban affected their businesses. A significant impact on exporters has been "*some tea shipments exported to Japan mainly getting rejected because the MCPA and Hexaconazole residue in tea exceeding the MRLs set by Japan*" (J1). This led to serious challenges to tea exports from Sri Lanka as "*Japan was among the topmost tea exporting countries for Sri Lanka and the market is being threatened now even for the company*" (J1) as "*tea importing countries such as Japan, European countries and Vietnam are more concerned over MRLs and request for reports on MRL checks thus getting strict on quality standards*" (J2). Direct costs of the ban on tea export sector were *"costs on checking MRLs of every batch of tea exported and the cost that has to be born if the consignments get rejected*" (J2). They have been able to recover some of the costs of rejected shipments with insurance as explained during interviews.

6.9 Summary

In this chapter the qualitative analysis of data collected from in-depth interviews has been presented with supporting information from findings from the secondary data sources. Detailed interviews in the primary data collection facilitated extracting rich information from participants and stakeholders of key market levels in the value chain of the tea industry about the questions being explored in the study.

As suggested by the data collected, the ban directly affected the weed management activity in tea cultivations, mainly affecting those who depended on Glyphosate before it was banned. Given the labour shortage and increasing wage rates, and because of the large area under cultivation, chemical weed management was an essential activity in the entire estate sector. It was observed in many private tea landholdings that, even before the ban on Glyphosate, chemicals were used in weed control regardless of the landholding size even before the ban on Glyphosate. In fact, labour scarcity and wage hikes were increasingly challenging to grower sectors because of labour out-migration leading to inefficiencies in cultivations.

The choice of weed management was influenced by the cost and labour required, efficiency, weather, type of weeds in the field, condition and production status of the tea bush stand, among other things. Whereas the choice decision makers faced about switching between weed control options or continuing with the same approach during the ban on Glyphosate was strongly influenced by the availability or absence of illegal Glyphosate and other alternative weedicides in markets, and their inefficiencies, in addition to other aforementioned factors.

The ban on Glyphosate resulted in tea growers from both sectors completely moving or switching to approaches incorporating increased manual weeding and extra costs to compensate for the absence of an effective alternative for Glyphosate. The availability of over-priced illicit sources of Glyphosate from informal markets, in addition to other recommended alternative weedicides that were usually expensive led to increased costs on chemicals for landholdings that adapted chemical weed management during the ban. Increased weeding costs have eventually led to declined profits in both grower sectors.

Other factors such as fertilizer policy change, extreme weather events, green leaf price fluctuations affected both estate and private sectors. Unsuccessful weed management because of the outcomes of these challenges added to the impact on the farm sector including abandoning marginal tea fields without weed controlling, hindered plucking and fertilizer application activities, labour inefficiencies eventually leading to production and gross margin losses. The ban also caused costs of production to increase in the manufacturing sector while the black tea export sector experienced losses through consignment rejections from tea importing countries. The effects of the ban on key market levels of the tea industry damaged the performance of the entire industry.

Key findings from this chapter are used in Chapter 7 in achieving Objective 2 of quantifying changes in weed management practices, production and tea production gross margins in the farm sector of the tea industry. Subsequently in Chapter 9, findings of this study already analysed above are compared and contrasted with evidence in the literature where the implications of the Glyphosate ban are discussed.

Chapter 7 Economics of Weed Management in Tea Cultivation

7.1 Introduction

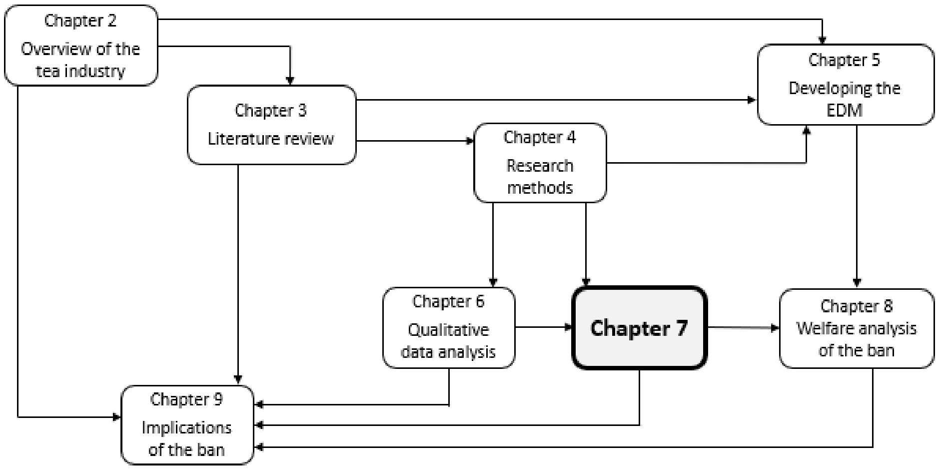


Figure 7.1. Flow of chapters in the thesis

The ban on Glyphosate has resulted in a crisis for the tea grower sector as highlighted during interviews discussed in Chapter 6. In this chapter a quantitative analysis of costs incurred by tea grower sector in tea cultivation is presented. In the first part of this chapter a cost analysis of the main weed management approaches undertaken in tea landholdings of both sectors before and during the ban is discussed. The costs of weed management is used to develop activity budgets for representative landholdings to assess the overall impact of the ban on farm budgets. A mini appendix consisting of quotes from interview participants that provided justifications and clarifications of some variable selection in cost analysis is included at the end of this chapter. Changes in variable costs and gross margins are analysed as key financial parameters of green leaf production businesses based on main weed management approaches identified from Chapter 6 to capture the budgetary impact of the ban of input substitution in farm budgets. These parameters are used as inputs for the EDM application in the tea industry in Chapter 8. Furthermore, key findings of the changes in costs in the farm sector are compared with literature in Chapter 9 highlighting implications of the ban on the farm sector of the tea industry as shown in Figure 7.1.

7.2 Introducing and defining variables and assumptions

Representative landholding

It is assumed that representative landholdings, considered for computational purposes in this chapter, are matured cultivations that have undergone several pruning cycles with vacancies resulted because of not practicing infilling through the years. Based on detailed interviews from the field, which highlighted the availability of vacancies in many tea fields, it is assumed that there is only 60 per cent bush cover in the representative landholding. Further, the 60 per cent bush cover in tea cultivations is selected in the present study to comply with crop loss estimations computed by Shyamalie (2015a).

Additionally, the composite representative landholding in the private tea grower sector (including both smallholders and medium-scale growers) refers to a tea landholding that conducts all weed management approaches in their respective proportions based on the distribution of the sample of private tea growers in the study. Every other landholding in private and estate grower sectors is representative of the weed management approach specified.

The following defines the variables and assumptions used in the cost analysis:

- Before the ban on Glyphosate and during the ban period: The calendar years 2014 and 2017 are selected as representative of before the ban and during the ban periods, respectively. Wage rates and prices prevailed during these representative years are used where necessary, when computing costs in tea cultivation.
- Frequency of tea field activities: This refers to the mode of the number of weeding rounds practiced per year in tea cultivation (based on data collected from farm sector participants during the interviews).
- Labour units allocated per round per unit land area: This is the average number of labour units allocated for each activity carried out in a field. All tea field operations are conducted by labourers unless specified. The following assumptions are made on the use of labour for tea field operations in private tea landholdings; (i) plucking is done completely by female labourers, and (ii) all other field activities are done by male labourers, especially, chemical weeding. Although field activities were interrupted during the ban, no change is assumed in labour allocation on these activities except for weed management activities.

- Wage rate: The daily earning of a labourer is referred to as wage rate. Representative wage rates common across all tea growing districts in the sample paid to labourers engaging in different tea field activities – assuming no wage rate variations across districts – are used for the private sector as shown in Table 7.2.

  Wage rates in the estate sector are the government-set wages of residential labour. It is assumed that wage rates paid on harvesting reflect the plucking norm and exclude additional kilograms of tea leaves plucked beyond the norm value.

- *Type of weedicide used on chemical weeding*: Glyphosate is assumed as the weedicide used by all landholdings in both the private and estate sector before the ban (based on the interview findings). Illicit Glyphosate products in the informal market and Diuron were found to be the weedicides often used by private tea landholders during the ban. Similarly, mostly used alternatives to Glyphosate in the estate sector during the ban were illicit Glyphosate products and Basta – active ingredient; Glufosinate Ammonium.

- Price of weedicides: Price of Glyphosate before the ban is the market price of retail packages and bulk purchases for the private and estate sector, respectively. Price of alternative chemicals used during the ban are the average prices across regions as revealed by respondents during interviews.

- Dosage used per application round: Dosages of each weedicide used before and during the ban by both sectors separately (see Table 7.1 – data is based on the interview findings).

Table 7.1. Dosages of weedicides used in tea cultivation

Weedicide	Dosage
Glyphosate	0.67l/ac- 0.8l/ac and 1.5l/ha
Diuron	500g/ac
Illicit Glyphosate	1.2l/ac and 2l/ha
Basta	1.5l/ha

Source: Field data 2019

- Machinery units allocated per round per unit land area: Types of machinery used in tea fields are mainly knapsack spray tanks for weedicide and foliar applications and grass cutters for weed slashing. This is the average number of machinery units allocated for each activity carried out in a field.

- Machinery rent: Representative machinery rents on knapsack sprayers and grass cutters common to all tea growing districts in the sample is used.
- Price of fertilizer: The subsidized price of fertilizer is used for the private tea grower sector. The change in the fertilizer policy from the price subsidy to the cash voucher system is also considered. The price of fertilizer with the cash transfer system is the market price prevalent instead of the subsidized price. The prices of fertilizer in the estate sector are the market prices. Transport costs of fertilizer are neglected in both sectors.
- Price received for green leaves: National averages of annual green leaf prices (for all tea growing elevations) for representative years as given in TSHDA Annual reports are used for the private tea grower sector. The same prices are imputed in the estate sector as opportunity costs of green leaf production by the sector.
- Green leaf yields: Based on the interview findings, it is assumed there is only 60 per cent bush cover in the representative landholding *(*due to the number of vacancies*).* The potential annual yields in private and estate tea cultivations with a 60 per cent bush stand are 11,856 kg/ha/year and 8,820kg/ha/year respectively, if weeds are controlled below the ETL using any weed management approach; chemical or manual weed management based on above assumptions. It is assumed that there is no phytotoxic effect with chemical weeding using Glyphosate before the ban, hence the potential yield could be achieved. For simplicity in calculations, it is assumed that the target yield[8] for a given level of weed control that manage weeds below the ETL is same as the potential yield.

  During instances when weeds cannot be managed below the ETL (that is, during the ban when weed management efforts are not sufficient to control weeds below ETL) it is assumed that the level of weed control is reduced to 50 per cent and leads to 3.5 per cent crop loss as adopted from Shyamalie (2015a). It is assumed that this 3.5 per cent crop loss accounts for production losses by weed pressure, interrupted harvesting and fertilizer application associated with high weed densities. Crop losses are accounted under certain weed management approaches during the ban as revealed during interviews.

[8] Usually the target yield, which is the profit maximizing yield in a cultivation is lesser than the potential yield which is the maximum yield that can be obtained from a cultivation for a given number of tea bushes.

Although there could be a slight yield enhancement potential along with manual weeding approaches that facilitate improvements in the microclimate of soil around tea bushes and soil properties because of the addition of green manure from weeds, such effects associated are neglected. Therefore, no yield differences between landholding categories based on weed management approaches (taken within two periods) are considered given that phytotoxic effects are also neglected.

Quality losses in the crop due to weeds will be considered negligible as there is not enough evidence to quantify the effect of quality falls in yields.

It is assumed that there is not any green leaf production loss due to weather effects. The weed growth during the rainy season is faster while drought periods extend weeding rounds. Extreme weather events are therefore neglected assuming average weather with no continuous rainy or drought periods.

A summary of parameters including wages and prices used in the cost analysis in tea grower sectors as discussed is given in Table 7.2.

Table 7.2. Summary of variables used in the budget analysis

Parameter		Before ban (2014)	During ban (2017)
Wage rates (Rs/day)			
Private tea grower sector	Harvesting	500	600
	Manual weeding	800	1000
	Chemical weeding	1000	1200
	Fertilizer application	800	1000
	Shade management	800	1000
Estate grower sector		620	730
Weedicide prices - (Rs. /l or Rs. /kg)			
Glyphosate (retail- private grower sector)		1200	
Glyphosate (bulk purchases-estate sector)		1075	
Diuron - dimethyl, 3-(3',4'-dichlorophenyl) urea			2500
Illicit Glyphosate products (unknown formulations)			3000
Basta – Glufosinate-Ammonium			4000
Machinery rent (Rs. /day)			
Grass cutter/mechanical weeders in manual weeding		95	100
Knapsack sprayer in fertilizer and foliar application		95	100
Price of fertilizer (Rs/kg)		25 (with the price subsidy)	60 (with the cash voucher system)
Green leaf price (Rs/kg)		67.54	90.69
Green leaf yield (kg/ha) Private grower sector		11,856	11,441
Green leaf yield (kg/ha) Estate grower sector		8,820	8,511

Source: Field data 2019 and Sri Lanka Tea Board

7.3 Cost analysis of weed management approaches in tea grower sectors

Weed management is an important activity in tea cultivation. To study the cost structure of different weed management approaches in tea grower groups it requires an understanding about the labour, machinery and material used in controlling weeds below the ETL before and during the ban on Glyphosate. Since Glyphosate is an important input in weed control in many tea cultivations, it is worth assessing how growers controlled weeds before the ban on Glyphosate and how they made changes to adjust to the ban. In the following sections, the results of an analysis of costs related to weed management before and during the Glyphosate ban of both private and estate growers, based on their responses provided during interviews, is presented.

7.3.1 Private tea landholding sector

A detailed representation of weed management approaches practiced before and during the ban on private tea landholdings and their costs are given in Tables 7.3 and 7.4 respectively. The weed management approaches carried out in private tea landholdings (manual weeding only, chemical weeding only and chemical weeding with supplementary manual weeding) are compared using parameters such as frequencies of weed control, labour, chemical and machinery units allocated.

Manual weeding is the most labour-intensive method of weed control that requires the highest number of labour units and is costlier than other approaches. It can be carried out by uprooting, slashing and as a combination of uprooting and slashing (as discussed in Chapter 6). Slashing is practiced at shorter intervals throughout the year; eight rounds on average to control weeds because underground parts are not removed and tend to regrow quickly. Since uprooting of weeds is more likely to remove weeds fully, it is considered that a manual weeding round by uprooting tends to sustain weed re-growth for nearly three months. The labour requirement and cost of slashing is relatively less than the other two manual weeding methods, but it is not recommended because of potential risks on tea bushes. The total number of labour units needed on manual weeding by uprooting varies with the ground cover or availability of vacancies (see Table 7.3). Weed uprooting within tea bushes and slashing along boundaries in a field with a considerable number of vacancies requires the highest number of labour units resulting in costly weed management. Hence, manual weeding involving labour in uprooting and slashing of tea cultivation with many vacancies incurs the highest cost of weeding (Rs. 120, 437/ha). Findings also suggest that maintaining a good tea bush stand

Table 7.3. Weed management approaches in the private grower sector before the ban

			Rounds per year	Labour cost (Rs.)		Weedicide cost (Rs.)		Machinery cost (Rs)		Total labour units per year		Total cost	
				Labour units per round per acre	Wage rate (Rs. /day)	Litres per round per acre	Price per litre (Rs. /l)	Machinery days per round per acre	Rent per day (Rs. /day)	per acre	per ha	per acre (Rs. / ac)	per hectare (Rs. /ha)
Manual weed management		Manual weeding by uprooting within tea bushes (few vacancies) and boundaries	4	10	800	-	-			40	98.8	32,000	79,040
		Manual weeding by uprooting within tea bushes (many vacancies) and slashing along boundaries	4	15	800	-	-	2	95	60	148.2	48,760	120,437
		Slashing within tea bushes and boundaries – many vacancies	8	2	800	-	-	2	95	16	39.5	14,320	35,370
Chemical weed management	Chemical weeding only	Chemical weeding using only Glyphosate	4	2	1000	0.8	1200	1	95	8	19.8	12,220	30,183
	Chemical and manual weeding	Chemical weeding using Glyphosate	3	2	1000	0.67	1200	1	95	6	14.8	8,697	21,482
		Manual weeding	2	9	800	-	-			18	44.5	14,400	35,568
		Total								24	59.3	23,097	57,050

Table 7.4. Weed management approaches in the private grower sector during the ban

			Rounds per year	Labour cost (Rs.)		Weedicide cost (Rs.)		Machinery cost (Rs)		Total labour units per year		Total cost	
				Labour units per round per acre	Wage rate (Rs. / day)	Litres per round per acre	Price per litre (Rs. /l)	Machinery days per round per acre	Rent per day (Rs. / day)	per acre	per ha	per acre (Rs. / ac)	per hectare (Rs. /ha)
Manual weed management		Manual weeding within tea bushes and boundaries	4	9	1000	-	-			36	88.9	36,000	88,920
		Manual weeding within tea bushes and slashing in boundaries	4	15	1000	-	-	2	100	60	148.2	60,800	150,176
		Slashing within tea bushes and boundaries	8	2	1000	-	-	2	100	16	39.5	17,600	43,472
Chemical weed management	Chemical weeding only	Chemical weeding using only Diuron	4	2	1200	0.5	2500	1	100	8	19.8	24,400	60,268
		Chemical weeding using only illicit Glyphosate products	4	2	1200	1.2	3000	1	100	8	19.8	15,000	37,050
	Chemical and manual weeding	Chemical weeding using illicit Glyphosate	3	2	1200	1.2	3000	1	100	6	14.8	18,300	45,201
		Manual weeding	3	10	1000	-	-			30	74.1	30,000	74,100
				Total						36	88.9	48,300	119,301
		Chemical weeding using Diuron	3	2	1200	0.5	2500	1	100	6	14.8	11,250	27,788
		Manual weeding	3	10	1000	-	-			30	74.1	30,000	74,100
				Total						36	88.9	41,250	101,888

with a few vacancies can cut down the labour requirement on manual weeding by around 50 LPH for a year and save Rs. 40,000 per ha and Rs. 60,000 before and during the ban respectively, depending on prevailing wage rates.

Although it's not recommended, some landholdings with many vacancies, aged and/or seedling cultivations are inclined to practice slash weeding within tea bushes and along boundaries as the least expensive manual weeding approach in order to cut down weeding costs on such low yielding fields. Hence, frequencies of manual weeding in tea fields can vary within a wide range as reflected by interview findings.

Chemical weed management is carried out either with or without supplementary manual weeding rounds. Landholdings that depend entirely on chemicals for weed control, practice more chemical weeding rounds than the approach using chemical and manual methods together. Supplementary manual weeding rounds are carried out in between chemical weeding rounds to manage weeds that are not controlled by weedicides or those that reappear after the earlier weeding round. Hence, the labour requirement per round of manual weeding is not as high as in the manual weeding-only approach. Labour allocation on weedicide applications can vary across districts based on the type of terrain where tea fields are located. Low-country tea fields are mostly found in flat terrains, while mid- and up-country tea fields are mostly in hilly/inclined lands. Therefore, tea cultivation in hilly areas requires more labour days for weedicide applications because of the difficulty in carrying a 16l spray tank compared to flat terrains and avoiding continuous exposure to chemical drift. As a norm in some areas, two labourers are hired for a day to complete chemical spraying in 1 ac; one labourer to carry water and do chemical mixing, the other labourer for spraying. At the same time, labour allocation depends on the density of weeds in the field. The higher the density of weeds, the higher the number of labour units per acre because of difficulties in walking within the field with weeds and amounts of weedicides applied. (See mini appendix 7.7.a).

Before the ban, chemical-only weeding used the least amounts of labour followed by chemical weeding with supplementary manual weeding and manual weeding only approaches. Findings suggest that labour employment before the ban on manual weeding only and integrated chemical and manual weeding was five and three times, respectively, than that of chemical weeding only approach. Similarly, average costs incurred by representative landholdings practicing chemical only, chemical and manual weeding together, and weed uprooting only approaches were Rs. 30,183/ha, Rs. 57,050/ha and Rs. 79,040/ha respectively, the latter being the most expensive approach before the ban on Glyphosate.

Changes in weed management within two periods

Slight changes have taken place in manual weed management; labour allocation per weeding round has reduced by one unit during the ban. Some growers who continued manual weeding during the Glyphosate ban period have argued that increasing costs for labour and shortages of labourers led to slight reductions in employing labour for manual weeding (See mini appendix 7.7.b).

As shown in Table 7.4, during the ban on Glyphosate changes have occurred in integrated chemical and manual weed management related parameters. Growers have increased manual weeding efforts in terms of the labour allocation and frequency, in addition to increased doses of informal Glyphosate product application. The frequency of supplementary manual weeding rounds practiced during the ban has increased by an additional round, from 2 to 3 per year. Tea growers argued that because of the inefficiency of alternative weedicides used during the ban, additional manual weeding rounds in between chemical rounds was needed. Therefore, with the ban, as suggested by interview findings, the labour allocation per year on supplementary manual weeding rounds in chemical weed management has increased by 50 per cent. Interestingly, chemical with supplementary manual weeding and manual uprooting of weeds approaches have employed equal amounts of labour which is slightly more than three times the number of labour units allocated on chemical weeding only. Hence it is evident that integrated chemical and manual weed management has become much labour intensive during the ban than it used to be in the pre-ban period.

No changes were made to the frequency in chemical weeding only practice during the ban, rather continuing the same approach with other weedicide options instead of Glyphosate.

Representative landholdings that have used illegal Glyphosate products during the ban have increased dosages of application (almost double) due to the inefficiency of weedicides (as reported during interviews). Furthermore, prices of alternative weedicides used during the ban were greater than Glyphosate before its ban. This has eventually increased chemical costs on weeding.

Average costs on weeding during the ban on Glyphosate incurred by representative landholdings that carried out chemical only, integrated chemical and manual weeding and manual weed uprooting only approaches were Rs. 48,659/ha, Rs. 119,301/ha and Rs. 88,902/ha, respectively. Interestingly, integrated weed management with chemical and manual weeding methods has incurred a higher cost than manual uprooting of weeds in vacancy less fields, but less cost than the manual weeding approach done on tea fields with many vacancies involving uprooting and slashing (in Tables 7.3 and 7.4).

7.3.2 Estate Grower Sector

Findings about parameters used in weed management in the estate sector are shown in Table 7.5. All estate sector tea plantations in the sample of the study have used weedicides with supplementary weeding rounds throughout the period. The use of illicit Glyphosate during the ban was mentioned indirectly during the interviews but they were reluctant to reveal the extent of its use.

The representative landholding in the estate sector has incurred a cost of Rs. 36,490/ha on weeding with Glyphosate before its ban. Inefficiencies of alternative weedicides including illicit Glyphosate products and Glufosinate Ammonium had been common to the estate sector during the ban. As suggested by the data in Table 7.5, estate management has reduced the number of rounds of chemical weeding and replaced it with a manual weeding round with an extra 10 labour units per ha on average during the ban to cope with weedicide inefficiencies. The annual labour requirement has increased by nearly 89 per cent on average in the representative estate landholding during the ban on Glyphosate. Furthermore, chemical costs on chemical weeding have been increased as weedicide alternatives; illegal Glyphosate products and Basta were expensive during the ban. Therefore, the average cost of weeding in the estate sector was Rs. 82,710/ha during the ban.

A comparison between weed management approaches of the private and estate tea grower sectors helps reveal several differences in weed management between the two sectors. Data suggests that the frequency of Glyphosate application in the estate sector was higher than the private sector before the ban implying their dependency on chemicals to control weeds. On the other hand, labour allocation on chemical and manual weeding in the private sector is higher than the estate sector for the integrated chemical and manual weed management approach throughout the period. However, the cost of weeding per hectare in the estate sector with respect to the private grower sector is less because of lower wage rates on residential labour than casual labour and reduced costs on bulk purchase of material. There could be cost advantages for the estate sector when bulk purchasing chemicals, unlike private growers who buy from the retail market at slightly higher prices.

Table 7.5. Weed management approaches in the estate grower sector before and during the ban

Chemical weed management	Labour cost (Rs.)			Weedicide cost (Rs.)		Machinery cost (Rs)		Total labour units per year	Total cost
	Rounds per year	Labour units (LPH)	Wage rate (Rs. /day)	litres per round per ha (l/ha)	Price per litre (Rs. /l)	Machinery days per round per ha	Rent per day (Rs. /day)	per ha	Rs. /ha
				Before ban					
Chemical weeding using Glyphosate	4	4	620	1.5	1075	4	95	16	17,890
Manual weeding (within tea bushes)	2	15	620	-	-	-	-	30	18,600
				Total				46	36,490
				During ban					
Chemical weeding using illegal Glyphosate	3	4	730	2	3000	4	100	12	27,960
Manual weeding (within tea bushes)	3	25	730	-	-	-	-	75	54,750
				Total				87	82,710
Chemical weeding using Basta	3	4	730	1.5	4000	4	100	12	27,960
Manual weeding (within tea bushes)	3	25	730	-	-	-	-	75	54,750
				Total				87	82,710

7.4 Activity budget development for the farm sector

In the following pages, activity budgets developed for the two grower groups are presented. Pruning, pre and post pruning activities that are carried out once in 3,4 or 5 years based on the elevation of growing region, are not included in this budget computation. The cost may increase in years when pruning and related activities are carried out.

Frequencies of practice, labour and machinery units allocated per unit area and amounts of material used per unit area in tea field activities can vary across tea growing regions, grower sectors and even within individual cultivation. Averages of those parameters obtained from interviews are used in budget calculation as discussed in section 7.2.

In the budgets, all variables, except the weed management operation, are held constant over the two periods. The only difference is in nominal wage rates, green leaf prices and weedicides prices between representative years as explained above.

7.4.1 Private tea grower sector

The composite representative landholding in the private tea grower sector consists of all weed management approaches in their proportionate extent carried out in respective periods. In Tables 7.6 and 7.7 total variable costs of the private grower sector before and during the ban, respectively are depicted. The total variable cost of Rs. 402,061/ha in the representative landholding in the private tea grower sector before the ban has increased to Rs. 501,685/ha during the ban. Furthermore, the share of the cost on weeding of the total cost of the landholding has increased over time from 15 per cent to 19 per cent because of the impact of the absence of Glyphosate on respective changes to weed management approaches in addition to wage rate and price changes. Consequently, there has been an increase in total variable costs of nearly 25 per cent during the ban.

Table 7.6. Summary of variable costs of green leaf production in a composite representative private tea landholding before ban

Activity	Frequency of practice	Labour cost (Rs)		Material cost (Rs)		Total cost	Total cost	
		No.of units	Wage rate	No.of units	Price			
	(rounds/year)	(Labour days/round/ac)	(Rs/labour day)	(No.of units/round/ac)	(Rs/kg or Rs/l)	(Rs/ac/year)	(Rs/ha/year)	Cost as a %
Green leaf harvesting	36	6.56	500			118,080	291,658	72.5
Weed management								
Manual weeding (49%)						16,052	39,649	
Chemical weeding (34%)						4,155	10,262	
Both chemical and manual weeding (17%)						3,926	9,698	
Composite weed management						24,134	59,610	14.9
Fertilizer application (at the subsidized price)	3	1.61	800	148	25	14,964	36,961	9.2
Shade management	2	3.5	800			5,600	13,832	3.4
		Total Variable cost				162,876	402,061	100

Table 7.7. Summary of variable costs of green leaf production in a composite representative private tea landholding during the ban

Activity	Frequency of practice	Labour cost (Rs)		Material cost (Rs)		Total cost	Total cost	Cost
		No.of units	Wage rate	No.of units	Price			
	(rounds/year)	(Labour days/round/ac)	(Rs/labour day)	(No.of units/round/ac)	(Rs/kg or Rs/l)	(Rs/ac/year)	(Rs/ha/year)	as a %
Green leaf harvesting	36	6.56	600			141,696	349,989	69.9
Weed management								
Manual weeding (60%)						22,080	54,538	
Chemical weeding (6%)						1,182	2,920	
Both chemical and manual weeding (34%)						15,224	37,602	
Composite weed management						38,486	95,059	18.9
Fertilizer application (at the subsidized price)	3	1.61	1000	148	25	15,930	39,347	7.8
Shade management	2	3.5	1000			7,000	17,290	3.4
Total Variable cost						162,876	501,685	100

Note: Fertilizer subsidy policy change is neglected

In Table 7.8 the activity budgets for the composite representative landholding and for landholdings that carried out different weed management approaches is presented. Chemical only weeding is the lowest cost approach in the two periods (and has the highest gross margin). However, it should be noted continuous chemical use is not encouraged because of consequences on tea bushes and the environment (as reported by tea growers' responses during interviews). Hence, long-term chemical use on weed control leads to weakening of tea bushes, deformities in bud formation, in addition to the threat to the environment and biodiversity.

Manual weeding only and chemical weeding with supplementary manual weeding were identified as approaches with the highest costs before and during the ban, respectively. The dependence on labour and high wage rates were reasons for soaring costs in such weeding approaches involving manual weeding rounds and use of expensive alternative weedicides in chemical weeding. It was noted during the field interviews that performing manual/non-chemical weed management entirely or as an integrated approach had beneficial effects on tea bushes helping better microclimatic conditions that would've enhanced yield in return. However, this effect was not accounted for yield estimates and assumed negligible as mentioned in Section 7.2.

As shown in Table 7.8, the gross margin was derived based on assumptions about yield as explained in section 7.2 above (that is, the potential yield had been achieved by all landholding before the ban, while effects on weed management by restricting the use of Glyphosate in tea cultivation led to yield declines in some landholdings during the ban). Consequently, crop losses were assumed for landholdings that carried out chemical weed management – chemical weeding only and integrated chemical and manual weeding – during the ban to account for 50 per cent of weed control that failed to control weeds below the ETL. Therefore, the yield reduction in landholdings practicing chemical weeding with supplementary manual weeding rounds during the ban was assumed despite increased efforts on weeding by employing more labour on manual weeding – extra weeding round with extra labour units per round, to align with interview findings. To reflect the overall impact of the restriction on Glyphosate and the corresponding weed pressure, due to less efficiency in weed control as experienced by landholdings engaged in chemical weed control, the composite representative landholding assumed a fall in yield by the same amount as other representative landholdings did.

As expected, the highest annual gross income of Rs.1,075,221/ha was earned by landholdings that practiced manual weed management with no/least effect by the ban, by reaching the potential yield, while those who have practiced chemical weed management have received slightly lower yields and gross incomes. However, all landholdings had higher gross incomes, and gross margins, from green

Table 7.8. Activity budgets of the private tea landholding sector before and during the ban

	Composite representative landholding		Manual weeding only		Chemical weeding with supplementary manual weeding		Chemical weeding only	
	Before the ban	During the ban	Before the ban	During the ban	Before the ban	During the ban	Before the ban	During the ban
Price of green leaves (Rs. /kg)	67.54	90.69	67.54	90.69	67.54	90.69	67.54	90.69
Annual yield per ha (kg/ha)	11,856	11,441	11,856	11,856	11,856	11,441	11,856	11,441
Gross income per year (Rs. /ha)	800,754	1,037,584	800,754	1,075,221	800,754	1,037,584	800,754	1,037,584
Total Variable Costs (Rs. /ha)	402,061	501,685	423,368	497,522	399,500	517,220	372,634	455,285
Gross margin (Rs. /ha)	398,693	535,899	377,386	577,698	401,254	520,364	428,120	582,299
Gross margin per kg (Rs. /kg)	33.63	46.84	31.83	48.73	33.84	45.48	36.11	50.90
Variable cost of production (Rs. /kg)	33.91	43.85	35.71	41.96	33.70	45.21	31.43	39.79

leaf sales compared to pre-ban period, because higher green leaf price ranges prevailed during the ban. In the following section, average annual green leaf price prevailed in 2017 during the ban is considered in the scenario analysis. If it was not for these high green leaf prices, tea growers would have been devastated. This is better presented in the summary table under scenario analysis.

Similarly, representative landholdings who have done chemical weeding only have obtained the highest gross margins over both periods owing to lowest costs and slightly reduced yields with weed pressure. However, given the assumptions made on the decline in yield, the real situation may not have been fully estimated, thus an overestimation of the gross margin is possible. Following the opposite trend in variable costs, landholdings that have practiced manual weeding only and integrated chemical and manual weeding gained lowest gross margins before and during the ban, respectively.

7.4.2 Estate tea grower sector

The estate sector has taken an integrated approach with chemical and manual methods in weed management. Tables 7.9, 7.10 and 7.11 present summaries of variable costs of green leaf production in a representative estate holding before the ban, during the ban and the activity budget over the two periods respectively. As in Tables 7.9 and 7.10, the shares of weeding cost as a percentage of the total variable cost per ha has increased over the period by 6.8 percent from 8.5 per cent before the ban on Glyphosate to 15.3 per cent because of the high cost of alternative weedicides and the extra manual weeding required (according to interview findings). The total variable cost per ha has increased by 26.21 per cent.

A 3.5 per cent decrease in the potential yield was assumed to account for inefficient weed control efforts using alternative weedicide options, and insufficient weed control efforts with manual weeding to control weeds and yield losses in abandoned marginal tea cultivations. Additionally, the green leaf price was imputed from the private tea grower sector as the opportunity cost of green leaf production in the estate sector because the harvest is not sold but used for black tea manufacturing by the factory in the estate itself. As shown in Table 7.11, the gross income of a representative estate sector landholding from green leaves therefore was calculated to have a growth of nearly 50 per cent during the ban owing to better green leaf prices. Consequently, the gross margin has improved by 38.35 per cent - Rs. 10.42/kg of green leaves- while the average variable cost of production has escalated by Rs.15.48/kg during the ban which relates to an increase by 31.98 per cent. The total variable cost per ha has increased by 26. 21 during the ban with respect to before the ban on Glyphosate.

Table 7.9. Activity budget of green leaf production in the estate sector before the ban

Activity	Frequency of practice	Labour cost (Rs)		Material cost (Rs)		Machinery cost (Rs)		Total cost	Cost as a %
		No.of units	Wage rate	No.of units	Price	No.of units	Unit cost		
	(rounds/year)	(Labour days/round/ha)	(Rs/labour day)	(No.of units/round/ha)	(Rs/kg or Rs/l)	(Machine days/round/ha)	(Rs/machine day)	(Rs/ha/year)	
Green leaf harvesting	48	12	620					357,120	82.3
Weed management									
Manual weeding	2	15	620					18,600	
Chemical weeding	4	4	620	1.5	1075	4	95	17,890	
								36,490	8.5
Fertilizer application	3	4	620	250	21.9			23,865	5.5
Foliar application	5	1.5	620			1.5	95	5,873	1.4
Zinc				2.5	20				
Urea				2	6				
Epsom salt				2	20				
Shade management									
Medium shade	2	2	620					2,480	0.6
High shade	1	5	620					3,100	0.7
Disease (Blister blight) management	1	1.5	620	85	9	1.5	95	1,838	0.4
		45						430,766	100

Table 7.10. Activity budget of green leaf production in the estate sector during the ban

Activity	Frequency of practice	Labour cost (Rs)		Material cost (Rs)		Machinery cost (Rs)		Total cost	Cost as a %
		No.of units	Wage rate	No.of units	Price	No.of units	Unit cost		
	(rounds/year)	(Labour days/round/ha)	(Rs/labour day)	(No.of units/round/ha)	(Rs/kg or Rs/l)	(Machine days/round/ha)	(Rs/machine day)	(Rs/ha/year)	
Green leaf harvesting	48	12	730					420,480	77.3
Weed management									
Manual weeding	3	25	730					54,750	
Chemical weeding	3	4	730	2	3000	4	100	27,960	
								82,710	15.3
Fertilizer application	3	4	730	250	21.9			25,185	4.6
Foliar application	5	1.5	730			1.5	100	6,735	1.2
Zinc				2.5	20				
Urea				2	6				
Epsom salt				2	20				
Shade management									
Medium shade	2	2	730					2,920	0.5
High shade	1	5	730					3,650	0.7
Disease (Blister blight) management	1	1.5	730	85	9	1.5	95	2,010	0.4
		55						543,690	100

Table 7.11. Activity budget of the estate tea grower sector before and during the ban

	Unit	Before the ban (2014)	During the ban (2017)
Price of a kilogram of green leaves	(Rs. /kg)	67.54	90.69
Annual yield per ha	(kg/ha)	8,820	8,511
Gross income per year	(Rs. /ha)	595,703	771,890
Total variable cost	(Rs. /ha/year)	430,766	543,690
Gross margin	(Rs. /ha/year)	164,938	228,200
Gross margin per kg	(Rs. /kg)	18.70	26.81
Variable cost of production	(Rs. /kg)	48.40	63.88
Percentage change in variable cost of production per kg	(%)	31.98	
Percentage change in gross margin per ha	(%)	38.35	
Percentage change in total variable cost per ha	(%)	26.21	

Note: Green leaf prices are imputed prices on the estate sector from the private tea landholding sector

7.4.3 Comparison of gross margin budgets of private and estate grower sectors

There are a few key assumptions, common to both grower sectors, which can affect actual financial performance indicators. Average frequencies of tea field activities were assumed in the landholding to be representative of the sample of tea growers, however variations were observed across study districts and individual farms. Green leaf harvesting intervals showed slight differences across tea growing elevations in general. Short harvesting intervals were observed in low, mid-country and Uva regions while up-country tea growing regions tend to practice long intervals depending on the rate of shoot growth with weather and sunshine availability. Additionally, tea cultivation and management specific factors as well have possibly influenced the harvesting interval at farm-level, that new and young, well maintained, selectively plucked cultivations tend to have shorter intervals, while interruptions to harvesting, non-selective plucking extend plucking interval. Most landholdings were practicing 10 days' interval in plucking at a rate of 3 times a month with some others doing it more often at 7,8 days interval. However, all landholdings practice shorter plucking intervals during the rush crop period to ensure harvesting of the flush of leaves. Although extended plucking intervals were reported from both grower sectors during the ban on Glyphosate, it was not accounted for activity budgets since there was not sufficient evidence to quantify the delay in harvesting and associated yield loss.

Female labourers do the plucking as per the assumption. But during the rush crop period, both male and female labour are employed to meet the high labour requirement in plucking. Female labourers are also hired for manual weeding and fertilizer application. Male labour is mostly hired for arduous work such as land preparation and that involve machinery (shade tree management, chemical spraying etc.). Daily wage rates vary with different activities and the gender of labour engaged in the activity. In the private grower sector, male labourers are paid higher than female labourers for the same activity.

Private growers hire casual labour in addition to family labour (if available) for their tea field activities. Wages of these casual labour are nationally decided by the government by placing a minimum wage rate. Additionally, the Central Bank of Sri Lanka has specified the average daily wage rates for selected activities in the tea cultivation sector as discussed in section 7.2. However, in practical terms, daily wage rates on casual labour vary across tea cultivating regions/districts and deviates from minimum wage rates implemented by the Government. Provision of non-cash benefits such as meals and refreshment depend on the landholder hiring the labour. If meals and/or refreshment are not provided, the wage rate is slightly higher.

In most cases, daily wage rates of casual labour in the private grower sector are multiples of 100 as stated by key informants and growers. At the same time some tea landholders tend to pay slightly higher daily wage rates for hired labour to keep labourers in daily work because of high demand by labourers (See mini appendix 7.7.c). In such instances variable costs would be higher than the average values calculated for representative landholdings.

7.5 Scenario analysis of weed management approaches

Based on the interview findings, discussed in chapter 6, an analysis is conducted using the main weed management combinations as scenarios that existed during the ban in the estate and private grower sectors are presented in Figures 7.2 and 7.3 respectively.

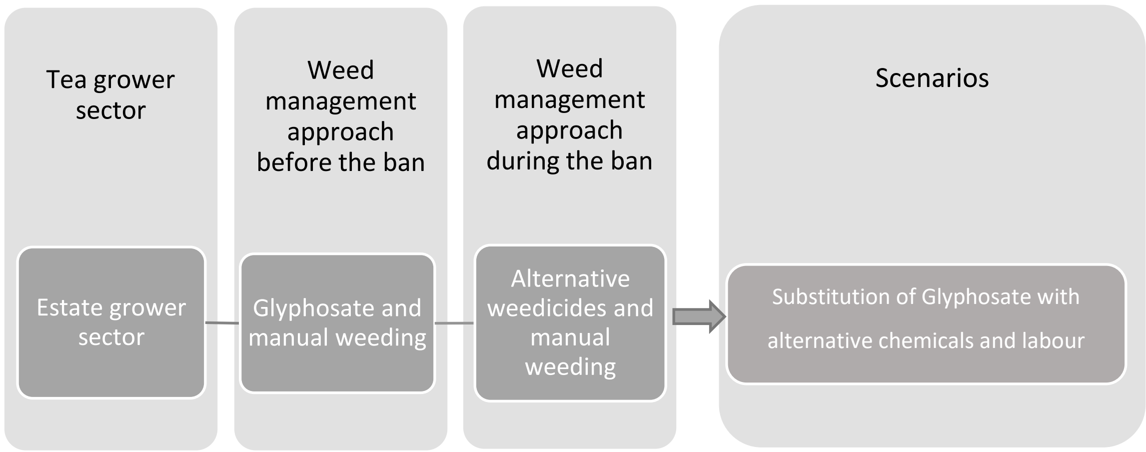


Figure 7.2. Scenarios of weed management combinations before and during the ban in the estate grower sector

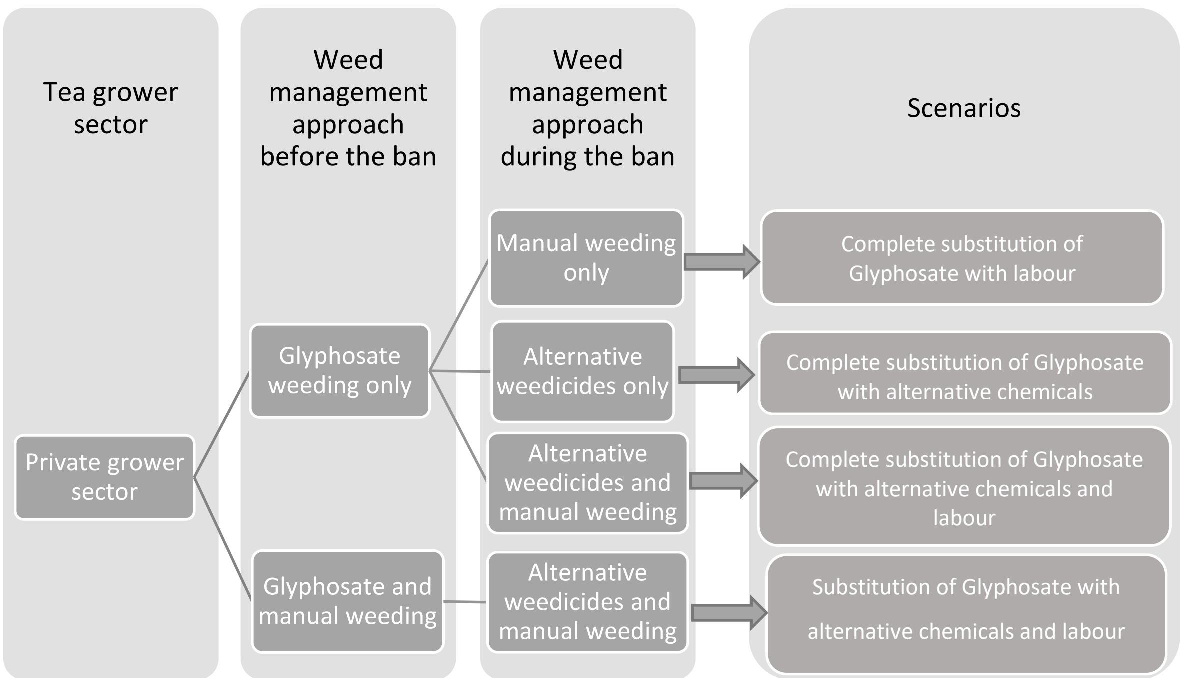


Figure 7.3. Scenarios of weed management combinations before and during the ban in the private grower sector

7.5.1 Further assumptions and variable descriptions

Predicted, theoretical and actual scenarios

A predicted scenario was introduced to explain what growers would have expected at the beginning of the ban period, assuming that it is to continue with the same weed management approach practiced before the ban on Glyphosate by achieving the same yield potential. Analysing this aspect of scenarios helped evaluate by how much the financial performance of landholdings changed with different approaches they have taken instead of continuing with the same weed controlling approach.

In addition to the predicted scenario, weed management decisions were evaluated in terms an actual scenario in all cases and theoretical scenario in one case based on information highlighted during interviews. The theoretical scenario refers to the situation describing what growers should have practiced with respect to the labour allocation per round and frequency of weeding to maintain weeds below the ETL during the ban. The actual scenario is the situation that describes the labour allocation per round and frequency of weeding practiced by growers in their cultivations as highlighted during interviews. In the theoretical scenario, it is assumed that weeds are controlled below the ETL with the allocated amount of labour, hence the target yield is achieved with no crop losses. All actual scenarios where the total labour allocation per year does not meet the theoretical allocation encounter a reduction in the green leaf output based on the argument as explained in Section 7.2.

Additionally, increasing wage rates, green leaf prices that change with time regardless of the ban as highlighted in Section 7.2 were captured under two periods before the ban and during the ban.

Basically, each scenario is analysed under four situations namely, (i) theoretical scenario with the ban, (ii) theoretical scenario during the ban (weed management parameters, green leaf price, nominal labour wage rates changed), (iii) actual scenario with the ban (only weed management parameters changed) and (iv) actual scenario during the ban (weed management parameters, green leaf price, nominal labour wage rates changed). A summary of parameters used under each scenario in the private and estate sector are provided in Tables 7.12 and 7.13.

In Table 7.12, weed control methods are specified in rows, while weed management approaches practiced before the ban are labelled as (1) and (2), and respective approaches during the ban are labelled as (a), (b), (c) and (d) in columns. Predicted scenarios labelled as (i) and (ii) are simply continuation of the approach practiced before the ban by only replacing Glyphosate with Glufosinate Ammonium (GA) in recommended dosage assuming similar efficacy between Glyphosate and GA. For an example, weed management decisions practiced during the ban by those who used Glyphosate only before ban (1) is switching to manual/labour only (a), alternative chemicals only (b) or alternative chemicals and labour (c). Parameters of frequency and labour unit allocation in the theoretical scenario in manual weeding only decision that ensured no yield loss when obtaining the expected yield is higher than the same parameters used by growers when the ban was in place. This is because of constraints on costs on labour and the availability.

The summary of weed control parameters in the estate sector as shown in Table 7.13 can be used similarly to explain weed management decision of continued use of integrated chemical and manual weeding before and during the ban in terms of predicted and actual scenarios. Glyphosate was replaced by Glufosinate Ammonium in the estate sector in both scenarios, but in different doses – higher dose in the actual situation at a low frequency. In the actual situation, the total labour allocation per year on manual weeding is increased than the predicted value by the estate management.

Table 7.12. Summary of parameters used in predicted, theoretical and actual scenarios of weed management approaches in the private grower sector

Scenario		**(1) Glyphosate only before the ban**	**During the ban**							**(2) Glyphosate and labour Before the ban**	**During the ban**		
			(i) Predicted (with GA)	(a) Labour only		(b) Alternative chemicals only		(c) Alternative chemicals and labour			(ii) Predicted (GA and labour)	(d) Alternative chemicals and labour	
				Theoretical	Actual	Actual (with Diuron)	Actual (with Illegal Glyphosate)	Actual (with Diuron and labour)	Actual (with Illegal Glyphosate and labour)			Actual (with Diuron and labour)	Actual (with Illegal Glyphosate and labour)
Chemical weeding	Frequency of application per year	4	4	N/A	N/A	4	4	3	3	3	3	3	3
	Dose of application per round per ha (l/ha)	0.8	0.53	N/A	N/A	0.5	1.2	0.5	1.2	0.67	0.53	0.5	1.2
Manual weeding	Frequency of rounds per year	N/A	N/A	6	4	N/A	N/A	3	3	2	2	3	3
	Labour allocation per round per ha (labour units/ha)	N/A	N/A	15	9	N/A	N/A	8	8	9	9	10	10
Yield (kg/ha/year)		11,856	11,856	11,856	11,441	11,441	11,441	11,441	11,441	11,856	11,856	11,441	11,441

Table 7.13. Summary of parameters used in predicted and actual scenarios of the weed management approach in estate grower sector

Scenario		Glyphosate and labour before ban	Alternative weedicide and labour during the ban	
			Predicted	Actual with Illegal Glyphosate or GA
Chemical weeding	Frequency of applications per year	4	4	3
	Dose of application per round per ha	1.5	1.6	2
Manual weeding	Frequency of rounds per year	2	2	3
	Labour allocation per round per ha	15	15	28
	Yield (kg/ha/year)	8,820	8,511	8,511

Figure 7.4 below graphically illustrates changes in labour allocation and Glyphosate use for a given level of green leaf yield obtained before and with the ban. L1, G1 and L2, G2 are the least-cost input combinations for before the ban and during the ban respectively, that yield the target green leaf yield Y1.

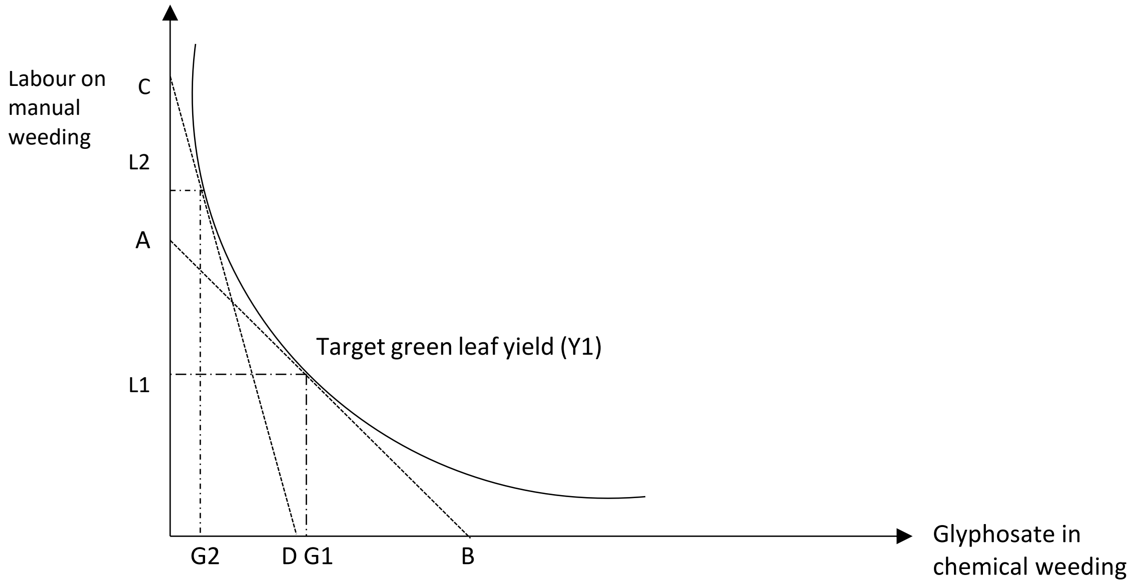


Figure 7.4. Graphical representation of least-cost input combinations for a given level of output

As suggested by the theory, growers try to adjust their inputs during the ban in order to move around the isoquant and maintain the same level of output as before the ban. However, given the influence of external factors such as efficiency of weedicides in controlling weeds, weed pressure on crop growth etc. as explained above, the same yield could not be achieved by growers in the real context. It is assumed that the use of alternative weedicides including illegal Glyphosate with the restricted use of Glyphosate is complementary to increased cost of controlling weeds that eventually lead growers to shift to a different cost curve. Use of illegal Glyphosate products cost more during the ban.

Change in fertilizer subsidy

In addition to changes in weed management practices, wages, green leaf prices, a separate situation was evaluated under each scenario with the effect of the change in the fertilizer subsidy to a cash voucher system that simultaneously implemented during the ban independently as to separate policies. The private tea grower sector was included in this policy decision. Private growers have complained about severe yield losses associated with reduced fertilizer applications because of unavailability of fertilizer at the subsidized price, thus now at a higher price in the open market (See mini appendix 7.7.d). Based on arguments made by tea growers, the fertilizer subsidy change assumed a reduction in the number of application rounds per year from three to one, but still using the recommended dosage per round eventually accounting to a 25 per cent production decline of the potential yield. Price of fertilizer before the ban with the price subsidy and during the ban with the cash voucher system are as given in Table 7.2.

Scenarios identified above in Figures 7.2 and 7.3 based on weed management choices before and during the ban are analysed using financial performance indicators of representative landholdings by developing activity budgets for each scenario. Tables 7.14 and 7.15 are summaries of key financial performance indicators of scenarios under each weed management combination specified for private and estate grower sectors respectively, using parameters specified in Tables 7.12 and 7.13. Table 7.14 is a summary of the table in APPENDIX 5 that provides financial performance indicators of weed management combinations across the predicted, actual and theoretical scenarios.

In APPENDIX 5, financial performance parameters of green leaf production are given in rows, while scenarios in weed management decisions before and during the ban follow the same labelling as in Table 7.12. For example, column labelled as (1) refers to Glyphosate only weed control before the ban, while column (ii) provides the predicted scenario in terms of two instances as with the ban (wb) and during the ban (db). The main column (a) represents theoretical (T) and actual scenarios (A) in terms of with the ban, during the ban and actual scenario with fertilizer subsidy change accounted (AF) for the weed control decision of complete substitution of Glyphosate with labour or manual weeding with the ban in place. Likewise, sub columns in the main column (b) represent comparisons of actual scenarios for weed management decisions complete substitution of Glyphosate by Diuron (D) or Illegal Glyphosate (IG) and substitution of Glyphosate with either Diuron or Illegal Glyphosate and labour respectively, with the ban in place. The main column (ii) refers to predicted scenario of the weed management decision of integrated chemical and manual weeding before the ban - column (2), while sub column in the main column (d) represent corresponding actual scenarios with the ban and during the ban conditions as (AD) and (AIG), and with fertilizer subsidy change accounted as (AFD) and (AFIG) of the weed management decision that used Diuron and Illegal Glyphosate.

Data in Table 7.15 clearly represent financial performance parameters of the estate sector of the weed management combination before and with the ban in place.

7.5.2 Scenario analysis on private grower sector

Chemical weeding only with Glyphosate before its ban

The predicted scenario, continuing the chemical weeding only approach during the ban with the TRI recommended weedicide Glufosinate Ammonium (used as GA in tables), could increase weeding costs by almost 38 per cent with the ban accounting to the higher price of Glufosinate Ammonium compared to Glyphosate (see APPENDIX 5, columns 1 and (ii)). If the predicted scenario was practiced growers could have experienced a contraction of the gross margin by nearly 2.7 per cent with increased chemical cost on weeding.

Complete substitution of Glyphosate with labour

The decision of switching from chemical weeding only to manual weed management during the ban on Glyphosate is referred to in this scenario. Glyphosate is substituted totally with labour on manual weeding.

The sub column (a)(wb)(A) in APPENDIX 5 represents that there has been an increase in weed management cost by 141.9 per cent with the ban corresponding to 350 per cent increase in the labour allocation on weeding when switching from chemical only weeding to manual weeding. This in addition to the decreased green leaf output by 3.5 per cent of the potential/target yield that has eventually led to a gross margin fall by 16.5 per cent with the ban in place. Although growers predicted a gross margin loss by 2.7 per cent at the beginning of the ban with continued chemical weeding using Glufosinate Ammonium, in reality the ban along with fertilizer policy change has resulted in a slight reduction in gross margin by 24.7 per cent. By switching to manual weeding totally, growers could have reached the potential yield with a 40 per cent increase in the total variable cost given the abundant allocation of labour, instead they have achieved 3.5 per cent less of the potential yield at a 11.5 per cent of cost increase. According to data on the theoretical scenario in column (a)(wb)(T), it would have costed 40 per cent more on the total variable cost with the ban, at a reduction of the gross margin by 35 per cent. Instead of incurring a weeding cost increase by nearly 500 per cent accounting to 40 per cent increase in total variable cost to achieve the potential yield, growers have spent 356.63 per cent less on weeding with respect to the theoretical scenario by giving up 3.5 per cent of expected yield as crop loss because of weed pressure. Hence, the amount saved by employing less labour is higher than the income lost with crop damage due to weeds. Decline in the gross margin is greater in actual scenario than predicted scenario under both with ban and during ban conditions and predicted scenarios is eight and two times smaller with the ban and during the ban respectively. Although it was predicted for the gross margin to improve by 45 per cent during the ban, it has shrunk by 17 per cent with the fertilizer subsidy change in place during the ban. Increase in total variable cost, weeding cost and gross margin of the predicted scenario are higher than the theoretical and actual scenario under all conditions.

Complete substitution of Glyphosate by alternative chemicals

This scenario represented in column (b) refers to the continued use of chemicals on weed management in tea fields, by replacing Glyphosate either with Diuron or illicit Glyphosate products. Cost on weeding is increased in general in all these situations as all alternatives were expensive than Glyphosate before its ban. Also, increased doses have resulted in increased chemical cost on weeding.

According to the data shown in the table in APPENDIX 5, using illegal Glyphosate products during the ban has been costlier on landholdings than using Diuron. Although the predicted scenario assumes the use of Glufosinate Ammonium as recommended by the TRI, growers have actually used Illegal Glyphosate mostly and Diuron. The switch from Glyphosate to illegal Glyphosate from informal markets with the ban has resulted in an increase in the total variable cost by seven per cent because of the increased cost on weedicides by 86.42 per cent as such products were overpriced in the black market and used in higher doses. Crop loss associated with their inefficiency with respect to pre-ban Glyphosate in weed control along with cost rise has shrunk the gross margin by 12.64 per cent. Similarly, the change in gross margin with Diuron use was 7.22 per cent with a slight increase in the total variable cost. The predicted scenario would have been a bit expensive than using Diuron, yet cheaper than illegal Glyphosate.

Substitution of Glyphosate with both alternative weedicides and manual weeding

Integrated chemical and manual weed management during the ban represented in column (c) in the table in APPENDIX 5 is looked at in this scenario. It relates to situations where weeds had not been controlled below the ETL with the continued use of weedicides, therefore carrying out weed control with three rounds of either Diuron or illicit Glyphosate per year at respective doses as given in Table 7.11, while incorporating a manual weeding round following each chemical weeding round as an attempt to compensate the inefficiency of Diuron.

This approach of switching from chemical only weed control to using both alternative weedicides and manual weeding rounds to control weeds has resulted in soaring weeding costs by 139.24 per cent and 196.94 per cent with Diuron and illegal Glyphosate respectively, used with supplementary manual weeding with the ban. This is because of increased weedicide cost and added labour costs on manual weeding. Costs of supplementary manual weeding rounds incorporated following chemical weeding rounds accounted to a cost increase by 57.12 per cent with respect to the weeding cost before the policy was implemented. It is evident that actual scenarios with the ban have been considerably expensive than what was predicted with Glufosinate Ammonium in terms of increased total variable costs and reduced gross margins. Growers in this category who used illegal Glyphosate and Diuron have experienced a gross margin fall by 27.88 per cent and 23.82 per cent respectively, during the ban with changes in fertilizer policy.

Use of Glyphosate and manual weeding before the Glyphosate ban

Data in columns (2) and (ii) in APPENDIX 5 that refer to continued use of manual and chemical weeding combined even with the ban on Glyphosate was predicted to be slightly disadvantageous on landholdings because of 17 per cent increase in chemical cost in weeding because of using Glufosinate Ammonium, and respective reduction in gross margin by 2.43 per cent before the ban.

Substitution of Glyphosate and labour with both alternative weedicides and labour

Continuation of weed control with chemicals and labour is referred under this scenario shown in column (d) in the table in APPENDIX 5. Hence, chemical weed management is continued even during the ban period, by doing three manual weeding rounds were carried out with ten labour units per acre per round supplementary to three chemical weeding rounds but being unable to manage weeds below the ETL as shown in Table 7.12.

Data suggests that there was an increased cost on weeding mainly because of more weeding rounds and alternative weedicide use with increased prices and doses. Continuing chemical and manual weeding together with the Glyphosate ban policy in place while trying to compensate inefficiencies of expensive alternative weedicides with extra manual weeding rounds and labour units have resulted in additional 47.35 per cent and 77.88 per cent of costs on weeding with Diuron and illicit Glyphosate, respectively. At the same time, gross margins have been narrowed down by 16 per cent on average with the ban. Actual scenarios are expensive than the predicted scenario in terms of increased costs and reduced gross margins. Even though the increase in gross margin under the predicted scenario during the ban was 47 per cent, growers have experienced declines in gross margin by 22.41 per cent with Diuron and 26.75 cent with illegal Glyphosate, including fertilizer subsidy changes.

7.5.3 Summary of budget parameters of selected actual scenarios in weed management – private tea grower sector

A comparison of budget parameters – percentage changes in weeding cost, gross margin and total variable costs of private tea landholdings that switched from chemical weed management to other different weed management approaches with the ban on Glyphosate as presented in the table in APPENDIX 5 is shown in Table 7.14. This table is quite revealing in several ways as it presents the variation of budget parameters across three situations as; with the ban – considering changes in weed management approach only, during the ban - including wage rate changes, price changes in the green leaf output in addition to changes in weed management, and during the ban with fertilizer subsidy change – accounting to changes in weed management, wage rate and price changes with changes in fertilizer application in the presence of the cash voucher system instead of the usual fertilizer subsidy. The study of budget parameters under these three conditions helps evaluating the impact of the ban under distinct aspects. The true impact of the policy of banning Glyphosate is reflected by 'with the ban' condition since it isolates changes in weed management practice exclusively holding everything else constant. This will essentially help in predicting potential impacts of a similar policy change in the future. The condition 'during the ban' investigates the historical impact of the policy inclusively, price and wage rate variables prevailed in a representative year during 2015 till 2018. Moreover, the actual financial status in the same representative year between 2015 and 2018 is explored under the 'during the ban with fertilizer subsidy change' condition by including the common sequels of the cash voucher system implemented simultaneously to the policy of banning the use of Glyphosate.

Table 7.14 Summary of budget parameters of weed management scenarios (actual) related to the Glyphosate ban in the private tea grower sector

Weed management approaches		With the ban			During the ban			During the ban with fertilizer subsidy change	
Pre ban	Ban in place	% Change in weeding cost	% Change in GM	% Change in TVC	% Change in weeding cost	% Change in GM	% Change in TVC	% Change in GM	% Change in TVC
Composite landholding	Composite landholding	19.61	(9.96)	2.91	55.10	35.01	24.13	(19.54)	20.78
Glyphosate weeding only	Manual weeding only	141.90	(16.55)	11.50	201.15	26.15	33.51	(24.71)	29.98
	Alternative chemical weeding only								
	Diuron	9.50	(7.22)	0.77	22.75	38.72	19.06	12.13	15.54
	Illicit Glyphosate products	86.42	(12.64)	7.00	99.67	33.30	25.30	(17.56)	21.69
	Alternative chemical and manual weeding								
	Diuron and labour	139.24	(16.36)	11.28	188.47	27.04	32.49	(23.82)	28.88
	Illicit Glyphosate products and labour	196.94	(20.43)	15.95	246.15	22.97	37.16	(27.88)	33.55
Glyphosate and manual weeding	Alternative chemical and manual weeding								
	Diuron and labour	47.36	(13.72)	6.76	78.59	31.85	27.29	(22.41)	23.92
	Illicit Glyphosate products and labour	77.88	(18.06)	11.12	109.12	27.51	31.65	(26.75)	28.28

Comparison of budget parameters of landholdings with the ban

The ban on Glyphosate has increased costs for almost all tea landholdings (due to an increase in the cost of weed management) and gross margins decreased with the ban. Parameters calculated for composite landholdings hypothesised based on weighted averages of the distribution of landholdings based on weed management decisions in respective periods suggest increased weeding cost by nearly 20 per cent, total variable cost by 3 per cent, while the gross margin reduced by ten per cent.

Significant impacts of the ban on Glyphosate have been on landholdings that have carried out both chemical weeding with alternative weedicides and supplementary manual weeding together, and those who switched to manual weeding totally with the ban.

Landholdings that controlled weeds using only Glyphosate before its ban and switched to weeding with illegal weedicides along with supplementary manual weeding rounds have incurred an increase in weeding cost of 197 per cent on average and decrease in gross margin by 20.43 per cent with nearly 16 per cent increase in variable costs. This group has the highest increase in weeding cost, total variable cost and the highest decrease in gross margin of all other landholdings. The landholdings that continued to use chemicals regardless of the ban (Glyphosate before its ban and alternative weedicides with the ban) had the lowest change in cost of weeding, lowest total variable cost change and lowest gross margin change. Hence, the least impact of the Glyphosate use policy change has been on landholdings that continued using chemicals only on weed management.

Similarly, the second highest impact has been experienced by landholdings that have continued with integrated chemical and manual weeding throughout the period; using illicit Glyphosate during the ban. The cost of weed management has escalated by 78 per cent, by increasing total variable cost by 11 per cent while declining gross margin by 18 per cent.

Subsequently, landholdings that have completely substituted Glyphosate using labour with the ban in place have had incurred a considerable cost in their cultivation with their weeding cost soring by 142 per cent, gross margin shrinking by 16.5 per cent and total variable costs increasing by 11 per cent.

Comparison of budget parameters of landholdings during the ban

All budget parameters show an improvement during the ban because variables in addition to weed management decision related are subjected to change and reflect prices in the year 2017. Accordingly, the composite landholding has incurred an increase in weeding cost and total variable cost by 55 per cent and 24 per cent respectively, while the gross margin as well has improved by 35 per cent. An interesting aspect of this table 7.15 is the gross margin of almost all landholdings have increased during the ban. The main reason behind this phenomenon has been improved green leaf prices over the period of the ban. The representative price of green leaves during the ban used in the calculation of budget parameters is Rs. 90.69 which was the average price prevailed during 2017 (representative year during the ban). In fact, average annual green leaf prices prevailed throughout years during the ban have had significant improvements than they used to be before the ban because of better prices received at the auction for made tea during the ban. Furthermore, variable costs during the ban show an increase compared to 'with the ban' condition because of soring wage rates of hired labour also influenced by labour shortage. However good green leaf prices during the ban have reduced the shock on landholdings to go into financial difficulties.

The highest total variable cost change of 37.16 per cent and lowest change in gross margin by 62.24 per cent during the ban were reported in the representative landholding that carried out chemical weeding with illicit Glyphosate products followed by manual weeding rounds using labour. The representative landholding that had completely shifted from chemical only weeding to weeding with labour has incurred the second highest weeding cost increase and lowest gross margin improvement. The highest gain on gross margins during the ban was experienced by landholdings that continued with chemical only weed management, reporting 83 per cent and 76 per cent increase using Diuron and illegal Glyphosate, respectively. Yet incurring the lowest rise in total variable costs by 22.18 on average.

Comparison of budget parameters of landholdings during the ban with fertilizer policy change

Although two policies about Glyphosate use and fertilizer subsidy change were implemented independently, especially private tea growers faced the joint effect of both together. Having to buy fertilizer at the market price which was more than double the price paid on subsidized fertilizer, most private growers have reduced amounts of fertilizer applied. The scenario under consideration that evaluates the impact of the fertilizer policy change as well assumed applying only one round of fertilizer within the year.

Changes in total variable costs under this condition in almost all landholdings were higher than 'with the ban' scenarios, but lesser than 'during the ban' scenarios. The latter condition was resulted with reduced cost on fertilizer application within the year. Total variable costs could've gone up if the number of fertilizer application rounds were increased more than one. Under the current context, all landholdings have experienced variable cost increases ranging from 15.5 per cent to 34 per cent because of increased wage rates, chemical and fertilizer prices. Owing to 25 per cent yield reduction resulted from reduced fertilizer application, most tea cultivations except for those continued with chemical weeding only, have had their gross margins shrinking or slightly improved.

So, the composite landholding has incurred 20 per cent increase in weeding cost with a fall in gross margin by 20 per cent. The largest shock on gross margin was experienced by representative landholding that switched from chemical weeding only with Glyphosate to chemical weeding using illegal Glyphosate products with supplementary manual weeding, having a 4.9 per cent drop associated with 33.63 per cent variable cost rise. Those who completely substituted Glyphosate with labour for weeding have experienced the slightest gross margin reduction out of the others but incurred almost 30 per cent cost increase. Landholdings that were better off with minimal impact during the ban with the fertilizer policy change had been those who continued chemical weeding only with Diuron and illegal Glyphosate products.

7.5.4 Scenario analysis on estate grower sector

The only scenario to be evaluated in the estate sector is the continued use of integrated chemical and manual weeding approach throughput the period.

Use of chemical and manual weeding before the policy implementation

Parameters related to predicted and actual scenarios of this weed management combination are given in Table 7.12 in Section 5.7.1. Accordingly, Glyphosate used before its ban is replaced by Glufosinate Ammonium during the ban in both predicted and actual scenarios, but in different dosages. Additionally, in the actual scenario during the ban, three chemical weeding rounds were practiced instead of four times using either illicit Glyphosate products or Glufosinate Ammonium with two manual weeding rounds at a rate of 28 labour units per ha during the ban instead of 17 labour units per ha.

The sample of RPC tea cultivations that fall under the estate sector manage considerable extent of more than 200ha. The only weed management option with the Glyphosate use policy change in this sector has been continued use of the same approach as they did before the ban, by replacing Glyphosate with alternative chemicals. As revealed during interviews, the estate sector has vastly used either illicit Glyphosate products or Glufosinate Ammonium under the trade name Basta.

According to the data in Table 7.15, as predicted at the beginning/ initial period of the ban if estates replaced Glyphosate with Glufosinate Ammonium and continued with same manual and chemical weeding frequencies without any change, they could have incurred 52.48 per cent and 4.45 per cent increase of cost on weeding and total variable cost respectively, as Glufosinate Ammonium is quite expensive than Glyphosate, with only 11.61 per cent gross margin reduction with the ban in place.

However, estates as well experienced harder times owing to increased manual weeding efforts with reduced efficiencies of other weedicide options, and yield decline eventually. Substituting Glyphosate with illegal products of Glyphosate or Glufosinate Ammonium has been expensive – with increased weeding costs when using 100.27 per cent and 141.38 per cent respectively with the ban in place because of increased prices and quantities of chemicals related to inefficiencies. Simultaneously, gross margins have declined by 34.8 per cent and 43.9 per cent in estate holdings that used Illegal Glyphosate products and Glufosinate Ammonium respectively, along with supplementary weeding rounds.

Similarly, the same trend in cost changes could be seen during the ban because of the escalation of wage rates of estate labour. Thus, weeding costs soared by 126.6 per cent and 167.7 per cent during the ban leading to 26.2 and 29.7 per cent increase in total variable costs on using Illegal Glyphosate and Glufosinate Ammonium respectively. Given that with better prices for green leaves during the period of the ban imputed from the private tea grower sector, gross margins in the estate sector have improved by 38.6 per cent and 29.2 per cent in estate holdings that have used Illegal Glyphosate and Glufosinate Ammonium respectively.

Table 7.15 Budget parameters of scenarios related to continued chemical weed management using illicit Glyphosate and Basta, and supplementary manual weeding in the estate sector

Parameters	Units	Before the ban with Glyphosate	With the Glyphosate ban			During the Glyphosate ban		
			Predicted scenario With GA	Actual scenario with IG	Actual scenario with GA	Predicted scenario with GA	Actual scenario with IG	Actual scenario with GA
Cost of manual weeding	Rs/ha	18,600	18,600	46,500	46,500	21,900	54,750	54,750
Cost of chemical weeding	Rs/ha	17,890	37,040	26,580	41,580	38,880	27,960	42,960
Cost on weed management	Rs/ha	36,490	55,640	73,080	88,080	60,780	82,710	97,710
Total variable cost	Rs/ha	430,765	449,923	467,363	482,363	521,760	543,690	558,690
Gross income	Rs/ha	595,703	595,703	574,853	574,853	799,886	771,890	771,890
Gross margin	Rs/ha	164,938	145,780	107,491	92,491	278,126	228,200	213,200
Change in GM	Rs/ha	N/A	(19,158)	(57,447)	(72,447)	113,188	63,262	48,262
% Change in GM	%	N/A	(11.61)	(34.83)	(43.92)	68.62	38.36	29.26
Change in TVC	Rs/ha	N/A	19,158	36,598	51,598	90,995	112,925	127,925
% Change in TVC	%	N/A	4.45	8.50	11.98	21.12	26.21	29.70
% Change in weeding cost	%	N/A	52.48	100.27	141.38	66.57	126.66	167.77

7.5.5 Comparison of the impact of Glyphosate ban across private and estate grower sectors

A wide variation in weed management approaches in the private tea landholding sector unlike the estate sector can be seen generally because of the diversity in the extent of land holdings, availability of family labour, well-managed VP tea cultivations with minimal vacancies and good agricultural practices and so on. Characteristics of most plantation units in the estate sector such as land extent range, labour use and management hierarchy are the same except for company-specific practices relating to frequencies of practice and labour allocation. However, the effect of the ban on tea growing entities have been approximately the same.

Data from Table 7.14 and Table 7.15 suggest that the ban has severely affected gross margins of both sectors to shrink. The impact has been far more severe in the estate sector than the private grower sector representative landholding that continued with integrated chemical and manual weeding. The estate sectors weeding cost has almost doubled while adapting to the Glyphosate ban.

On the other hand, regarding the private grower sector, the highest effect of the ban was faced by landholdings that switched from Glyphosate weeding only to integrated chemical and manual weeding particularly with illicit Glyphosate products, affecting the financial status of green leaf production businesses by incurring extra costs on weeding.

The issue with both sectors using alternative chemicals to Glyphosate during the ban was that the impact has been worsened because of high/unregulated prices in alternative weedicides (in case of illicit Glyphosate products) and inefficiencies of such alternatives available during the ban. Growers had to increase doses of chemicals and more labour units to compensate for inefficiencies. Eventually, these landholdings had been worse-off in terms of increased costs and making least profits of the business.

Cost increases in the estate sector are severe because of the nature of their operation within a limited budget. These estimated costs ignore costs/ loss of income because of abandoning marginal tea lands.

7.6 Summary

A cost analysis of weed management approaches and activity gross margin budgets of representative landholdings under the two periods before and during the ban on Glyphosate is shown. First, costs of weed management approaches practiced by grower sectors across the two periods are analysed. Data suggested manual only weed control as the most expensive approach before the ban because of the labour-intensive nature of the method. Integrated chemical and manual weed control approach has incurred the highest cost approach during the ban because of increased cost on labour and chemicals on weeding with increased weed control efforts. In the meantime, availability of over-priced weedicides labelled as Glyphosate in the informal market has eventually led to unexpected increase in chemical costs. Chemical only weeding approach was found to be the least costly method because of lesser labour employment on the activity, but it is not identified as an effective weed control method. Trends in the costs of different weed management approaches was reflected on activity budgets of representative landholdings categorized based on the weed management approach.

A scenario analysis is carried out on representative landholdings categorized based their on weed management approaches before and during the ban practiced by growers in the study sample as identified in Chapter 6. This cost analysis allowed study budgetary changes on green leaf production of those representative landholdings in terms of change in total variable costs and gross margins. Data from this gross margin budget analysis revealed that highest cost changes were incurred by landholdings that substituted Glyphosate with illegal Glyphosate and labour with the ban in place, and landholdings that continued with integrated chemical and manual weeding but substituted Glyphosate with illegal Glyphosate and extra manual weeding. The least cost was incurred by landholdings that just substituted Glyphosate with alternative illicit weedicides in chemical only weed management during the ban. Changes of total variable costs calculated for the representative landholdings in the private grower and estate sector are used as inputs in the EDM in evaluating the impacts of the ban on tea grower sector in Chapter 8.

7.7 Mini appendix (supporting quotes from field interview transcripts)

(a) "*Chemical application is done by 2 labourers in 1 ac within a day*" (G7).

"*For Glyphosate spraying it takes around 4 labour days to complete 1 ac because weedicide spraying is done only half a day and the full daily wage is paid. This is because it is very heavy to carry the 16l knapsack tank. For one day, it requires 2 labourers for the activity, one to carry water, do the mixing and the other to spray it*" (K3).

"*Weedicide application required two labourers, one to bring water to the tea field*" (R6).

(b) "*These days the wage rate is Rs.1200/day with food, and cost has increased over years. So, a slight labour cut offs on weeding was done, by hiring around 20 labourers in some rounds"* (G6).

"But had to cut down some labour hired on weeding because of shortage and increasing labour rates" (B6).

(c)" Wage *rate drastically increased during the past five years was, Rs. 800 in 2015, Rs.1000 in 2017, Rs.1200 in 2018 and Rs. 1500 at present. Labourers tend to increase their wages in multiples of 100 Rupees regardless of minimum wages imposed*" (TSHDATIK).

"*Since there is a labour shortage, the demand is so high for labour, thus most of the smallholders must be more flexible with the time and payments as demanded by labourers*" (R3).

"*He pays Rs. 1500/day (higher than the other landholdings) to retain labour in the field*" (R9).

(d) "*There was a fall in the yield by 25 per cent due to reducing the amount of fertilizer*" (B2).

"*25 per cent yield drop due to low fertilizer application. Fertilizer applied 3 times a year. During the ban this dropped to once a year"* (K1).

Chapter 8 Welfare Analysis of the Impacts of the Glyphosate Ban on the Tea Industry

8.1 Introduction

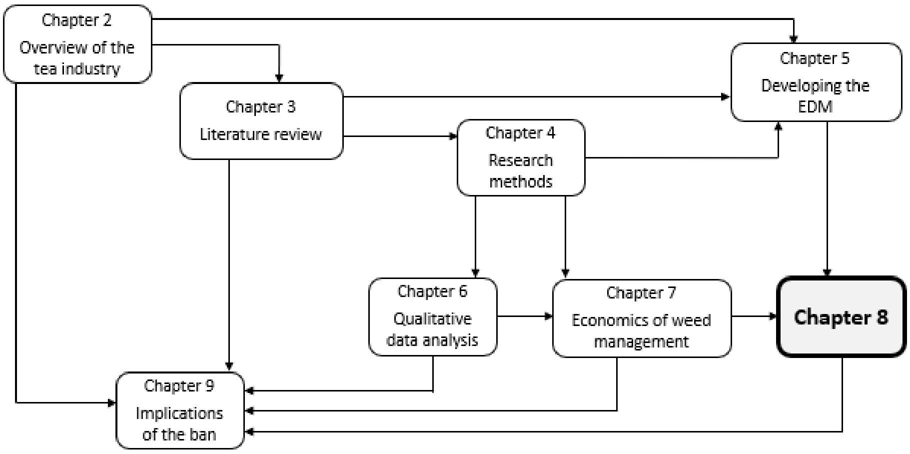


Figure 8.1. Flow of chapters in the thesis

In this chapter the fourth objective of the study is addressed, that is, estimating the welfare changes of the ban on Glyphosate on key market levels along the value chain of the tea industry in Sri Lanka. The policy banning the use of Glyphosate in the tea industry was described in Chapter 3. This policy relates only to the farm sector, where the direct effects were outlined in Chapters 6 and 7. The impacts on the rest of the value chain are consequences of the adjustments caused by the ban in decision making at the farm sector. These effects and consequences of the ban are evaluated using the EDM developed for the tea industry in Sri Lanka in Chapter 5, which has also been technically validated using hypothetical scenarios that assume shocks on different market levels in the industry.

The impacts of the ban on the farm sector with respect to weed management decisions made in representative landholdings under different production scenarios, in terms of changes in variable costs of production, as described in Chapter 7, are used as inputs in the EDM in this Chapter as presented in Figure 8.1. Furthermore, an unintended consequence of the ban in terms of a demand decline in VAT exports was also evaluated. In the EDM these changes in costs and demand are modelled as shocks on exogenous variables – also known as k-shifts - that displace the system of equations and eventually create a new equilibrium depending on the length of run assumed in the specification of the elasticity values. The resulting estimated changes in market prices and quantities, and in surplus changes and their respective distributional impacts due to the modelled imposition of the ban across all market levels in the tea value chain are presented in Tables 8.2 and 8.3. Subsequently, sensitivity analyses were conducted for each scenario to monitor changes in model outcomes using the @RISK program (as done on one of the hypothetical scenarios in Chapter 5). The @RISK distributions of economic surplus changes are presented in Figures 8.2 and Figures in APPENDIX 6.

The economic surplus changes across key market levels of the effects and consequences of the ban are interpreted and discussed further in Section 8.3.4. The key findings of this chapter are discussed in Chapter 9 highlighting implications of the ban on the farm sector of the tea industry as shown in Figure 8.1.

8.2 Descriptions of scenarios reflecting the impact of ban on the tea industry tested on the Equilibrium Displacement Model

The direct impacts of the ban are changes in farmer decision making which impact on the variable costs of production. These were outlined in detail in earlier chapters. These changes in costs of production at the farm level create subsequent price and quantity changes throughout the value chain, including in domestic and export markets for Sri Lankan tea. Some of these subsequent changes could be described as unintended consequences of the ban. One such impact was a decrease in demand for bulk tea exports brought about by higher than permitted MRLs by the misuse of substitute chemicals for Glyphosate.

To cover both of these broad areas, the impact of the ban on the tea industry was evaluated using two main scenarios: (i) increased variable cost of production in the farm sector and (ii) decrease in the demand for bulk tea exports for an international market.

An assumption is made on the inputs used from Chapter 7 on the EDM – that are the in the private grower and estate sector in the scenario (i). Hence, the parameters - percentage changes in total variable costs per hectare in private grower and estate sectors are used as measures of the impacts of the Glyphosate ban on percentage changes in average variable cost of production - k shifts - in the farm sector. The basis for the assumption is small yield changes in farm sectors with no large difference between percentage changes in total and average variable costs. The average variable cost of production is the common measure for k shift that is taken across to the EDM on industries.

8.2.1 Increased variable cost of production in the farm sector

The farm sector comprises both private and estate landholdings. A representative combination of weed management decisions taken with the Glyphosate ban in place is made by using the respective weighted averages of the distribution of landholdings in each grower sector in this main scenario. This refers to the composite landholding of the private tea grower sector shown in Table 7.14 in Chapter 7 that assumes a landholding that has carried out all weed management approaches selected for the analysis. The average of 'actual scenarios' of the representative landholding in Table 7.15 is referred to for the estate grower sector.

The increased variable cost scenario is further disaggregated into three more specific production scenarios: 'with the Glyphosate ban in place', 'during the ban' and 'during the ban with the cash voucher system in place'. The formal definitions for these conditions were provided in Section 7.5.1 in Chapter 7.

Table 8.1 is a summary of increased variable costs of production in representative composite landholdings of private and estate grower sectors under the specified production scenarios with respect to the ban on Glyphosate.

Each of these scenarios indicate increases in variable cost in both tea grower sectors. In the modelling these are represented as upward shifts of the respective supply curves under each production scenario. In each scenario there is a larger shift in the estate sector than in the private sector, and in the 'with the ban' scenario the increase in variable cost in the estate sector as a percentage is three times higher than that in the private sector.

Table 8.1. Changes in variable costs in the farm sector

	Scenario	Increase in the variable cost of production in the farm sector		
		Actual scenario (what growers practiced with the ban in place)		
		With the ban	During the ban	During the ban with fertilizer subsidy change
	Parameters changed	only weed management parameters changed	weed management parameters and wage rates changed	weed management parameters, wage rates and fertilizer application rates changed
Inputs (k shift as a percentage)	Increase in VC			
	Private growers	2.91	24.13	20.78
	Estate growers	10.24	27.96	27.96

Each upward shift in supply results in changes in prices and quantities of products in all market levels and they are listed in Tables 8.2 and 8.3 as percentage changes in prices and quantities respectively.

8.2.2 Decline in demand for value-added black tea exports

This scenario relates to an unintended consequence of the Glyphosate ban on the export marketing of tea products. Given that tea growers used more hazardous and non-recommended weedicides such as Diuron, MCPA and illegal Glyphosate products from the black market for weed control in the absence of Glyphosate, there were instances where tea consignments were rejected by importing countries because of weedicide residues exceeding MRLs in tea products exported were detected (Marambe and Herath 2019).

This situation has been referred to in this scenario as a demand decrease in tea exports. Specifically, the rejection of tea consignments exported from Sri Lanka to Japan in 2017/18 due to excessive MRLs of MCPA in tea products (news.lk 2019) was evaluated. Sri Lanka is usually one of the top black tea exporters to Japan with bulk tea covering a major share of exports (Sri Lanka Export Development Board 2021). Tea exports to Japan in 2018 dipped from 8 million kgs in 2017 to 7.5 million kg in 2018 (news.lk 2019).

Consequently, it is assumed that the export demand by Japan for bulk tea exports declined by 6.25 per cent between 2017 and 2018 during the ban. This was considered as an unintended consequence of the ban that has led to a shock on demand for bulk black tea as Japan is a main destination of Sri Lankan tea exports. Since the Japanese market is not directly specified in the EDM, when applying the shock on the overall demand of bulk tea, this demand reduction was converted to a proportion of total bulk tea exports to be used as an input in the EDM. Therefore, this decline is expressed as 0.39 per cent of total bulk tea exports.

8.3 Results of the welfare analysis of selected scenarios using the Equilibrium Displacement Model

Results of the welfare analysis of different scenarios with respect to the Glyphosate ban are evaluated in terms of changes in prices, quantities and economic surplus, with their distributions across market levels.

8.3.1 Percentage changes in prices

Table 8.2 is a representation of percentage changes in prices of tea products at each market level along the value chain specified in the EDM in response to the exogenous shocks specified above. Price changes of the shock on farm sectors across different scenarios are straight forward with all positive changes implying price increases because of the increased variable costs in variable inputs.

In all scenarios related to shocks on the farm sector, the highest and lowest price increase could be seen in the auction price of primarily processed tea used for secondary processing of domestically consumed value-added tea and price of bulk black tea to export market respectively, although no price variations were assumed across primarily processed tea used in secondary processing for exports and domestic consumption in the initial equilibrium. This is because of the changes across markets and products. Once the export market is restricted, some of the VATs get transferred to other lower value export markets and domestic consumption. There has been an increase of green leaf price by 2.5 percent, 13.4 per cent and 12 per cent with the ban, during the ban and during the ban with the cash voucher system for fertilizer in place respectively, (while change in the green leaf price between 2014 and 2017 has had an increase by 34.27 per cent).

Table 8.2. Percentage changes in market prices reflecting shocks on the tea industry

Price variable	Proportionate change in price			
	Shocks on tea grower sectors			Shock on bulk tea export sector
	With the ban	During the ban	During the ban with fertilizer subsidy change	
Price of GL	0.0248	0.1344	0.1206	-0.0013
Auction price of primarily processed tea used to produce bulk black tea for export markets	0.0057	0.0307	0.0275	-0.0043
Auction price of primarily processed tea used to produce value-added black tea for export markets	0.0089	0.0484	0.0434	0.0009
Auction price of primarily processed tea used to produce bulk black tea for domestic markets	0.0289	0.1565	0.1405	0.0031
Auction price of primarily processed tea used to produce value-added black tea for domestic markets	0.0769	0.4164	0.3736	0.0082
Price of bulk black tea to export market	0.0026	0.0143	0.0128	-0.0037
Price of value-added black tea to export market	0.0021	0.0114	0.0103	0.0002
Price of bulk black tea to domestic market	0.0132	0.0714	0.0641	0.0014
Price of value-added black tea to domestic market	0.0264	0.1429	0.1282	0.0028

Furthermore, the demand reduction in bulk tea exports has resulted in different outcomes across market levels in the industry that it clearly represents a shock on one part of the industry and not on the other. Accordingly, with the demand decline in bulk tea exports, price received for green leaves in the farm sector, primarily processed tea used to produce value-added black tea for export markets sold at the auction, and bulk black tea sold to export markets have declined. Simultaneously, all the other tea products in the rest of the market levels had prices improved upon the demand decline as presented in Table 8.2. The highest increase in price could be seen in the auction price of primarily processed tea used to produce value-added black tea for domestic markets as also seen in other scenarios.

Differences in prices can be observed because of changes across markets and products. There are distinctions within market sector and across sectors. For example, private and estate growers in the farm sector differ from each other in many aspects including the scale of production, cost structures, contribution to the total production. Also, as clearly explained in Chapter 5 about the relationship between market levels in the value chain while developing the model, they are all interrelated where an output in one market level becomes an input in the next market level. Hence, when there is a shift in one sector, that effect is transferred to other sectors in varying degrees eventually resulting in different price changes.

8.3.2 Percentage changes in quantities

Changes in quantities of tea products traded at market levels with respect to shocks on the farm sector and bulk tea export marketing sector are given in Table 8.3.

Table 8.3. Percentage change in quantities reflecting shocks on the tea industry

Quantity variable	Proportionate change in quantity			
	Shocks on tea grower sectors			Shock on bulk tea export sector
	With the ban	During the ban	During the ban with fertilizer subsidy change	
Quantity of green leaves supplied from the green leaf producing private sector to the black tea manufacturing sector	0.0013	-0.0550	-0.0428	-0.0012
Quantity of green leaves supplied from the green leaf producing estate sector to the black tea manufacturing sector	-0.0417	-0.0629	-0.0734	-0.0010
Total national green leaf production	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of black tea from the manufacturing sector to the bulk tea export marketing sector for secondary processing	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of black tea from the manufacturing sector to the VAT export marketing sector for secondary processing	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of black tea from the manufacturing sector to the loose bulk tea domestic marketing sector for secondary processing	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of black tea from the manufacturing sector to the VAT domestic marketing sector for secondary processing	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of bulk black tea from secondary processing to export market	-0.0105	-0.0571	-0.0513	-0.0011

Quantity of value-added black tea from secondary processing to export market	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of bulk black tea from secondary processing to domestic market	-0.0105	-0.0571	-0.0513	-0.0011
Quantity of value-added black tea from secondary processing to domestic market	-0.0105	-0.0571	-0.0513	-0.0011

The shock on the farm sector in the tea industry with increased variable costs of production has yielded an improvement in the quantity of green leaves produced in the private tea grower sector by 0.13 per cent under the 'with the ban' scenario that takes only the changes in weed control parameters into account. This is in contrary to what was expected. One explanation for this is that this could be a result of inaccuracies of the data, as the percentage change in quantity of green leaves produced in the private grower sector is very close to zero. Alternatively, it is also possible that relative changes in cost shares are enough to divert some of those lower cost inputs from estate to private grower sector. However, with respect to the other two scenarios – 'during the ban' and 'during the ban with the cash voucher system in place' the private grower sector has experienced the anticipated quantity reductions.

Besides that, all other market levels in all scenarios including shock on bulk tea exports have followed the same trend with decline in quantities as expected.

8.3.3 Economic surplus changes and their distributions across market levels

This section outlines changes in the economic surpluses and distributions across market sectors in the tea industry from shocks on the farm sector and bulk tea export marketing sector.

It should also be noted that the distribution of the total economic surplus change across different market sectors for a given scenario is independent of the size of the initial shift. This is clearly represented that apart from the changes in distributions of producer surplus in private and estate grower sectors in the farm sector, distributions of surplus shares across all other market sectors are close to each other, consistent and move in the same direction as expected in all three scenarios related to variable cost increases. This is due to the assumption of parallel shifts in supply and demand and provides more evidence and reassurance on validation of the EDM.

It can be also observed that these shares of surplus distributions have a variability across scenarios at the market level where the shock takes place – farm sector, however the variability diminishes when moving away from that market level. Table 8.4 is a summary of economic surplus changes and their

Table 8.4. Economic surplus changes (Rs. million) and surplus distributions (%) across market levels in the tea industry

	Scenario	Increase in the variable cost of production in the farm sector						Loss of demand for bulk exports to Japan 2018 with respect to 2017	
		Actual scenario (what growers practiced with the ban in place)							
		With the ban		During the ban		During the ban with fertilizer subsidy change			
	Parameters changed	only weed management parameters changed		weed management parameters and wage rates changed		weed management parameters, wage rates and fertilizer application rates changed			
Inputs (k shift as a percentage)	Increase in TVC							Decline in demand	
	Private growers	2.91		24.13		20.78		2.75	
	Estate growers	10.24		27.96		27.96			
Outputs		Rs. m	%	Rs. m	%	Rs. m	%	Rs. m	%
Producer surplus	Private grower sector	93.46	(2.68)	(3,816.16)	21.56	(2,993.45)	18.70	(83.82)	23.61
	Estate grower sector	(1,341.88)	38.41	(2,003.40)	11.32	(2,326.18)	14.52	(31.94)	8.99
	Farm sector (subtotal)	(1,248.42)	35.73	(5,819.56)	32.88	(5,319.63)	33.22	(115.8)	32.60
	Black tea manufacturing sector	(449.98)	12.88	(2,380.70)	13.45	(2,142.73)	13.38	(47.94)	13.50
	Secondary processing for bulk tea exports	(174.73)	5.00	(924.46)	5.22	(832.05)	5.20	(18.62)	5.24
	Secondary processing for VAT exports	(271.57)	7.77	(1,436.80)	8.12	(1,293.18)	8.08	(28.93)	8.15
	Secondary processing for domestic consumption of loose bulk tea	(7.89)	0.23	(41.74)	0.24	(37.57)	0.23	(0.84)	0.23
	Secondary processing for domestic consumption of VAT	(174.04)	4.98	(920.81)	5.20	(828.77)	5.18	(18.54)	5.22
	Total producer surplus	(2,326.63)	66.59	(11,524.07)	65.11	(10,453.93)	65.29	(230.64)	64.96
Consumer surplus	Black tea exports in bulk form	(234.11)	6.7	(1,238.60)	7.00	(1,114.80)	6.96	(24.94)	7.02
	Black tea exports in value-added form	(155.02)	4.44	(820.16)	4.63	(738.18)	4.61	(16.51)	4.65
	Black tea in loose form for domestic consumption	(24.76)	0.71	(131.00)	0.74	(117.91)	0.74	(2.63)	0.74
	Black tea in value-added form for domestic consumption	(753.30)	21.56	(3,985.47)	22.52	(3,587.09)	22.40	(80.26)	22.60
	Total consumer surplus	**(1,167.19)**	**33.41**	**(6,175.24)**	**34.89**	**(5,557.98)**	**34.71**	**(124.36)**	**35.03**
Total economic surplus		**(3,493.82)**	**100**	**(17,699.31)**	**100**	**(16,011.91)**	**100**	**(355.00)**	**100**

distribution as a percentage of the total economic surplus change across market levels in the tea industry resulted from exogenous shocks on supply and demand in the farm sector and VAT export marketing sector respectively. In addition to all market levels, the entire producer and consumer sectors aggregated separately to give changes in producer and consumer surpluses.

Increased variable cost of production in the farm sector

There is a larger shift in the estate sector relative to the private sector in terms of the variable cost change under 'with the ban' scenario. The percentage increase of variable cost in the estate sector is three times higher than that in the private sector. This scenario indicates that the private tea grower sector has better off with an economic surplus gain by Rs. 93.5 million annually with the ban in place by producing green leaves. Conversely, the estate sector has faced a loss in economic surplus by Rs. 1,342 million annually because of the ban. A possible reason for this outcome of positive surplus change on the private grower sector could be spill over effect of increased costs in the estate sector. As the production declines in the estate sector, that could result in inputs not being used in the sector, making it available for the private grower sector to be used on their production as cheaper inputs, leading to a likely productivity gain. Alternatively, another plausible argument for the surplus gain in the private tea grower sector could be errors and inaccuracies in the model that has produced positive surplus, while the private sector was not much affected as the estate sector did.

However, the other two scenarios – 'during the ban' and 'during the ban with the cash voucher system in place' that no longer hold variabilities in wage rates and fertilizer application parameters constant in addition to weed control parameters have incurred cost increases that are much closer and have yielded productivity losses in both tea grower groups of the farm sector. This is because, the magnitude of the surplus loss from increased labour wage rates is much larger and exceeds the productivity gain in the private sector if there is any, while holding labour wage rates constant. This indicates a loss of economic surplus by Rs. 5,820 million and Rs. 5,320 million annually to the farm sector during the ban and during the ban with changes in fertilizer application because of the change in the fertilizer subsidy considered respectively.

Apart from the farm sector, every other market sector across all scenarios in TVC increase has experienced economic surplus losses with the ban on Glyphosate in place as presented in Table 8.4. The entire producer sector has faced the biggest impact of the ban annually indicating a loss in total producer surplus by Rs. 2,327 million per year with the ban if only weed management was changed, however the effect of increased wage rates and cash voucher system in the fertilizer subsidy has exacerbated the situation of producers to be worse off by more than Rs. 1,454 million annually.

Correspondingly, the total consumer surplus changes as well reflect Rs. 1,167 million per year and more than Rs. 5,558 million losses per year to all consumers for with and without changing variables (labour wage rates and fertilizer application parameters) respectively.

Overall, changes that have taken place in the farm sector with respect to changes in weed management activities as a response to increased variable costs affected by the Glyphosate ban has resulted in a total economic surplus loss annually by Rs. 3,494 million. However, as computed by the EDM, the shock on the farm sector by banning Glyphosate along with increased labour wage rates has resulted in losses of nearly Rs. 17,700 million annually, worsening the tea industry and national economy.

With the changes pertaining to fertilizer application activity with the cash voucher system introduced during the ban instead of the price subsidy change are taken into account, the change in the total economic surplus calculates a loss in value by Rs. 16,012 million per year.

Demand decline in value-added black tea exports

Tea exports rejected from specific international markets as an unintended consequence of the Glyphosate ban was modelled as a shock on bulk tea export demand. As presented in table 8.4, it has led to surplus losses in all market levels, while producers were worse-off having to incur a cost of Rs. 230.6 million. The farm sector as individual market level has faced the largest loss of surplus by Rs. 115.8 million, while Rs. 83.8 million were borne by private growers although the initial shock took place in the bulk tea export sector.

With respect to consumers in the tea industry, domestic consumers of VAT tea were the most impacted group even though the shock was on the bulk tea export sector. Domestic consumers of VAT have incurred a loss of Rs. 80.2 million with the reduction in demand for bulk exports.

Reduction in the demand for bulk tea exports from Sri Lanka to an important market like Japan has led to consequences of losing Rs. 355 million of value to the industry. This is a cost that was incurred on the tea industry in addition to the effects caused by the change in variable costs in the farm sector.

Comparison of economic surplus change distributions across market sectors

The farm sector – especially the estate tea grower sector has incurred more than 35 per cent or one third of the total economic surplus. The farm sector was heavily affected by the ban on Glyphosate because there was no effective alternative for Glyphosate. In the other two scenarios 'during the ban' and 'during the ban with the cash voucher system in place', the private tea grower sector bore the highest share of losses. The total economic surplus loss was 20 per cent because of increasing labour wage rates and having to buy fertilizers at higher prices, while the estate sector lost between 9 to 14.5 per cent of total economic surplus. Overall, it was always producers who were worse off, bearing around 65 per cent of the declined total economic surplus.

On the other hand, consumers have shared only 34 per cent of total losses, with highest cost on domestic consumers of VAT by 22 per cent.

8.3.4 Notes about results of scenario analysis using the EDM

The changes in prices, quantities and economic surpluses across market sectors in the tea value chain obtained using the EDM may not give the same results as occurred over this time. This section highlights several plausible arguments as to why this could be the case.

The outputs derived from this modelling work are indicative of the whole industry, being approximations calculated based on several assumptions and not exact measures of impacts. As the study attempts to investigate the research question from many different points of view, each aspect would give different answers. There could be variabilities in the actual impact of the Glyphosate ban across market levels as there were a series of assumptions hypothesized while developing the model. The activity budgets do not cover every possibility. This is because findings from the survey and interviews reflect detailed disaggregated data about what happens in individual farms. The economic model averages all those detailed data and eventually generalizes to the whole industry.

For instance, the representative composite landholding in the private sector is a hypothesized landholding that is assumed to carry out all weed management approaches specified by private growers in the study sample, in respective proportions of their distribution. The proportionate distribution of private tea landholdings based on their weed management approaches before and during the ban are given in Table 8.5. Change in the variable cost in the private grower sector has been calculated based on this distribution. However, there could have been other proportionate distributions of weed management approaches in the private grower sector with the ban.

Furthermore, according to findings of interviews with private tea growers, it is obvious that there had been numerous combinations and variations in resource use on weed management approaches. Variable cost and gross margin calculations were done for representative landholdings based on several assumptions averaging variables that might be different from actual resource use.

Table 8.5. Distribution of private tea landholdings before and during the ban based on the weed management decisions

Weed management decisions		Distribution (%) of landholdings with the ban
Before the ban	During the ban	
Glyphosate only	Labour only	0.17
Glyphosate only	Alternative chemicals only	0.06
Glyphosate only	Alternative chemicals and labour	0.14
Labour only	Labour only	0.43
Labour only	Alternative chemicals and labour	0.06
Labour and glyphosate	Alternative chemicals and labour	0.14

Therefore, the analysis of shocks on demand and supply of banning Glyphosate in this study does not take account of every possibility of landholding distribution or cost shares. The model is available to interested parties for investigating any sort of scenario relating to the Glyphosate ban.

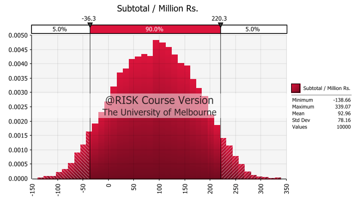
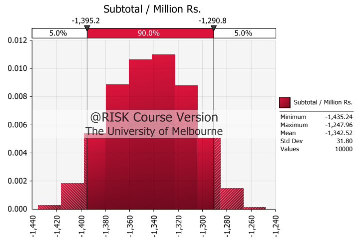
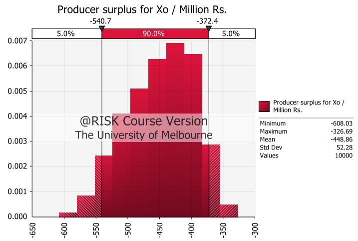
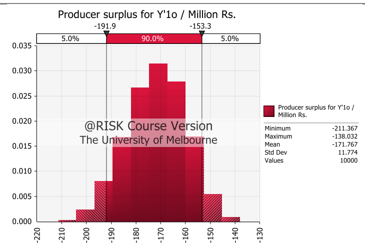
Another argument for any differences between EDM predictions and actual outcomes is that the model becomes less reliable because of the assumed linearity of demand and supply curves) as the value of the k shift increases indicating shifts further away from the initial equilibrium. The model provides good approximations of price and quantity changes from small parallel shifts from the initial equilibrium.

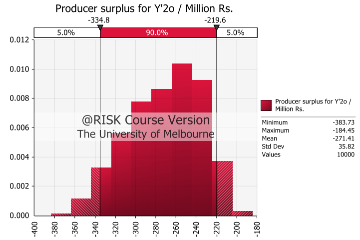
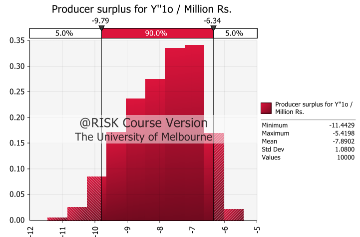
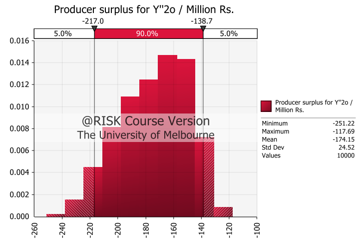
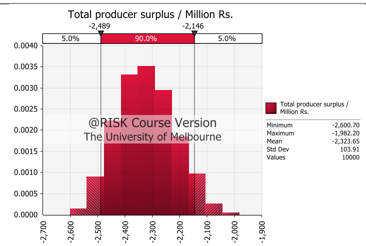
The reason for the two scenarios 'during the ban' and 'during the ban with the cash voucher system in place' to have large changes in variable costs is that given the distribution of landholdings based on weed management approaches as in Table 8.5, a considerable proportion - 60 per cent of private growers - have used labour only, driving the cost of labour much higher. That's why k shifts have magnitudes around 20 per cent or more during the ban.

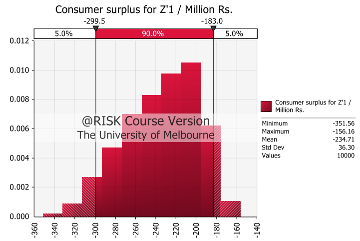
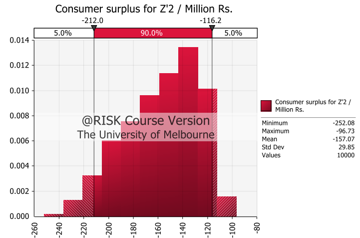
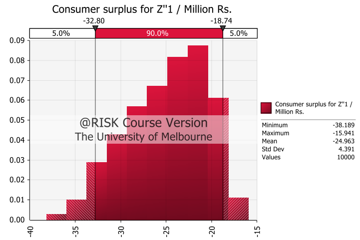
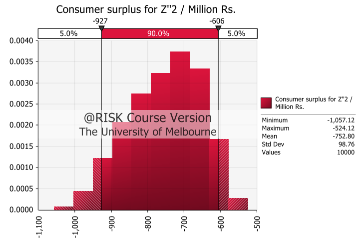
8.4 Sensitivity analysis of economic surplus changes with @RISK

The calculated economic surplus changes are highly sensitive to elasticity estimates used as inputs in the model. It has been noted above that many of the required elasticities are either not available or potentially unreliable. It is important to conduct a sensitivity analysis to check to what extent the distributions of model outcomes depend on the range of values that market elasticities can take. Thus, all point market elasticity estimates derived from best estimates were used as if coming from truncated normal distributions. Furthermore, correlation coefficients were assigned across products in market levels. Then, the respective distributions of economic surplus changes across all market levels were obtained using the @RISK program as previously done for the hypothetical scenario in Chapter 5.

The results obtained from the @RISK program for the scenario 'with the ban' that specify shock on the supply in the farm sector is give in Figure 8.2 below. The results for the other scenarios – 'during the ban', 'during the ban with cash voucher system in place' and decline in demand for bulk tea exports are provided in APPENDIX 6 – A, 6 – B and 6 – C respectively. In all cases, outputs of economic surplus changes from the @RISK program are presented for the minimum, mean, maximum, credible intervals at 5 per cent and 95 per cent of model parameters and standard deviation. The means of the @Risk distributions of surplus changes are close to the point estimates shown in Table 8.6 and in the Appendix. All distributions of the total economic surplus change are normally distributed around the mean, with some figures being slightly skewed because of the truncations of positive or negative values. These results are likely values of economic surplus changes obtained from simulations using the range of likely values of market elasticities based on the specified truncated normal distribution.

Market level	Graph	Minimum value	Mean value	Maximum value	5%	95%	Standard deviation
Farm sector							
Private grower sector		(138.66)	92.96	339.07	(36.3)	220.3	78.16
Estate grower sector		(1,435.24)	(1,342.52)	(1,247.96)	(1,395.2)	(1,290.8)	31.80
Black tea manufacturing sector		(608.03)	(448.86)	(326.69)	(540.7)	(372.4)	52.28
Secondary processing of black tea for bulk exports		(211.36)	(171.76)	(138.03)	(191.9)	(153.3)	11.77

Secondary processing of black tea for VAT exports		(383.73)	(271.41)	(184.45)	(344.8)	(219.6)	35.82
Secondary processing of black tea for domestic marketing of loose bulk tea		(11.44)	(7.89)	(5.41)	(9.79)	(6.34)	1.08
Secondary processing of black tea for domestic marketing of VAT		(251.22)	(174.15)	(117.69)	(217.0)	(138.7)	24.52
Producer sector		(2,600.70)	(2,323.65)	(1,982.20)	(2,489)	(2,146)	103.91

Bulk tea export sector		(351.56)	(234.71)	(156.16)	(299.5)	(183.0)	36.30
VAT export sector		(252.08)	(157.07)	(96.73)	(212.0)	(116.2)	29.85
Domestic consumption of loose bulk tea		(38.18)	(24.96)	(15.94)	(32.80)	(18.74)	4.39
Domestic consumption of VAT		(1,057.12)	(752.80)	(524.12)	(927.0)	(606.0)	98.76

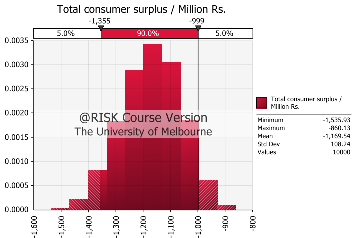
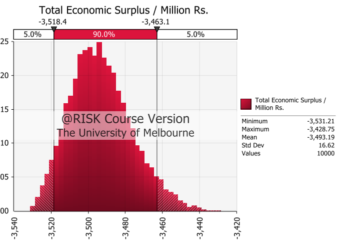
Consumer sector		(1,535.93)	(1,169.54)	(860.13)	(1,355)	(999)	108.24
Tea industry		(3,531.21)	(3,493.19)	(3,428.75)	(3,518.4)	(3,463.1)	16.62

Figure 8.2. Distribution of surplus changes across market levels in the scenario 'with the ban' for increased variable cost in the farm sector

8.5 Summary

In this chapter is presented a welfare analysis of the impacts and consequences of the ban on Glyphosate on the tea industry in Sri Lanka. Impacts and consequences of the ban are shocks on the industry that lead to changes in the total value distributed across all market levels. Economic surplus changes resulting from different shocks on demand and supply of the tea industry are obtained using the EDM developed in Chapter 5. The magnitudes of shocks on the farm sector supply in terms of percentage change in variable costs in private and estate tea grower sectors as an impact of the Glyphosate ban were derived from Chapter 7. Furthermore, the decline in tea exports from Sri Lanka to Japanese markets was devised as a shock on the demand on export marketing sector as an unintended consequence of the ban.

Scenarios evaluated in the farm sector with respect to increased variable costs are 'with the ban', 'during the ban' and 'during the ban with the cash voucher system in place'. The demand decline in bulk tea exports is evaluated on the bulk tea export marketing sector. Changes in prices, quantities and total economic surpluses and their distributions were obtained for each scenario.

All scenarios resulted in total economic surplus losses between Rs. 355 million per year for the bulk tea export reduction and Rs. 17,700 million per year for the variable cost increase during the ban. Sensitivity analyses were conducted for each scenario to address uncertainties in market elasticities used in the EDM by using @RISK program. Results obtained from @RISK provided distributions of the likely total economic surplus changes for each scenario for the given truncated normal distributions and correlation coefficients of market elasticities.

Chapter 9 Implications of the Glyphosate Ban for the Sri Lankan Tea Industry

9.1 Introduction

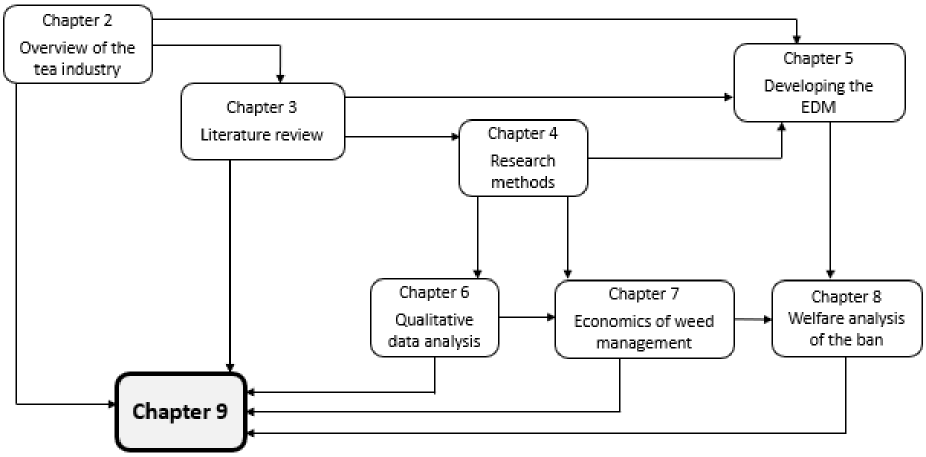


Figure 9.1. Flow of chapters in the thesis

In this chapter, the final objective of the study is achieved by evaluating the overall implications of the ban. The key outcomes from Chapters 2, 3, 6, 7 and 8 obtained while achieving the research objectives of the study are synthesized and discussed, highlighting recommendations for stakeholders and key participants in the tea industry as presented in Figure 9.1.

The tea industry in Sri Lanka is critical to the economy as it is the industry that earns the highest share of foreign exchange out of all agricultural commodities. Policies that affect the competitiveness, sustainability, performance and production capacity of the industry directly or indirectly must be carefully managed throughout the process from policy formulation to implementation and monitoring. All economic, political, intellectual, logistical and technological dimensions warrant consideration.

Government policies in Sri Lanka are unpredictable and subject to frequent changes. There is a tendency for bans that were implemented in the past and then lifted to be reintroduced. The ban on Glyphosate that was in place from mid-2015 till late 2018 is no exception. Glyphosate use is increasingly subjected to questioning and intermittent bans in most countries of the world, hence further restriction on its use is highly likely in the time to come.

The key research question that was investigated in this study was ‘How has the ban on Glyphosate affected the tea industry in Sri Lanka’. There were two secondary questions: (i) What have been the impacts of the ban on Glyphosate on the farm sector of the tea industry during the period of the ban? and (ii) What have been the effects of the ban on Glyphosate on participants in the tea value chain?

The main objectives of the study were:

(i) to study the factors affecting decisions about weed management as a result of the ban on Glyphosate and the effects of the ban on the farm sector

(ii) to quantify the changes in weed management practices, and tea production gross margins in the farm sector of the tea industry

(iii) to develop an economic modelling framework for the tea industry in Sri Lanka

(iv) to estimate the welfare changes of the ban on Glyphosate on participants in the main market levels along the tea value chain and the on the industry

(v) to evaluate the overall implications of the ban on Glyphosate on the tea industry.

The study relies on eight research propositions derived from the literature in investigating the impacts of the ban:

(i) weed management strategies changed in the case of a Glyphosate ban
(ii) the demand for labour increased during the Glyphosate ban
(iii) the cost of weed management increased during the Glyphosate ban
(iv) the ban on Glyphosate adversely affected the yields
(v) the gross margin per hectare decreased during the Glyphosate ban
(vi) the ban on Glyphosate caused economic losses for producers
(vii) the ban on Glyphosate caused economic losses for consumers
(viii) the ban on Glyphosate caused economic losses for the whole industry

The first four research objectives were achieved and discussed in Chapters 6, 7, 5 and 8 respectively. In this chapter, the final research objective of this study is achieved by evaluating the implications of the ban on the tea industry First, the key findings about each objective are analysed and synthesized.

9.2 Key findings of the study

Objective 1: to study the factors affecting decisions about weed management as a result of the ban on Glyphosate and the effects of the ban on the farm sector

Factors that influence decision making on weed management approaches in tea cultivation were mainly investigated in the first part of this objective. The main weed controlling strategies adopted in tea cultivations were non-chemical weed management that involved labour and/or machinery in uprooting, slashing, or scraping weeds, and chemical weed management using weedicides with or without supplementary manual weeding. Accordingly, factors such as the cost-effectiveness, cost structure, labour intensiveness, labour availability, convenience, type of weeds in the field, land area, impact on the health of tea bushes, the environment and the age, production status and the condition/ availability of vacancies in the tea bush stand were identified as affecting decision making about the choice of weed management method. The substitutability between weedicides and labour mostly depends on the relative costs of each method. Prior studies by Shyamalie (2015a) and Silva (2015) had highlighted that labour intensiveness, cost-effectiveness, costs involved in weed control including direct control costs and external costs on human health and the environment were key determinants of the weed management strategies used.

Silva (2015) also revealed that the only feasible weed control option for estate sector plantations is chemical weeding because of issues with the availability of labour. Moreover, large areas under cultivation, availability of many vacancies mostly in seedling plantations, and limited budget allocations by management limit the range of weed management options. In contrast the diversity of tea smallholdings means they have all weed control options to consider in deciding the appropriate method. Tea cultivations with the smallest areas under cultivation are highly likely to adopt manual weed controlling with the available family labour as many fields are well maintained in good condition with minimum vacancies. These findings in the study accord with Abeywickrama, Sandika *et al.* (2017) on the fact that the use of chemical weedicides in small landholdings can be minimized with no or occasional use of chemicals on weed control, and the use of weedicides increases with sizes of landholdings.

Depending on the severity of labour issues and the conditions of the tea bush stand, such as aged bushes with many vacancies, landholders may use chemical weed management. Similar to other businesses, regardless of the scale of production, green leaf production businesses operating under profit maximization would seek the least cost weed control method. This is chemical weeding with weedicides that requires less labour than the more labour-intensive manual weeding. Cost-effectiveness and labour intensiveness are key factors that decision makers at the farm-level generally consider in choosing their weed management approaches.

Glyphosate was the most popular weedicide in both tea smallholdings and estate plantations. Most of the growers in the sample used chemical weed management before the ban. Although there are no published statistics on the trends in Glyphosate use in the farm sector, this finding is supported by Shyamalie (2015a), Silva (2015), Abeywickrama, Sandika *et al.* (2017) and Marambe and Herath (2019). Dependence on Glyphosate for weed control before its ban influenced the decision making on weed control approaches following the ban, with the entire estate sector and some smallholders continuing to rely on alternative weedicides. Although there were alternative chemicals recommended by TRI of Sri Lanka, such weedicide options were not so popular among growers for several reasons. Various products labelled as Glyphosate became available in the black market that were double the price of legitimate Glyphosate before the ban. The TRI-recommended weedicide alternatives were expensive and not as efficient as Glyphosate which highly influenced the decision between continuing with the same approach or switching to other approaches.

The data that was collected revealed that most tea smallholders carried out manual weeding followed by chemical weeding with supplementary manual weeding during the ban. This reflects the decisions to switch to employing more labour, based on the inefficiency and unavailability or not having access to illegal Glyphosate products and/or facing limited alternative weedicides. This finding is supported by evidence from Abeywickrama, Sandika *et al.* (2017) and Marambe and Herath (2019). Moreover, the same outcome was predicted by Cruz, Cruz-Hipolito *et al.* (2021) in international contexts as well under potential bans on Glyphosate where use of mechanical or weedicide free approaches increased.

Additionally, harmful impacts of alternative chemicals such as Diuron, MCPA and Glufosinate Ammonium in addition to informal Glyphosate products on tea bush health and environment likely influenced decisions by growers to discontinue the use of such chemicals on weed control in tea fields.

Nevertheless, some farmers were reported to be still opting for alternative weedicides that replace Glyphosate regardless of their negative attributes such as limited stocks and inefficiency as also shown in literature (Liu, Carlson *et al.* 1995; Beckie, Flower *et al.* 2020). Growers who used illegal Glyphosate products in the informal market reported these products were the priority for them out of available alternative weedicides even at higher prices as also found by Abeywickrama, Sandika *et al.* (2017). This was because of issues with labour availability in tea cultivation areas and the difficulties of having to pay higher wage rates for labour. Findings from Ye, Wu *et al.* (2021) and (Beckie, Flower *et al.* 2020) support this conclusion about growers perceptions of alternative weedicide options that could replace the banned chemical.

An equally important factor that contributed to continued use of chemical weed control during the ban on Glyphosate was the existence of a market for illegal Glyphosate products. As indicated by Cruz, Cruz-Hipolito *et al.* (2021), there was an inflow of illegal Glyphosate products from informal sources, smuggled from neighbouring countries. There was a black market in Glyphosate which included product that included over-priced, diluted or highly concentrated toxic substances labelled as Glyphosate, with unknown formulations which were often ineffective. This was an unintended consequence made known during interviews in the study and also highlighted by Abeywickrama, Sandika *et al.* (2017), and Marambe and Herath (2019).

Investigations of issues faced by the farm sector as a result of the ban on Glyphosate use suggested that impacts of the ban were worsened by labour related issues including shortages and higher wage rates, with related effects on the weed management. Growers inclined towards less labour-intensive practices. As most of the alternative weedicides were inefficient in controlling weeds below the level that caused economic losses, using less labour-intensive methods led to increased uncontrolled weed densities in fields. An outcome was that some marginal tea lands were abandoned, while there were enhanced threats of pest and disease incidences, increased weed competition for tea bushes, worker inefficiency, interrupted harvesting and fertilizer applications resulting in reductions in quantity and quality of yield. Inefficiency of labourers in field activities directly contributed to decline in productivity in tea cultivation. These effects were highlighted by Malkanthi, Sandareka *et al.* (2019), Marambe and Herath (2019) and Abeywickrama, Sandika *et al.* (2017) in the Sri Lankan context, while yield reductions were reported by Cruz, Cruz-Hipolito *et al.* (2021), Walsh and Kingwell (2021), and Mennan, Bozoğlu *et al.* (2020).

Moreover, even though the likelihood of increased use of more mechanical approaches in weeding that involve activity with soil tillage is reported in the literature, this was not seen in the tea fields as highlighted during interviews. This is in part because of possible risks of soil erosion in tea fields situated in hilly areas with many ground exposures from vacancies. Many growers except for a few from both sectors reported that they have avoided weed scraping and harrowing for these reasons. Abeywickrama, Sandika *et al.* (2017) pointed out instances of such enhanced soil erosion in tea fields.

Objective 2: to quantify changes in weed management practices, and tea production gross margins in the farm sector of the tea industry

With the knowledge of factors that affected the decision making of tea growers in choosing a weed management option before and during the ban, actual changes in weed control practices and their costs were quantified along with production in this objective. Activity budgets developed from interview findings in the study revealed escalated costs of weeding following the ban, which aligns well with the literature.

Most literature that assessed the effects of a ban reported actual or expected increases in weeding costs as a result of switching to alternative weed control approaches. These alternative weed control methods were found to utilize more labour, mechanical means, and/or expensive weedicide options following the ban, ultimately increasing total costs and reducing the profitability of green leaf production. This was discussed by studies done globally by Brookes (2019), Walsh and Kingwell (2021), Pardo and Martinez (2019), Taylor and Koo (2001) and also in Sri Lanka by Malkanthi, Sandareka *et al.* (2019), Marambe and Herath (2019) and Abeywickrama, Sandika *et al.* (2017).

The weed control system with the highest variable costs of production before the ban was manual weeding, as chemical weeding was done cost-effectively with Glyphosate. Following the ban on Glyphosate, the highest variable cost of production was reported on landholdings practicing integrated chemical and manual weed management in the tea smallholder sector. Overall weeding costs increased due to using expensive alternative chemicals and allocating more labour on manual weeding, with increased frequency of weeding and labour used per supplementary manual weeding round. Integrated chemical and manual weed management became more labour intensive during the ban than in the pre-ban period. The estate sector continued integrated chemical and manual weeding during the ban by partially replacing chemicals with labour with reduced chemical application rounds and increased frequency and labour allocation per round on manual weeding, resulting in increased weeding costs.

As supported by interview data and the literature on yield losses in the case of a Glyphosate ban, in this research an overall yield loss of 3.5 per cent because of inefficient weed management that achieved only 50 per cent control of weeds in the field was assumed on both tea smallholdings and estates during the ban. Yield losses from the absence of effective weed control with chemicals are also included in the study. Additionally, apart from cost increases because of increased chemical and manual weeding costs during the ban, all landholdings were experiencing cost rises with labour wage rates increasing as the Sri Lankan economy grew.

This trend of rising costs on tea landholdings from increasing weeding costs was evident in all variable costs. However, in the period studied both the tea smallholder and estate sector received higher gross incomes from green leaf sales thus, despite increases in variable costs, activity gross margins per hectare increased compared to the pre-ban period because of the improved green leaf prices that prevailed during the ban. This indicated to tea landholdings that they could be better-off by trying to minimize yield losses in their cultivations if they were receiving better prices for the harvest, regardless of the more expensive weed control options they may adopt. In the tea smallholder sector, the highest activity gross margin per hectare was reported in those who practiced chemical weeding only.

Investigation into different weed management combinations in the smallholder sector across the two periods before and with the ban on Glyphosate was also done. Accordingly, weed management combinations based on substitution between weedicides and labour were studied using several scenarios.

- what growers would have expected they would do at the beginning of the ban period before the ban was imposed,
- the actual scenario of what growers actually did with the ban in place
- the theoretical scenario assuming what growers should have done instead of what they actually did in terms of weed control practices.

Further, each scenario was looked at with respect to two aspects, namely with the ban (only weed management parameters changes considered), during the ban (weed management parameters, GL price, nominal labour wage rate changes considered) and during the ban with the fertilizer subsidy policy change (66 per cent reduction in the quantity of fertilizer applied in tea fields considered with changes in weed management parameters, GL price and nominal labour wage rates). With the latter scenario, the effect of imposing changes on the fertilizer subsidy on weed management practices in the farm sector has also been captured in the study.

The highest change in total variable costs was experienced by tea smallholdings that substituted Glyphosate with alternative weedicides and supplementary manual weeding. The next largest change in variable costs was for smallholdings that completely substituted Glyphosate with manual weeding with the ban, during the ban and during the ban with a fertilizer subsidy change in place as well. It was common for both the estate and smallholder sector to experience reductions in activity gross margins per hectare with the ban as weeding costs escalated when they substituted Glyphosate with labour only or used both more labour and alternative chemicals.

The comparison of actual versus predicted changes in total variable costs and gross margin with the ban, for weed management combinations, reflect how costly weed management was in fact relative to the anticipated costs prior to the ban.

Objective 3: to develop an economic modelling framework for the tea industry in Sri Lanka

An Equilibrium Displacement Model (EDM) was developed for the black tea industry under this objective. The EDM is a comparative static approach that uses a partial equilibrium framework for linear approximation of changes in price and quantities of inputs and outputs in a production system resulting from exogenous shocks to the initial equilibrium using base prices, quantities and market elasticity estimates of demand and supply. This economic model was developed for the tea industry with the aim of assessing policy interventions on the industry – especially considering the Glyphosate ban.

The complex structure of the tea industry with multiple outputs including black tea, green tea and instant teas, was simplified, to develop a model on the black tea industry only that constitutes more than 90 per cent of the national production. Thus, the simplified structure of the black tea industry included the farm sector, manufacturing sector, secondary processing sector of bulk and value-added black tea for export marketing and secondary processing sector for domestic retail marketing in loose bulk and value-added form. While specifying general functional forms, it was assumed that production functions in all market levels exhibit constant returns to scale, all multi-output production functions are separable in inputs and outputs, and each market level in the model operates with the objective of profit maximization and perfect competition in firms.

Accordingly, the EDM was based on a system of 52 equations consisting of production functions, green leaf production equality, cost functions and derived demand schedules, revenue functions and derived supply schedules, profit functions and exogenous factor supply, utility functions and exogenous demand equations. There are altogether 38 price and quantity variables from 19 factor markets in the black tea industry. These equations are subsequently converted to displaced forms by total differentiation to study the impacts of exogenous shocks on the industry that lead to shifts from the base equilibrium. Integrability conditions are then imposed at the base equilibrium to minimize associated errors for mall displacements.

Price and quantity details obtained from published secondary data sources and market elasticity estimates derived from the literature and subjective judgements were used as inputs in expressing the base equilibrium status of the EDM. Finally, the developed EDM was technically validated using hypothetical 1 per cent exogenous shocks on the system of equations to ensure proper calibration.

Objective 4: to estimate welfare changes of the ban on Glyphosate on participants in main market levels along the tea value chain and on the industry

In this objective, welfare effects of the impacts of the Glyphosate ban on key market levels in the tea value chain are quantified. The main impacts assessed are changes in total variable cost in the farm sector measured while achieving the second objective as direct impacts, and reductions in demand for bulk tea exports to international tea markets as an unintended consequence of the ban. This is done using the EDM developed when achieving the third objective of constructing an economic model to the tea industry of the study.

As found in the study, the total variable cost of production increased in representative landholdings from both smallholder and estate sectors, with costs in an estate holding being nearly three times higher than costs in a smallholding with the Glyphosate ban in place. This is because of the increased efforts of manual weeding in the absence of Glyphosate.

Imposing the shock to the tea industry with increased cost of production of green leaves in the farm sector resulted in prices increasing and quantity of products at all market levels declining across all scenarios – with the ban, during the ban and during the ban with the fertilizer subsidy policy change in place. This is because of the relationships between market levels in the value chain where an output at one market level becomes an input in the subsequent market level, and the shock on the primary market level is transmitted across other levels in varying degrees.

An interesting point to note is that increased variable costs of production with the ban on the farm sector led to an output gain for the smallholder farm sector, in contrast to what was expected. This could be either because of inaccuracies of the data or that the relative changes in cost shares are enough to divert some of the lower cost inputs from the estate to the smallholder sector.

The welfare analysis of the effect of increased total variable costs in the farm sector with the ban showed that the largest reduction in economic surplus was experienced by producers – particularly by the farm sector - while the total economic surplus on the entire tea industry was reduced by Rs 3,494 million per year. These results obtained in the study are supported by Cashman, Martin *et al.* (1981), Böcker, Britz *et al.* (2017), Böcker, Möhring *et al.* (2019) and Ye, Wu *et al.* (2021) who also reported that a ban on Glyphosate can lead to economic losses of significant magnitudes on producers who used the banned weedicide. The welfare analysis of banning Glyphosate conducted by taking changes in wage rates, green leaf prices into consideration showed that the losses on the farm sector and the entire industry became severe.

The modelled reduction in demand for bulk tea exports in international markets gave mixed outcomes on product prices, representing a shock on one part of the industry and not on the other, with price falls in green leaves, primarily processed tea used to produce VAT for export markets sold at the auction and bulk black tea sold to export markets. As expected, a decline in demand for bulk black tea exports leads to declines in quantities in all market levels, with the highest decline on the tea smallholder sector. The welfare analysis showed that this unintended consequence on bulk black tea consumers in export markets resulted in total economic surplus losses of Rs 355 million annually to the industry, with the largest losses experienced by producers, especially the smallholders in the farm sector.

These key findings obtained while achieving the first four objectives in this study are the basis on which to achieve the final research objective, which is to evaluate the overall implications of the Glyphosate ban on the tea industry.

In Table 9.1 is shown the way the research propositions reviewed from the literature were tested in the study.

Table 9.1. Research propositions and addressing them using objectives

Research proposition	Research objective addressing the proposition	Outcome on the research proposition with remarks
Weed management strategies change in case of a Glyphosate ban	Objective 1	Weed management strategies adopted by tea smallholders changed while the estate sector continued with the same approach
The demand for labour increased during the Glyphosate ban	Objective 1	Demand for labour increased in both grower sectors during the ban because of issues with the availability and efficiency of alternative weedicides
The cost of weed management increased during the Glyphosate ban	Objective 2	Weeding costs of both tea smallholdings and estates increased during the Glyphosate ban because of the allocation of more labour on supplementary manual weeding and using expensive alternative weedicides

The ban on Glyphosate adversely affected the yields	Objective 1	Green leaf yields were affected in both grower sectors because of many reasons including inefficiencies in weed control approaches as the same levels of weed control were not achieved, worker inefficiencies and interrupted field activities including harvesting and fertilizer application due to uncontrollable weed densities in fields during the Glyphosate ban
The gross margin per hectare decreased during the Glyphosate ban	Objective 2	Gross margins of both grower groups declined during the ban (with no changes in green leaf price) because of extra costs on weeding
The ban on Glyphosate caused economic losses for producers	Objective 4	Producers including the farm sector faced the largest economic losses with the Glyphosate ban
The ban on Glyphosate caused economic losses for consumers	Objective 4	Consumers in the tea value chain incurred economic losses with the Glyphosate ban
The ban on Glyphosate caused economic losses on the industry	Objective 4	Tea industry faced economic losses with the Glyphosate ban

Comparing costs of the ban with literature

As discussed in Chapter 3, there is limited literature that has evaluated the economic impact of the Glyphosate ban in Sri Lanka between 2015 and 2018 on the tea industry. The relevant studies are by Abeywickrama, Sandika *et al.* (2017) and Marambe and Herath (2019).

Abeywickrama, Sandika *et al.* (2017) found that the estates in their study experienced a weed control cost increase between three and four times, due to a 30 per cent increase in labour requirement because of the ban on Glyphosate. In this study, the representative landholding from the estate sector incurred a weeding cost increase by 2.2 times owing to a labour allocation increase by 90 per cent during the ban. This difference could be because of variations in resource allocation of weed control in different estates. Moreover, the cost of production of green leaves in the estate sector in the study by Abeywickrama, Sandika *et al.* (2017) was Rs. 5.47 per kg while, while a cost of production of Rs. 6.69 on the estate sector with the ban was derived in this study.

Marambe and Herath (2019) showed that the ban on Glyphosate costed between Rs 10 – 20 billion per year, while the total loss on the tea industry of imposing this ban as calculated in this study was Rs 17.7 billion per year for the representative year 2017. Furthermore, the estimated cost of decline in the demand for tea exported to international markets (regarding the incident of rejected tea consignments by Japan) in this study was Rs 0.35 billion, whereas it had been Rs 1 billion according to Marambe and Herath (2019). While the overall costs are broadly similar, the differences in the costs presented in the literature and in this study can be accounted for by the assumptions used while quantifying the direct impacts and unintended consequences of the Glyphosate ban.

9.3 Evaluating implications of the ban on Glyphosate and recommendations

The key findings of the study into the effects of the Glyphosate ban on the tea industry as summarized in previous chapters and synthesized above have value to a range of stakeholders. These include government policymakers who were involved in formulating and implementing the ban, value chain participants in the tea industry who experienced the effects and consequences of the ban, especially those in the farm sector, and other researchers who conduct research on the same or similar policies. In the following sections, the importance of the study outcomes for each stakeholder group is discussed in detail.

9.3.1 Policymakers

Policymakers are one of the main target groups of the study outcomes as they were directly involved in formulating and implementing the policy to ban the use of Glyphosate. The goal that the government tried to achieve by placing a ban on Glyphosate use in 2015 was to reduce social costs of the presumed externalities.

Externalities are either costs or benefits of an economic activity that affects an unrelated third party. There can be several forms of externalities. Negative production externalities can occur when the production of a good or a service creates a negative impact on the third party outside the market. In such instances, government interventions are a common a response to solving market failures. State intervention to correcting negative externalities can involves government-imposed market-based mechanisms or command and control policies or a combination of both. Both these approaches require some regulatory system at various levels in the value chain.

The Sri Lankan government decided that CKDu was a negative externality of using Glyphosate on agricultural production, and they intervened to address this market failure by enacting legislation. While a regulation such as a ban is a feasible way of addressing the problem of social costs, its effectiveness was questionable considering the responses of participants in the industry and the impacts and consequences they experienced following the ban.

As explained by Cruz, Cruz-Hipolito *et al.* (2021), good crop production without Glyphosate can be achieved with proper planning and knowledge of economic, intellectual, political, logistical and technological aspects of production. State-imposed regulations become ineffective when standards that are hard or impractical to meet are implemented because of the lack of knowledge, skills or finance on the part of actors or mismanagement of policymakers in policy formulation. There were several findings of the study also supported by literature that provided evidence of incompetency of policymakers in effective implementation of the ban.

Although Glyphosate use was completely banned in the country, illegal sources of Glyphosate were channelling into the country throughout the ban period, and most growers had access to these illegal sources in the informal market. This can be viewed as an inefficiency in policy implementation as policymakers had not foreseen this as a consequence, nor did they monitor the operation of the regulations properly.

In contrast to voluntary participation, regulations are rigid and difficult to change. Therefore, in a way, bans properly enforced and monitored can be an effective means to execute policies and achieve the goals of a policy since the regulation applies to all the actors who undertake an activity as described in the regulation and treats them on the same basis regardless of the level of impact. This means the objective, if achieved, is unlikely to be achieved at least cost though. However, in this case the policy mechanism of total use restrictions on Glyphosate resulted in detrimental effects by encouraging use of highly toxic chemicals with unknown formulations from illicit markets on tea cultivations and on the environment, as growers used more environmentally damaging chemicals which were not regulated. Decision-making about which weed management approach to use during the ban revealed that the availability of chemical products labelled as Glyphosate in the informal market encouraged growers to continue with chemical weeding with weedicides that could be more toxic than Glyphosate. This is likely to have resulted in extra costs on the environment in terms of pollution. In that sense, the policy may have counteracted the achievement of the objectives that motivated the policy.

Moreover, some serious complaints made by tea growers affected by the ban and industry experts were that an effective alternative chemical was not introduced before the ban, and no prior announcement or phaseout period was provided to shift to alternatives even though some chemicals that were claimed to be ineffective had been recommended by the TRI. These issues can be highlighted as mismanagement and inconsistent decision making by respective policymakers.

Furthermore, having to allocate more labour despite the shortage and increasing wage rates to compensate for the inefficiency and low availability of even TRI- recommended alternative chemicals, most of the smallholders and the estate sector had to bear extra costs on weeding that was unanticipated when the ban was implemented. This is reflected by the comparison of actual and predicted changes in total variable costs and gross margins with the ban and during the ban on weed management combinations. The study outcomes provide estimations of how much landholders were made worse off relative to the predicted situation at the beginning of the ban period.

The expected social benefit outcomes from government interventions will not meet objectives when the government policy formation and implementation is dominated by short-term political considerations that lead to inefficient outcomes. It is highly likely that such inefficiencies in turn result in a government failure again. For instance, politically powerful pressure groups can influence the government decisions to change policies according to their interests. The same has apparently taken place with respect to the ban on Glyphosate in Sri Lanka regarding lifting the ban for commercially cultivated crops such as tea and rubber. Although this contradicted achieving the original aim of policy, it has been advantageous in terms of reducing further ban-related economic losses, especially in the tea industry at a time when Sri Lankan tea exports to Japanese markets were about to be suspended. However, there have been consequences of the ban even after it was lifted, observed on tea cultivations that were abandoned and remained so, without any weed control or harvesting.

Imposing a ban on an agricultural input should not be just restricting its use without considering other inputs. Instead, such policy ought to be devised by paying attention to the package of other current and possible alternative inputs simultaneously. It is the responsibility of the government banning an input such as a weedicide to make sure there are stocks of any recommended alternative weedicide. Moreover, it is not wise to implement policies on other related inputs at the same time as this could hinder the main aim of the primary policy. This refers to the folly at the time of the ban on glyphosate of also replacing the fertilizer subsidy with a cash voucher system, as was introduced and was in place through cropping seasons from 2016 till 2018. The consequential effect on tea growers was increased costs on fertilizer and thereby discouraged fertilizer application in the field that in turn were found to affect tea yields. On top of this were continuously increasing labour wage rates in both casual and estate labour, eventually exacerbating costs on tea growers.

Welfare analysis on impacts and consequences of the ban provides indications of economic consequences, and guidance for policymakers to consider, if and when introducing a similar policy banning Glyphosate or any other input in an agricultural industry is being considered. Informed adjustments to policy plans can be made while formulating the policy to better match the hoped-for intentions and minimize the unintended consequences that can lead to potential losses.

When there is a lack of complete information and knowledge on a potential negative externality during its preliminary stages, command and control policy instruments can be helpful up to a certain stage. If the desired effect on the negative externality is being achieved, more efficient price-based approaches can take over at a later stage. Additional to command and control and price-based policy instruments that requires regulatory framework, voluntary agreements are other options that operate through the voluntary participation of polluters agreeing to act by themselves. Government can encourage relevant parties through information and other incentives. There is a potential for policymakers to try such policies in the future.

9.3.2 The farm sector

Good agricultural practices are always important to minimize avoidable yield losses, contain costs and improve the productivity of the tea cultivation. High standards of cultural methods in weed management are the key to good yields. The farm sector consists of tea smallholders and estate planters. Tea growers directly and most significantly affected by the ban on Glyphosate were those who were using significant amounts of Glyphosate on weed control. Some of the results of this study provide important information for tea growers and managers in estates about decision making about weed management, related to costs of controlling their weeds and to trade-offs between yield improvements and cost savings.

The farm sector is highly vulnerable to be affected by and face losses from policies such as input bans. It is worth noting that poor policy can reduce the resilience of those in the farm sector. Development of budgets for weeding cost, total variable cost and activity gross margin analysis of landholdings based on weed management approaches assists the farm sector in weighing up future weed management options. Decisions of tea growers in both grower sectors determined the extent to which losses are incurred when faced with responding to changes in policies. Growers can choose between saving costs by opting for cost-effective, but ineffective weed control approaches that can possibly lead to yield losses or minimizing yield losses from less effective weed management activities and spending on approaches requiring more costs, all depending on prevailing prices on green leaves. As shown in the study findings, growers were better off only because of the improved green leaf prices during the ban. For non-export product domestic prices are likely to increase in the case where a ban on an input reduces the supply of output.

9.3.3 Participants in the tea value chain

Findings of this study are helpful not only for the farm sector, but also for the other participants in the value chain of the tea industry. The welfare analysis in terms of changes in prices, quantities, and economic surplus changes provides a good guide to how participants in each market level can be affected when the initial impact is on one part of the industry – usually the farm sector. Results of the EDM analysis gives a good indication for key market levels including manufacturers, secondary processors and marketers, and especially exporters, about potential losses when policies affecting farm production are introduced.

9.3.4 Other researchers

The EDM is an important type of economic model that can be adopted by any industry not only to assess effects of policy interventions, but also the same of research and development activities, investments and projects. The model provides valuable platform for other researchers studying in similar areas to conduct economic analysis. Given that an EDM has only been developed and applied on the coconut industry in Sri Lanka before this study, there is an opportunity for economic researchers to use the approach in other industries of economic importance to the country and where policies are being imposed and investments in research and development are being made.

9.4 Limitations

The ban was imposed by the government as a response to anticipated high social costs of using Glyphosate in agricultural productions. However, while total Glyphosate use did decline, whether it was enough to reduce the social cost was not assessed in the study as the EDM does not include social costs or benefits of the policy intervention. Rather, this study was mainly based on the economic surplus changes caused by the ban.

Given the huge variability across the smallholder sector, the estimated representative landholdings of this sector assumed for computational purposes are necessarily generalized and there will be a range of performance levels of individual operations around the representative levels of farm performance. Individual units of data collection such as from tea smallholders and estate sector managers of the study sample were aggregated despite the tea growing elevation they belong too, although data were collected from all three regions. While it is acknowledged that there are variations in systems and performances across tea growing elevations in Sri Lanka, findings are derived from the sample irrespective of the tea growing region.

One of the limitations of this research was the precision of some data such as green leaf yields, and quantities of materials used by tea smallholders, as recordkeeping is not properly practiced, unlike the estate sector. Information on those variables were estimations provided by tea smallholders.

Even though there were smuggled Glyphosate products available in illegal markets and growers from both smallholder and estate sectors used them, some respondents were reluctant to reveal this or the extent to which they may have used these alternative products. It could be most common in the estate sector since the estate management usually do not disclose information from their records and decisions to the public. Respecting the code of conduct in research, interviewees were not pressed on such sensitive matters. Therefore, there was a lack of precise data on alternative weedicide use during the ban.

The data collection of this study was conducted during the period from September to November 2019, soon after a situation that threatened the national security of the country. Hence, the researcher had to experience some constraints during the data collection as respondents were not quite welcoming or opening up although informed consents were obtained prior to data collection.

Another constraint while collecting secondary data from published government sources was the unavailability of some published statistics. There are no recently updated statistics on the distribution of tea landholdings and their extents, weedicide use on tea cultivations by grower groups and so on, although a national census has been recommended to be conducted by the TSHDA. The last census on tea landholdings was conducted two decades ago in 2002. Additionally, the availability of annual reports of institutes working closely with the tea industry such as the SLTB and TSHDA is limited, as their websites are not updated with recent reports for the public.

There are limited studies that provide information on values of price elasticity of demand and supply for tea products along the value chain in Sri Lanka. Subjective judgements and other evidence had to be used in such cases.

9.5 Suggestions for further research

Researchers who are interested to study the social costs of the ban on Glyphosate could expand the EDM to include social costs and benefits in addition to private economic costs and benefits. Rohr *et al.* (2020) have described a process for including externalities in EDMs. Moreover, secondary outputs in production processes were ignored in the EDM to make the model simple and since the potential/secondary outputs are not the main concern in the model. If such secondary outputs were considered in the model, valuations would have been difficult. This is an area for further research to include secondary outputs in the model and to see the impact of them.

This study has been done mainly focusing the farm sector of the tea value chain. Impacts of the ban on Glyphosate can be assessed on other market levels by investigating detailed further information about how the policy affected participants at different market levels.

9.6 Conclusions

Government interventions are justified when markets fail and there are social costs of an activity and when the benefits of the intervention exceed the costs of doing so. The government policy that banned the use of Glyphosate in Sri Lanka for purported public health and safety reasons was studied in this research by evaluating the economic impacts of the ban on the tea industry. It was found in the study that the ban resulted in private economic losses mainly in the farm sector and there were also unintended consequences on other sectors of the tea industry. Policies introduced to minimize the adverse impacts resulting from market failures ought to be executed with full attention given to the scientific, economic, social and political realities of the case at hand, and the likely consequences for the affected parties and their responses.

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Appendices

APPENDIX 1 Interview schedules used in the primary data collection

APPENDIX 1 – A: Semi-structured interviews with private tea growers (smallholders and medium-scale tea growers)

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For tea smallholders and medium-scale growers)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

<u>*Researcher's use only*</u>

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

1. <u>Household information</u>
   (i) Name of the landholding owner/interviewee:
   (ii) Name of the tea smallholders' society working with:
   (iii) Location of the landholding:
   (iv) Distance from the household:
   (v) Number of family members and their details:
   (vi) Their involvement in the farm workforce

2. <u>Tea landholding information</u>
   (i) Total extent under tea cultivation: (ii) Number of tea blocks under cultivation:
   (iii) Extent of each block:

Referring to the block of land under production during the period between 2015 to 2018 or the block with highest extent,

   (iv) Age of the block: (v) Current production status of the block:
   (vi) Number of tea bushes in the tea block: (vii) Availability of vacancies:
   (viii) Do you usually practice in filling of vacancies after every pruning cycle?

3. <u>Production related information</u>
   (i) Current average production (2018/19):

Highest: Month Lowest: Month Average: Average GL price:

   (ii) Average production during the ban (2016/17)

Highest: Month Lowest: Month Average: Average GL price:

   (iii) Average production before the ban (2014/2015)

Highest: Month Lowest: Month Average: Average GL price:

<u>Importance of the cashflow from the business</u>

   (i) Tea cultivation as a full time or part time business?
   (ii) Monocrop or mixed crop?

(iii) Intercrops available? (iv) Income from intercrop

(v) Percentage of the total household cashflow represented by sales of green leaf
(vi) How important is the income from green leaf sales to the household?

Management practices in a tea field

(i) What are the usual management practices carried out in the tea field, and how frequent do you practice them?

During the ban period (2016/2017)

Weed management

(i) Weeds found frequently in the tea land
(ii) Main weed management method used? (iii) Reason for choosing this method
(iv) Have you used weedicides? (Illegal or other alternative weedicides recommended)
(v) Type of the weedicide (vi) Price paid (vii) Place of purchase
(viii) Frequency of practice (ix) Dose used (x) Amount of labour used for applying
(xi) Cost incurred per round (including wage) (xii) Cost of chemical weeding before the ban
(xiii) How effective was that weedicide on weeds and the tea bush?

Herbicide efficacy – well/very well controllable (0.9), sufficiently controllable (0.33) and not sufficiently controllable (0).

(xiv) If used illegal weedicide, why did you decide to use them over other weed controlling methods?
(xv) How do you see the possibility of substituting formal glyphosate with informal glyphosate?
(xvi) What other weed control methods did you use?
(xvii) What would have been the cost/change in cost on weed management if you have not used Glyphosate or any other chemical weedicide?
(xviii) How is the suppressing efficacy of each weed control strategy used (0,1 1 – total eradication, 0 – no impact on the weed, between 0 and 1 – part of weed population is removed)
(xix) Has there been any changes in the labour usage on weed management during the past five years? Substituting chemical weed management with non-chemical weed management/labour?
(xx) Grower perceived benefits and costs/ pros and cons of the alternative weed management option practiced by them. (Risks/benefits involved in adopting these weed control approaches)
(xxi) Have you noticed any change in the growth rate of weeds in your field?
(xxii) Do you think weed growth in your tea field has increased during the period of the ban? (If you rank your answer in a scale of 0 to 5, what score can you give?)
(xxiii) Do you think weeds became a trouble for your cultivation? (If you rank your answer on a scale of 0 to 5, what score can you give?)
(xxiv) Have weeds affected the tea yield during the ban period? (If you rank your answer in a scale of 0 to 5, what score can you give?)
(xxv) Can you quantify the change in the yield during the period you changed the weed control method used to apply? (As a % or kg/ha)

Fertilizer application

(i) Price of fertilizer in 2016/17?
(ii) Usual frequency of fertilizer application, any changes in the frequency back then in 2016/17? Explain why.
(iii) Usual labour requirement for fertilizer application, any change in labour employed in 2016/17? Explain why.
(iv) Cost on fertilizer application Explain the cost breakdown.

Plucking

(i) To whom do you sell the harvest? (Green leaf dealer/ tea smallholders' society/tea factory). In what proportions?

(ii) Price paid to pluckers: if paid on wage rate basis or based on the amount of green leaf plucked, Mode of transportation of green leaf from the landholding to the place of purchase - bought by a green leaf dealer or sold to a tea factory.

(iii) Have you noticed any difference in the green leaf production/harvested in terms of quality? If so, what are they?

(iv) Have you come across instances where weed leaves were mixed with plucked tea leaves, size of green leaves plucked changed, changes in the growth of tea bush, production rate of tea buds? Explain.

(v) What would have been the change in yield or yield per month/year during the period of the ban if you have not used Glyphosate or any other chemical weedicide?

(vi) Have you experienced any significant yield reduction/rise during the past five years? If yes, what do you think are the reasons for the significant yield change?

(vii) Did you capitalize labour to be used on plucking, on other management practices such as weed controlling? If so, how did you make changes?

(viii) Do you think green leaf production in your tea field has decreased during the period of the ban? (If you rank your answer in a scale of 0 to 10, what score can you give?)

<u>Other management practices in a tea field</u>

(i) What is the resource allocation (labour and machinery) rates and costs involved on other field activities?

<u>General Questions</u>

(i) Have you or hired labourers encountered problems regarding weeds during green leaf plucking and other field activities in the past few years (including the ban period)?

(ii) What do you think about the labour shortage in the tea landholdings?

(iii) What government policies apply your cultivation?

(iv) Do you think those policies encourage/support/improve your business?

(v) What do you think are the reasons for low productivity of tea cultivation (your cultivation and industry as a whole)?

(vi) Do you recommend continuing the ban or lifting the ban?

(vii) What challenges do you face/come across when progressing forward in the business?

(viii) What do you think about the extension services available/provided to you by the government or private companies?

(ix) Are you updated about new technologies/knowledge circulated at the tea cultivation level?

(x) Do you practice any special management activities to meet any kind of standards such as organic tea, fair trade tea, GMP etc.

APPENDIX 1 – B: Semi-structured interviews with tea estate management

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For tea estate management)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

Researcher's use only

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

Estate management information

(i) Name of the interviewee:
(ii) Name of the estate to which the plantation belongs to
(iii) Location of the landholding:
(iv) Management company of the estate:

Tea landholding information

(i) Total extent under tea cultivation: (ii) Share of tea blocks under cultivation:
Referring to blocks of land under production during the period between 2015 to 2018
(iii) Average age of the block: (iv) Current production status:
(v) Average number of tea bushes in a tea block: (vi) Availability of vacancies:
(vii) Do you usually practice in filling of vacancies after every pruning cycle?

Information about the labour force

(i) How many labourers are employed in the estate? (ii) Are they hired or residential labour?
(iii) In what proportions are they employed? (iv) Are these hired labourers working full time or part time?
(v) What facilities do you provide for the labourers? (vi) What is the average total cost incurred for labourers?
(vii) What are the average wage rates for each management practice? With or without non-cash benefits?

Management practices in a tea field

(ii) What are the usual management practices carried out in the tea field, and how frequent do you practice them?

Production related information

(i) Current average production (2018/19):
Highest: Month Lowest: Month Average annual:
(ii) Production during the ban (2016/17)
Highest: Month Lowest: Month Average annual:
(iii) Production before the ban (2014/2015)
Highest: Month Lowest: Month Average annual:

During the ban period (2016/2017)

Weed management

(i) Weeds found frequently in the tea land
(ii) Main weed management method used? (iii) Reason for choosing this method
(vi) Have you used weedicides? (Illegal or other alternative weedicides recommended)
(vii) Type of the weedicide (vi) Price paid (vii) Place of purchase
(viii) Frequency of practice (ix) Dose used (x) Amount of labour used for applying
(xi) Cost incurred per round (including wage) (xii) Cost of chemical weeding before the ban
(xiii) How effective was that weedicide on weeds and the tea bush?
Herbicide efficacy – well/very well controllable (0.9), sufficiently controllable (0.33) and not sufficiently controllable (0).
(xiv) If used illegal weedicide, why did you decide to use them over other weed controlling methods?
(xv) How do you see the possibility of substituting formal glyphosate with informal glyphosate?
(xvi) What other weed control methods did you use?
(xvii) What would have been the cost/change in cost on weed management if you have not used Glyphosate or any other chemical weedicide?
(xviii) How is the suppressing efficacy of each weed control strategy used (0,1 1 – total eradication, 0 – no impact on the weed, between 0 and 1 – part of weed population is removed)
(xix) Has there been any changes in the labour usage on weed management during the past five years? Substituting chemical weed management with non-chemical weed management/labour?
(xx) Grower perceived benefits and costs/ pros and cons of the alternative weed management option practiced by them. (Risks/benefits involved in adopting these weed control approaches)
(xxi) Have you noticed any change in the growth rate of weeds in your field?
(xxii) Do you think weed growth in your tea field has increased during the period of the ban? (If you rank your answer on a scale of 0 to 5, what score can you give?)
(xxiii) Do you think weeds became a trouble for your cultivation? (If you rank your answer in a scale of 0 to 5, what score can you give?)
(xxiv) Have weeds affected the tea yield during the ban period? (If you rank your answer in a scale of 0 to 5, what score can you give?)
(xxv) Can you quantify the change in the yield during the period you changed the weed control method used to apply? (As a % or kg/ha)

Fertilizer application

(i) Usual frequency of fertilizer application, any changes in the frequency back then in 2016/17? Explain why.
(ii) Usual labour requirement for fertilizer application, any change in labour employed in 2016/17? Explain why.
(iv) Cost on fertilizer application Explain the cost breakdown.

Plucking

(i) Price paid to pluckers: if paid on wage rate basis or based on the amount of green leaf plucked?
(ii) Have you noticed any difference in the green leaf production/harvested in terms of quality? If so, what are they?
(iii) Have you come across instances where weed leaves were mixed with plucked tea leaves, size of green leaves plucked changed, changes in the growth of tea bush, production rate of tea buds? Explain.
(iv) What would have been the change in yield or yield per month/year during the period of the ban if you have not used Glyphosate or any other chemical weedicide?
(v) Have you experienced any significant yield drop/rise during the past five years? If yes, what do you think are the reasons for the significant yield change?
(vi) Did you capitalize labour to be used on plucking, on other management practices such as weed controlling? If so, how did you make changes?
(vii) Do you think green leaf production in your tea field has decreased during the period of the ban? (If you rank your answer in a scale of 0 to 10, what score can you give?)

Other management practices in a tea field

(i) What is the resource allocation (labour and machinery) rates and costs involved on other field activities?

General Questions

(i) Have pluckers or labourers encountered problems regarding weeds during green leaf plucking and other field activities in the past few years (including the ban period)?
(ii) What do you think about the labour shortage in the tea estate?
(iii) What government policies apply your cultivation?
(iv) Do you think those policies encourage/support/improve your business?
(v) What do you think are the reasons for low productivity of tea cultivation (your cultivation and industry as a whole)?
(vi) Do you recommend continuing the ban or lifting the ban?
(vii) What challenges do you face/come across when progressing forward in the business?
(viii) Are you updated about new technologies/knowledge circulated at the tea cultivation level?
(x) Do you practice any special management activities to meet any kind of standards such as organic tea, fair trade tea, GMP etc.

APPENDIX 1 – C: Focus group discussions with estate labourers

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For focus group discussions with labourers)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

Researcher's use only

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

Tea landholding information

(i) What problems did you face back in 3 years-time (during the period of the ban) when engaging in field work?
(ii) Have you been informed by the management to change some management practices during that time? (Such as changes in the amount of fertilizer applied, delaying pruning and/or other management practices)
(iii) Have pluckers encountered problems regarding weeds during green leaf plucking in the past few years (including the ban period)?
(iv) Any changes in the daily wage paid during that time?
(v) Have you experienced a period where weed leaves were mixed with plucked tea leaves, changes in the size of green leaves plucked, growth of tea bush, production rate of tea buds? Explain.
(vi) Are you aware that there had been a ban on Glyphosate?
(vii) Has there been any change in the green leaf production (yield) during the past 5 years? With respect to the plucking norm, how has the daily harvest of green leaves changed, above or below the plucking norm? Change in the norm of green leaf plucked? Average kgs plucked above or below the norm?
(viii) Are these hired labourers working full time or part time?
(ix) Do you have a separate labour force for green leaf harvesting?
(x) What facilities do you receive from the management?
(xi) What are the average wage rates you receive for each management practice? With or without non-cash benefits? Have these wage rates changed during the ban period?

APPENDIX 1 – D: Focus group discussions with smallholders

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For focus group discussions with smallholders)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

Researcher's use only

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

Tea landholding information

(i) What is the land size that many tea growers in this area own?
(ii) What is the mostly practiced weed management approach among tea smallholders?
(iii) What factors affect the decision on choosing a weed management approach?
(iv) Are you aware that there had been a ban on Glyphosate?
(v) How have you been affected by the ban?
(vi) What problems did you face back in 3 years-time (during the period of the ban) when engaging in field work?
(vii) Have you encountered problems regarding weeds during field activities in the past few years (including the ban period)?
(viii) Have you done any change on resource allocation (labour, machinery or other inputs) during the ban period?
(ix) Any changes in the daily wage rates on hired labour paid during that time?
(x) How severe is the labour shortage in tea fields?
(xi) Have weeds affected the tea yield during the ban period? (If you rank your answer in a scale of 0 to 5, what score can you give?)
(xii) Can you quantify the change in the yield during the period you changed the weed control method used to apply? (As a % or kg/ha)
(xiii) How has the green leaf price changed over the period of the ban?
(xiv) What can you say about the cost of production in tea cultivations during the ban with respect to before the ban?

APPENDIX 1 – E: Key informant interviews in the farm sector

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For key informant interviews with extension officers, regional managers from institutes)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

Researcher's use only

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

General information

(i) To which institute doo you belong to?
(ii) What service do you provide to tea growers?
(iii) To what landholding size categories do majority of smallholders in the area belong to?
(iv) What are the average annual productions/ productivities of each land holding size category?
(v) What are the demographic factors about the tea growers in the area?
(vi) What are the important management practices in a tea field?
(vii) What are the average application rates, timing (of the year) and frequency of management practices in an average tea cultivation?
(viii) What is the mostly practiced weed management approach in the area by tea growers?
(ix) What are the reasons for their choice on weed management approach?
(x) What is your estimate of acreage treated with Glyphosate and other types of chemical weedicides?
(xi) What weed management approaches have tea growers in the area taken during the past five years (based on the landholding size)?
   a. Before the ban (2014, till mid 2015)
   b. During the ban (mid 2015 to mid-2018)
   c. After the ban (after mid 2018 till now)
(xii) What is your estimate of the acreage/percentage of acres/ha treated with other chemical weedicides which are alternatives of Glyphosate during the period of the ban?
(xiii) From where do they find hired labour?
(xiv) How did the wage rates of labour change during the past five years?
   a. Before the ban (2014, till mid 2015)
   b. During the ban (mid 2015 to mid-2018)
   c. After the ban (after mid 2018 till now)
(xv) Have you been notified by the government about the upcoming Glyphosate ban back in 2015?

(xvi) Were you informed by the relevant authorities about alternatives for Glyphosate that tea growers can use?

(xvii) How did the cost structure of average tea smallholders (using non-chemical and chemical weed management approach) change during the period of the ban?

(xviii) What might be the potential yield effects of possible bans considering the availability of alternatives during and after the period of the ban?

(xix) As you see, what is the impact of this government policy in the GL production businesses?

(xx) What are the challenges faced by the tea growers in the area?

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For key informant interviews with office bearers in tea smallholder development societies)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

Researcher's use only

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

General information

(i) How many members are there in your society?
(ii) What are their landholding size categories they belong to?
(iii) What proportion of your members provide GL to the society?
(iv) How much of GL harvest do you receive per day/week/month?
(v) Any change in the GL harvest quantity and quality received during the past five years? (at least as a percentage)
(vi) Average prices paid for green leaf harvest?
   Before the ban (2014, till mid 2015)
   During the ban (mid 2015 to mid-2018)
   After the ban (after mid 2018 till now)
(vii) To whom do you sell green leaves?
(viii) What have been the prices received for GL during the past five years?
   Before the ban (2014, till mid 2015)
   During the ban (mid 2015 to mid-2018)
   After the ban (after mid 2018 till now)
(ix) What are the weed management approaches used by the members?
(x) What proportion of your members use Glyphosate for weed controlling?
(xi) Are you aware about the availability of illegal sources Glyphosate?
   For how much were these illegal Glyphosate sold?
(xii) What is your estimate of the acreage/percentage of acres/ha treated with other chemical weedicides which are alternatives of Glyphosate during the period of the ban?

(xiii) What would have been the total cost/change in the cost structure and yield if you had used Glyphosate during the ban period? (In terms of other weedicides use and labour on weed control)

(xiv) How has been the response from your members towards the Glyphosate ban?

APPENDIX 1 – F: Semi-structured interviews with tea processing factory management

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For key informant interviews with office bearers in tea smallholder development societies)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

<u>*Researcher's use only*</u>

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

<u>General information</u>

(i) To what category of tea processors does the tea factory belong to? (Private factory/ RPC owned factory/state-owned factory)
(ii) What is the production scale?
(iii) From whom do you buy green leaves? (Bought leaf/own leaf)
(iv) What are the most common landholding size categories smallholders bringing GL to the factory belong to, and if the factory is estate owned, what is the size of the estate?
(v) How often do you receive GL from a particular green leaf producer/GL dealer?
(vi) Are you aware that there had been a ban on Glyphosate?
(vii) What changes in the business you noticed during that ban period?
(viii) Have you experienced a period where weed leaves were mixed with plucked tea leaves, changes in the size of green leaves in the harvest?
(ix) How do you decide on a price to be paid for the purchased green leaves? What are the quality parameters you consider in GL purchasing? What is the average price paid for green leaf harvest sellers? How did that price change during the past five years?
(x) What have been the average prices paid for GL received from GL dealers/smallholders/tea smallholder societies during the past five years?
    a. Before the ban (2014, till mid 2015)
    b. During the ban (mid 2015 to mid-2018)
    c. After the ban (after mid 2018 till now)
(xi) On average, how much harvest you receive from green leaf sellers daily/weekly/monthly? How did it change over the past five years?
(xii) Have you noticed any reduction/rise in the green leaf harvest received to the factory during past few years?
(xiii) What are the average quantities of green leaves received?
    a. Before the ban (2014, till mid 2015)
    b. During the ban (mid 2015 to mid-2018)
    c. After the ban (after mid 2018 till now)
(xiv) What types of made tea do you produce?
(xv) What is the cost of production of made tea?
(xvi) How did the cost structure change during the ban period (other input cost changes)?
(xvii) Who are your made tea buyers?
(xviii) Do you go through tea brokers to sell your products?
(xix) What have been the average prices received by selling made tea during the past five years? (Tea buyers or tea brokers)
    a. Before the ban (2014, till mid 2015)
    b. During the ban (mid 2015 to mid-2018)

c. After the ban (after mid 2018 till now)

(xx) What have been the average quantities (per month/year) of made tea traded during the past five years?

a. Before the ban (2014, till mid 2015)
b. During the ban (mid 2015 to mid-2018)
c. After the ban (after mid 2018 till now)

(xxi) (If they are not willing to reveal numbers, ask for a percentage increase or decrease of the volume with respect to a benchmark value)

(xxii) What is the average monthly income of the business?

(xxiii) As you see, what is the financial impact of the ban on the business? (Reduction in the quality of the produce, quantity of the amount of GL, made tea traded, prices paid for GL and received for made tea, profit of the business etc.)

(xxiv) What is the current status of the business?

(xxv) As you see, what is the impact of this government policy in the GL production businesses?

APPENDIX 1 – G: Semi-structured interviews with tea exporting companies

SEMI-STRUCTURED INTERVIEW GUIDELINE

(For key informant interviews with tea packers and exporters)

Research Topic: Evaluating the Economic Impact of the Government Policy of Banning Glyphosate in Sri Lanka: The Case of the Tea Industry

Researcher's use only

District:
GN region:
Date:
Explained the purpose of the study:
Obtained informed consent:

General information

(i) What percentage/quantity of the total made tea bought from the Colombo Tea Auction and/or direct sales is exported?
(ii) What proportion of the total national made tea production and total exports of made tea do you trade? What proportion of total exports do your buyers represent?
(iii) What kind of value addition do you perform at the packaging level?
(iv) What type of products do you export?
(v) Who are your main buyers? To what countries and what type of teas do you export?
(vi) Have you noticed any drop/rise in the made tea traded during past few years?
(vii) Has there been any change in the demand from the countries you export tea?
(viii) For what type of made tea does the highest demand exist? Any change in demand for tea during past few years?
(ix) Have you noticed any drop/rise in the made tea exported during the past few years?
(x) As you see, what is the financial impact of the ban on the business? (Drop in the quality of the produce, quantity of made tea traded, prices paid and received for made tea, change in the demand for tea from buyers, profit of the business etc.)
(xi) What is the current status of the business?
(xii) As you see, what is the impact of this government policy in the GL production businesses, tea processors, tea brokers and exporters?

APPENDIX 2 Sample interview transcript

Interview transcript for R10

The interviewee owned a tea estate with an area of 18 ac. He was a full-time tea planter. His main source of income was the tea cultivation that contributed around 90 per cent to the total household income. He did not receive any assistance from the family labour, so he totally relied on hired labour for carrying out field activities. Around 20 labourers were employed in the cultivation on daily basis from the village.

He did not consider that Glyphosate had negative impacts in his tea cultivation, nor on the health of labourers, not quite sure about the effect on the soil though. The ban Glyphosate had resulted in a big loss to his tea cultivation.

He had used Glyphosate to control weeds in the tea fields before the ban, illegal Glyphosate/alternatives during the ban and even after the ban. He practiced chemical weeding three times a year. For 1 ac in the cultivation, 8 tanks were usually applied. For each tank, 2 ounces of the weedicide were mixed with water. Recommended procedure in the label was practiced in applying weedicides. Two hired labourers were allocated for weedicide application. The wage rate paid to labourers was Rs. 850 per day without food during the ban.

He had bought Diuron at Rs. 1650 per 500g. This was mixed with MCPA and applied to control broad leaved weeds. This cocktail mixture was a contact weed killer and even weakens the tea bushes if comes in to contact during spraying. However, all weeds were not killed by this mixture. Once applied, it had lasted only about 1.5 months, less longer than Glyphosate. There were several tea bushes that had been exposed to the drift and started dying. He mentioned that this did not happen with the application of Glyphosate earlier. During the ban, he has even bought illegal glyphosate at Rs. 15,000/4l.

Illegal Glyphosate/ alternative chemicals used during the ban have not been effective relative to Glyphosate. Therefore, he had almost doubled the dose of such chemicals attempting to achieve the level of weed control with Glyphosate. He had even tried using several chemical options for weed controlling during the period of the ban on Glyphosate.

Although he continued with chemical weed management regardless of the inefficiency, he also had to abandon around 8 ac of his marginal tea lands during the period when alternative chemicals could not be found from the market. Therefore, during the ban when illegal Glyphosate was not available, additional labourers had to be used, then the cost almost doubled. The number of labourers to allocate for manual weeding had depended on the weed density, efficiency of labourers, where per acre labour requirement thus can go up to 20. It had been essential to do weeding at least once in two months with an average of ten labourers per acre.

He has been used to apply weedicide only in the dry period following the recommended harvesting interval. Weedicides were applied only in the cases where necessary; in places with more vacancies etc. otherwise applied to boundaries, roadsides etc.

For him, Glyphosate has been better than Diuron as an alternative in terms of the effect on the tea bushes. If Diuron was sprayed on to tea bushes accidentally, it had produced more clusters of branches leading to loss in productivity. Therefore, maximum effort was put to avoid the contact of chemical weedicides on the bush. Bushes die with Diuron unlike Glyphosate.

The cost increased by about 50 per cent, while using Diuron when illegal Glyphosate was not in the market.

He did not consider the ban on Glyphosate as a solution to the health issue, rather rules must be strengthened to make people follow the recommendation and proper practices.

He used machinery for shade tree lopping. He was willing to use machinery on plucking too, but the problem had been the unavailability of trained labour. Labour problem/lack of trained labour was a problem in the estate. There were labourers from all age categories, both young and aged in this area. Most of the young labourers were less educated and who could not read and write. Most of the younger generation of the labour community were engaged in non-agricultural jobs, they are reluctant to do labour work.

Labour shortage was a problem in green leaf plucking. Around 10,12 females were hired for green leaf plucking. Green leaf harvesting was done once in 9, 10 days (3 times a month) and a round usually lasted for 6,7 days.

The recommendation is followed for fertilizer application with 3 sacks of fertilizer per acre basis once every 3 months.

He had a negative perception on the ban. He was a very motivated and a genuine estate owner.

APPENDIX 3 Equations in Equilibrium Displacement Model

APPENDIX 3 – A: Model in Displacement Form

Green leaf production

Input supply to private green leaf production sector

(1) $EW'_v = \varepsilon_{W'v,\ p'v} * (Ep'_v + t_{W'v})$
(2) $EW'_f = \varepsilon_{W'f,\ p'f} * (Ep'_f + t_{W'f})$

Input supply to estate green leaf production sector

(3) $EW''_v = \varepsilon_{W''v,\ p''v} * (Ep''_v + t_{W''v})$
(4) $EW''_f = \varepsilon_{W''f,\ p''f} * (Ep''_f + t_{W''f})$

Output-constrained input demand of private green leaf production sector

(5) $EW'_v = -\ \kappa_{W'f} * \sigma_{W'v,\ W'f} * Ep'_v + \kappa_{W'f} * \sigma_{W'v,\ W'f} * Ep'_f + EX'_{GL}$
(6) $EW'_f = -\ \kappa_{W'v} * \sigma_{W'v,\ W'f} * Ep'_f + \kappa_{W'v} * \sigma_{W'v,\ W'f} * Ep'_v + EX'_{GL}$

Output-constrained input demand of private green leaf production sector

(7) $EW''_v = -\ \kappa_{W''f} * \sigma_{W''v,\ W''f} * Ep''_v + \kappa_{W''f} * \sigma_{W''v,\ W''f} * Ep''_f + EX''_{GL}$
(8) $EW''_f = -\ \kappa_{W''v} * \sigma_{W''v,\ W''f} * Ep''_f + \kappa_{W''v} * \sigma_{W''v,\ W''f} * Ep''_v + EX''_{GL}$

Input-constrained output supply of private green leaf production

(9) $EX' = -\ \lambda_{X'}\ \tau * Eq' + EW'_{GL}$

Input-constrained output supply of estate green leaf production

(10) $EX'' = -\ \lambda_{X''}\ \tau * Eq'' + EW''_{GL}$

Input-constrained output supply equality

(11) $EX = \rho x' * EX' + \rho x'' * EX''$

Equilibrium conditions of private green leaf production

(12) $\kappa_{W'v} * EW'_v + \kappa_{W'f} * EW'_f = \lambda_{X'} * EX'$
(13) $\kappa_{W'v} * Ep'_v + \kappa_{W'f} * Ep'_f = \lambda_{X'} * Eq'$

Equilibrium conditions of estate green leaf production

(14) $\kappa_{W''v} * EW''_v + \kappa_{W''f} * EW''_f = \lambda_{X''} * EX''$
(15) $\kappa_{W''v} * Ep''_v + \kappa_{W''f} * Ep''_f = \lambda_{X''} * Eq''$

Black tea manufacturing

Other input supply to black tea manufacturing

(16) $EX_o = \varepsilon_{Xo,\ qo} * (Eq_o + t_{Xo})$

Output-constrained input demand of black tea manufacturing

(17) $EX = - \kappa_{Xo} * \sigma_{X, Xo} * Eq + \kappa_{Xo} * \sigma_{X, Xo} * Eq_o + EY_{TM}$

(18) $EX_o = - \kappa_X * \sigma_{X, Xo} * Eq_o + \kappa_X * \sigma_{X, Xo} * Eq + EY_{TM}$

Input-constrained output supply of black tea manufacturing

(19) $EY'_1 = - (\lambda_{Y'2} * \tau_{Y'1, Y'2} + \lambda_{Y''1} * \tau_{Y'1, Y''1} + \lambda_{Y''2} * \tau_{Y'1, Y''2}) * Er'_1 + \lambda_{Y'2} * \tau_{Y'1, Y'2} * Er'_2 + \lambda_{Y''1} * \tau_{Y'1, Y''1} * Er''_1 + \lambda_{Y''2} * \tau_{Y'1, Y''2} * Er''_2 + EX_{TM}$

(20) $EY'_2 = - (\lambda_{Y'1} * \tau_{Y'2, Y'1} + \lambda_{Y''1} * \tau_{Y'2, Y''1} + \lambda_{Y''2} * \tau_{Y'2, Y''2}) * Er'_2 + \lambda_{Y'1} * \tau_{Y'2, Y'1} * Er'_1 + \lambda_{Y''1} * \tau_{Y'2, Y''1} * Er''_1 + \lambda_{Y''2} * \tau_{Y'2, Y''2} * Er''_2 + EX_{TM}$

(21) $EY''_1 = - (\lambda_{Y'1} * \tau_{Y'1, Y''1} + \lambda_{Y'2} * \tau_{Y'2, Y''1} + \lambda_{Y''2} * \tau_{Y''2, Y''1}) * Er''_1 + \lambda_{Y'1} * \tau_{Y''1, Y'1} * Er'_1 + \lambda_{Y'2} * \tau_{Y''1, Y'2} * Er'_2 + \lambda_{Y''2} * \tau_{Y''1, Y''2} * Er''_2 + EX_{TM}$

(22) $EY''_2 = - (\lambda_{Y'1} * \tau_{Y'1, Y''2} + \lambda_{Y'2} * \tau_{Y'2, Y''2} + \lambda_{Y''1} * \tau_{Y''1, Y''2}) * Er''_2 + \lambda_{Y'1} * \tau_{Y''2, Y'1} * Er'_1 + \lambda_{Y'2} * \tau_{Y''2, Y'2} * Er'_2 + \lambda_{Y''1} * \tau_{Y''2, Y''1} * Er''_1 + EX_{TM}$

Equilibrium conditions of black tea manufacturing

(23) $\kappa_X * EX + \kappa_{Xo} * EX_o = \lambda_{Y'1} * EY'_1 + \lambda_{Y'2} * EY'_2 + \lambda_{Y''1} * EY''_1 + \lambda_{Y''2} * EY''_2$

(24) $\kappa_X * Eq + \kappa_{Xo} * Eq_o = \lambda_{Y'1} * E\, r'_1 + \lambda_{Y'2} * E\, r'_2 + \lambda_{Y''1} * E\, r''_1 + \lambda_{Y''2} * E\, r''_2$

Secondary processing of made tea for export marketing in bulk form

Other input supply to secondary processing of made tea for export marketing in bulk form

(25) $E\, Y'_{1o} = \varepsilon_{Y'1o, r'1o} * (Er'_{1o} + t_{Y'1o})$

Output-constrained input demand of secondary processing of made tea for export marketing in bulk form

(26) $EY'_1 = - \kappa_{Y'1o} * \sigma_{Y'1, Y'1o} * Er'_1 + \kappa_{Y'1o} * \sigma_{Y'1, Y'1o} * Er'_{1o} + EZ'_{1M}$

(27) $EY'_{1o} = - \kappa_{Y'1} * \sigma_{Y'1, Y'1o} * Er'_{1o} + \kappa_{Y'1} * \sigma_{Y'1, Y'1o} * Er'_1 + EZ'_{1M}$

Input-constrained output supply of secondary processing of made tea for export marketing in bulk form

(28) $EZ'_1 = -\lambda\, \tau * Es'_1 + EY'_{1SP}$

Equilibrium condition of secondary processing of made tea for export marketing in bulk form

(29) $\kappa_{Y'1} * EY'_1 + \kappa_{Y'1o} * EY'_{1o} = \lambda_{Z'1} * EZ'_1$

(30) $\kappa_{Y'1} * Er'_1 + \kappa_{Y'1o} * Er'_{1o} = \lambda_{Z'1} * Es'_1$

Export demand for tea in bulk form

(31) $EZ'_1 = \eta_{Z'1, s'1} * (Es'_1 + n_{Z'1})$

Secondary processing of made tea for export marketing in value-added form

Other input supply to secondary processing of made tea for export marketing in value-added form

(32) $E\, Y'_{2o} = \varepsilon_{Y'2o, r'2o} * (Er'_{2o} + t_{Y'2o})$

Output-constrained input demand of secondary processing of made tea for export marketing in value-added form

(33) $EY'_2 = - \kappa_{Y'2o} * \sigma_{Y'2, Y'2o} * Er'_2 + \kappa_{Y'2o} * \sigma_{Y'2, Y'2o} * Er'_{2o} + EZ'_{2M}$

(34) $EY'_{2o} = - \kappa_{Y'2} * \sigma_{Y'2, Y'2o} * Er'_{2o} + \kappa_{Y'2} * \sigma_{Y'2, Y'2o} * Er'_2 + EZ'_{2M}$

Input-constrained output supply of secondary processing of made tea for export marketing in value-added form

(35) $EZ'_2 = -\lambda\, \tau_{Z'2, s'2} * Es'_2 + EY'_{2SP}$

Equilibrium condition of secondary processing of made tea for export marketing in value-added form

(36) $\kappa_{Y'2} * EY'_2 + \kappa_{Y'2o} * EY'_{2o} = \lambda_{Z'2} * EZ'_2$

(37) $\kappa_{Y'2} * Er'_2 + \kappa_{Y'2o} * Er'_{2o} = \lambda_{Z'2} * Es'_2$

Export demand for tea in value-added form

(38) $EZ'_2 = \eta_{Z'2, s'2} * (Es'_2 + n_{Z'2})$

Secondary processing of made tea for domestic marketing in bulk form

Other input supply to secondary processing of made tea for domestic marketing in bulk form

(39) $E\, Y''_{1o} = \varepsilon_{Y''1o, r''1o} * (Er''_{1o} + t_{Y''1o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in bulk form

(40) $EY''_1 = - \kappa_{Y''1o} * \sigma_{Y''1, Y''1o} * Er''_1 + \kappa_{Y''1o} * \sigma_{Y''1, Y''1o} * Er''_{1o} + EZ''_{1M}$

(41) $EY''_{1o} = - \kappa_{Y''1} * \sigma_{Y''1, Y''1o} * Er''_{1o} + \kappa_{Y''1} * \sigma_{Y''1, Y''1o} * Er''_1 + EZ''_{1M}$

Input-constrained output supply of secondary processing of made tea for domestic marketing in bulk form

(42) $EZ''_1 = -\lambda\, \tau * Es''_1 + EY''_{1SP}$

Equilibrium condition of secondary processing of made tea for domestic marketing in bulk form

(43) $\kappa_{Y''1} * EY''_1 + \kappa_{Y''1o} * EY''_{1o} = \lambda_{Z''1} * EZ''_1$

(44) $\kappa_{Y''1} * Er''_1 + \kappa_{Y''1o} * Er''_{1o} = \lambda_{Z''1} * Es''_1$

Domestic demand for tea in bulk form

(45) $EZ''_1 = \eta_{Z''1, s''1} * (Es''_1 + n_{Z''1})$

Secondary processing of made tea for domestic marketing in value-added form

Other input supply to secondary processing of made tea for domestic marketing in value-added form

(46) $EY''_{2o} = \varepsilon_{Y''2o, r''2o} * (Er''_{2o} + t_{Y''2o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in value-added form

(47) $EY''_2 = - \kappa_{Y''2o} * \sigma_{Y''2, Y''2o} * Er''_2 + \kappa_{Y''2o} * \sigma_{Y''2, Y''2o} * Er''_{2o} + EZ''_{2M}$

(48) $EY''_{2o} = - \kappa_{Y''2} * \sigma_{Y''2, Y''2o} * Er''_{2o} + \kappa_{Y''2} * \sigma_{Y''2, Y''2o} * Er''_2 + EZ''_{2M}$

Input-constrained output supply of secondary processing of made tea for domestic marketing in value-added form

(49) $EZ''_2 = -\lambda\ \tau * Es''_2 + EY''_{2SP}$

Equilibrium condition of secondary processing of made tea for domestic marketing in value-added form

(50) $\kappa_{Y''2} * EY''_2 + \kappa_{Y''2o} * EY''_{2o} = \lambda_{Z''2} * EZ''_2$

(51) $\kappa_{Y'2} * Er''_2 + \kappa_{Y''2o} * Er''_{2o} = \lambda_{Z''2} * Es''_2$

Domestic demand for tea in value-added form

(52) $EZ''_2 = \eta_{Z''2, s''2} * (Es''_2 + n_{Z''2})$

APPENDIX 3 – B: The Equilibrium Displacement Model with integrability conditions imposed

Green leaf production

Input supply to private green leaf production sector

(1) $EW'_v = \varepsilon_{W'v,\, p'v} * (Ep'_v + t_{W'v})$
(2) $EW'_f = \varepsilon_{W'f,\, p'f} * (Ep'_f + t_{W'f})$

Input supply to estate green leaf production sector

(3) $EW''_v = \varepsilon_{W''v,\, p''v} * (Ep''_v + t_{W''v})$
(4) $EW''_f = \varepsilon_{W''f,\, p''f} * (Ep''_f + t_{W''f})$

Output-constrained input demand of private green leaf production sector

(5) $EW'_v = - \kappa_{W'f} * \sigma_{W'v,\, W'f} * Ep'_v + \kappa_{W'f} * \sigma_{W'v,\, W'f} * Ep'_f + EX'_{GL}$
(6) $EW'_f = - \kappa_{W'v} * \sigma_{W'v,\, W'f} * Ep'_f + \kappa_{W'v} * \sigma_{W'v,\, W'f} * Ep'_v + EX'_{GL}$

Output-constrained input demand of private green leaf production sector

(7) $EW''_v = - \kappa_{W''f} * \sigma_{W''v,\, W''f} * Ep''_v + \kappa_{W''f} * \sigma_{W''v,\, W''f} * Ep''_f + EX''_{GL}$
(8) $EW''_f = - \kappa_{W''v} * \sigma_{W''v,\, W''f} * Ep''_f + \kappa_{W''v} * \sigma_{W''v,\, W''f} * Ep''_v + EX''_{GL}$

Input-constrained output supply of private green leaf production

(9) $EX' = - \lambda_{X'} \tau * Eq' + EW'_{GL}$

Input-constrained output supply of estate green leaf production

(10) $EX'' = - \lambda_{X''} \tau * Eq'' + EW''_{GL}$

Green leaf production equality

(11) $EX = \rho x' * EX' + \rho x'' * EX''$

Equilibrium conditions of private green leaf production

(12) $\kappa_{W'v} * EW'_v + \kappa_{W'f} * EW'_f = \lambda_{X'} * EX'$
(13) $\kappa_{W'v} * Ep'_v + \kappa_{W'f} * Ep'_f = \lambda_{X'} * Eq'$

Equilibrium conditions of estate green leaf production

(14) $\kappa_{W''v} * EW''_v + \kappa_{W''f} * EW''_f = \lambda_{X''} * EX''$
(15) $\kappa_{W''v} * Ep''_v + \kappa_{W''f} * Ep''_f = \lambda_{X''} * Eq''$

Black tea manufacturing

Other input supply to black tea manufacturing

(16) $EX_o = \varepsilon_{Xo,\, qo} * (Eq_o + t_{Xo})$

Output-constrained input demand of black tea manufacturing

(17) $EX = - \kappa_{Xo} * \sigma_{X, Xo} * Eq + \kappa_{Xo} * \sigma_{X, Xo} * Eq_o + EY_{TM}$
(18) $EX_o = - \kappa_X * \sigma_{X, Xo} * Eq_o + \kappa_X * \sigma_{X, Xo} * Eq + EY_{TM}$

Input-constrained output supply of black tea manufacturing

(19) $EY'_1 = - (\lambda_{Y'2} * \tau_{Y'1, Y'2} + \lambda_{Y''1} * \tau_{Y'1, Y''1} + \lambda_{Y''2} * \tau_{Y'1, Y''2}) * Er'_1 + \lambda_{Y'2} * \tau_{Y'1, Y'2} * Er'_2 + \lambda_{Y''1} * \tau_{Y'1, Y''1} * Er''_1 + \lambda_{Y''2} * \tau_{Y'1, Y''2} * Er''_2 + EX_{TM}$
(20) $EY'_2 = - (\lambda_{Y'1} * \tau_{Y'2, Y'1} + \lambda_{Y''1} * \tau_{Y'2, Y''1} + \lambda_{Y''2} * \tau_{Y'2, Y''2}) * Er'_2 + \lambda_{Y'1} * \tau_{Y'2, Y'1} * Er'_1 + \lambda_{Y''1} * \tau_{Y'2, Y''1} * Er''_1 + \lambda_{Y''2} * \tau_{Y'2, Y''2} * Er''_2 + EX_{TM}$
(21) $EY''_1 = - (\lambda_{Y'1} * \tau_{Y'1, Y''1} + \lambda_{Y'2} * \tau_{Y'2, Y''1} + \lambda_{Y''2} * \tau_{Y''2, Y''1}) * Er''_1 + \lambda_{Y'1} * \tau_{Y''1, Y'1} * Er'_1 + \lambda_{Y'2} * \tau_{Y''1, Y'2} * Er'_2 + \lambda_{Y''2} * \tau_{Y''1, Y''2} * Er''_2 + EX_{TM}$
(22) $EY''_2 = - (\lambda_{Y'1} * \tau_{Y'1, Y''2} + \lambda_{Y'2} * \tau_{Y'2, Y''2} + \lambda_{Y''1} * \tau_{Y''1, Y''2}) * Er''_2 + \lambda_{Y'1} * \tau_{Y''2, Y'1} * Er'_1 + \lambda_{Y'2} * \tau_{Y''2, Y'2} * Er'_2 + \lambda_{Y''1} * \tau_{Y''2, Y''1} * Er''_1 + EX_{TM}$

Equilibrium conditions of black tea manufacturing

(23) $\kappa_X * EX + \kappa_{Xo} * EX_o = \lambda_{Y'1} * EY'_1 + \lambda_{Y'2} * EY'_2 + \lambda_{Y''1} * EY''_1 + \lambda_{Y''2} * EY''_2$
(24) $\kappa_X * Eq + \kappa_{Xo} * Eq_o = \lambda_{Y'1} * E r'_1 + \lambda_{Y'2} * E r'_2 + \lambda_{Y''1} * E r''_1 + \lambda_{Y''2} * E r''_2$

Secondary processing of made tea for export marketing in bulk form

Other input supply to secondary processing of made tea for export marketing in bulk form

(25) $E Y'_{1o} = \varepsilon_{Y'1o, r'1o} * (Er'_{1o} + t_{Y'1o})$

Output-constrained input demand of secondary processing of made tea for export marketing in bulk form

(26) $EY'_1 = - \kappa_{Y'1o} * \sigma_{Y'1, Y'1o} * Er'_1 + \kappa_{Y'1o} * \sigma_{Y'1, Y'1o} * Er'_{1o} + EZ'_{1M}$
(27) $EY'_{1o} = - \kappa_{Y'1} * \sigma_{Y'1, Y'1o} * Er'_{1o} + \kappa_{Y'1} * \sigma_{Y'1, Y'1o} * Er'_1 + EZ'_{1M}$

Input-constrained output supply of secondary processing of made tea for export marketing in bulk form

(28) $EZ'_1 = -\lambda \tau * Es'_1 + EY'_{1SP}$

Equilibrium condition of secondary processing of made tea for export marketing in bulk form

(29) $\kappa_{Y'1} * EY'_1 + \kappa_{Y'1o} * EY'_{1o} = \lambda_{Z'1} * EZ'_1$
(30) $\kappa_{Y'1} * Er'_1 + \kappa_{Y'1o} * Er'_{1o} = \lambda_{Z'1} * Es'_1$

Export demand for tea in bulk form

(31) $EZ'_1 = \eta_{Z'1, s'1} * (Es'_1 + n_{Z'1})$

Secondary processing of made tea for export marketing in value-added form

Other input supply to secondary processing of made tea for export marketing in value-added form

(32) $E Y'_{2o} = \varepsilon_{Y'2o, r'2o} * (Er'_{2o} + t_{Y'2o})$

Output-constrained input demand of secondary processing of made tea for export marketing in value-added form

(33) $EY'_2 = - \kappa_{Y'2o} * \sigma_{Y'2, Y'2o} * Er'_2 + \kappa_{Y'2o} * \sigma_{Y'2, Y'2o} * Er'_{2o} + EZ'_{2M}$
(34) $EY'_{2o} = - \kappa_{Y'2} * \sigma_{Y'2, Y'2o} * Er'_{2o} + \kappa_{Y'2} * \sigma_{Y'2, Y'2o} * Er'_2 + EZ'_{2M}$

Input-constrained output supply of secondary processing of made tea for export marketing in value-added form

(35) $EZ'_2 = -\lambda \tau_{Z'2, s'2} * Es'_2 + EY'_{2SP}$

Equilibrium condition of secondary processing of made tea for export marketing in value-added form

(36) $\kappa_{Y'2} * EY'_2 + \kappa_{Y'2o} * EY'_{2o} = \lambda_{Z'2} * EZ'_2$
(37) $\kappa_{Y'2} * Er'_2 + \kappa_{Y'2o} * Er'_{2o} = \lambda_{Z'2} * Es'_2$

Export demand for tea in value-added form

(38) $EZ'_2 = \eta_{Z'2, s'2} * (Es'_2 + n_{Z'2})$

Secondary processing of made tea for domestic marketing in bulk form

Other input supply to secondary processing of made tea for domestic marketing in bulk form

(39) $E Y''_{1o} = \varepsilon_{Y''1o, r''1o} * (Er''_{1o} + t_{Y''1o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in bulk form

(40) $EY''_1 = - \kappa_{Y''1o} * \sigma_{Y''1, Y''1o} * Er''_1 + \kappa_{Y''1o} * \sigma_{Y''1, Y''1o} * Er''_{1o} + EZ''_{1M}$
(41) $EY''_{1o} = - \kappa_{Y''1} * \sigma_{Y''1, Y''1o} * Er''_{1o} + \kappa_{Y''1} * \sigma_{Y''1, Y''1o} * Er''_1 + EZ''_{1M}$

Input-constrained output supply of secondary processing of made tea for domestic marketing in bulk form

(42) $EZ''_1 = -\lambda \tau * Es''_1 + EY''_{1SP}$

Equilibrium condition of secondary processing of made tea for domestic marketing in bulk form

(43) $\kappa_{Y''1} * EY''_1 + \kappa_{Y''1o} * EY''_{1o} = \lambda_{Z''1} * EZ''_1$
(44) $\kappa_{Y''1} * Er''_1 + \kappa_{Y''1o} * Er''_{1o} = \lambda_{Z''1} * Es''_1$

Domestic demand for tea in bulk form

(45) $EZ''_1 = \eta_{Z''1, s''1} * (Es''_1 + n_{Z''1})$

Secondary processing of made tea for domestic marketing in value-added form

Other input supply to secondary processing of made tea for domestic marketing in value-added form

(46) $EY''_{2o} = \varepsilon_{Y''2o, r''2o} * (Er''_{2o} + t_{Y''2o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in value-added form

(47) $EY''_2 = - \kappa_{Y''2o} * \sigma_{Y''2, Y''2o} * Er''_2 + \kappa_{Y''2o} * \sigma_{Y''2, Y''2o} * Er''_{2o} + EZ''_{2M}$
(48) $EY''_{2o} = - \kappa_{Y''2} * \sigma_{Y''2, Y''2o} * Er''_{2o} + \kappa_{Y''2} * \sigma_{Y''2, Y''2o} * Er''_2 + EZ''_{2M}$

Input-constrained output supply of secondary processing of made tea for domestic marketing in value-added form

(49) $EZ''_2 = -\lambda\ \tau * Es''_2 + EY''_{2SP}$

Equilibrium condition of secondary processing of made tea for domestic marketing in value-added form

(50) $\kappa_{Y''2} * EY''_2 + \kappa_{Y''2o} * EY''_{2o} = \lambda_{Z''2} * EZ''_2$
(51) $\kappa_{Y'2} * Er''_2 + \kappa_{Y''2o} * Er''_{2o} = \lambda_{Z''2} * Es''_2$

Domestic demand for tea in value-added form

(52) $EZ''_2 = \eta_{Z''2, s''2} * (Es''_2 + n_{Z''2})$

APPENDIX 4 Technical validation of the Equilibrium Displacement Model

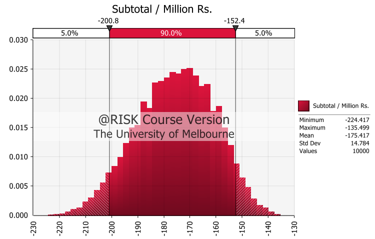
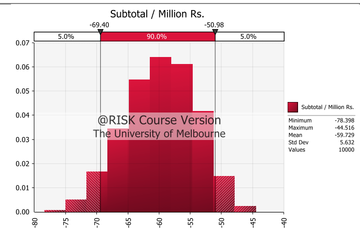
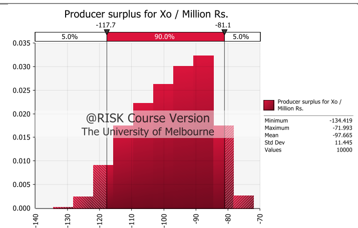
Appendix 4 - A: Price and quantity changes for 1 per cent shock of increased costs on variable inputs in private and estate tea grower sectors

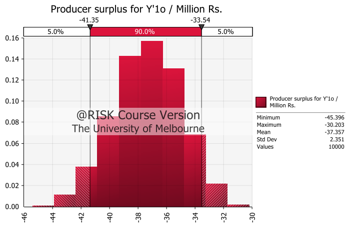
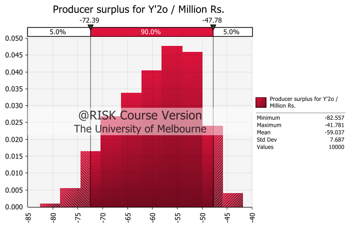
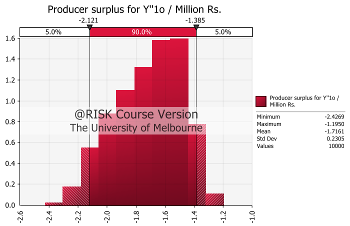
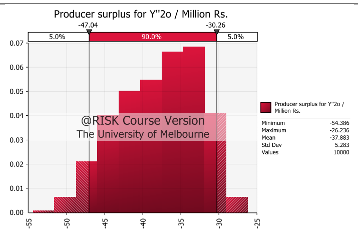
Price changes		Quantity changes	
Price variable	Proportionate change in price	Quantity variable	Proportionate change in quantity
Price of GL	0.0054	Quantity of green leaves supplied from the green leaf production private landholding sector to the black tea manufacturing sector	-0.0025
Auction price of primarily processed tea used to produce bulk black tea for export markets	0.0012	Quantity of green leaves supplied from the green leaf production estate sector to the black tea manufacturing sector	-0.0018
Auction price of primarily processed tea used to produce value-added black tea for export markets	0.0019	Total national green leaf production	-0.0023
Auction price of primarily processed tea used to produce bulk black tea for domestic consumption	0.0063	Quantity of black tea from the manufacturing sector to the bulk tea export marketing sector for secondary processing	-0.0023
Auction price of primarily processed tea used to produce value-added black tea for domestic consumption	0.0166	Quantity of black tea from the manufacturing sector to the VAT export marketing sector for secondary processing	-0.0023
Price of bulk black tea sold to export market	0.0006	Quantity of black tea from the manufacturing sector to the loose bulk tea domestic marketing sector for secondary processing	-0.0023
Price of value-added black tea sold to export market	0.0005	Quantity of black tea from the manufacturing sector to the VAT domestic marketing sector for secondary processing	-0.0023
Price of bulk black tea sold for domestic consumption	0.0029	Quantity of bulk black tea from secondary processing to export market	-0.0023
Price of value-added black tea sold for domestic consumption	0.0057	Quantity of value-added black tea from secondary processing to export market	-0.0023
		Quantity of bulk black tea from secondary processing to domestic market	-0.0023
		Quantity of value-added black tea from secondary processing to domestic market	-0.0023

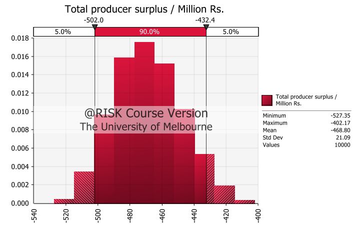
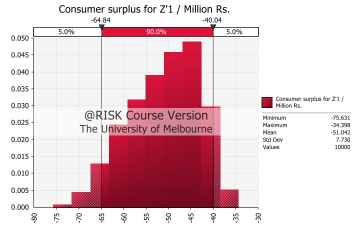
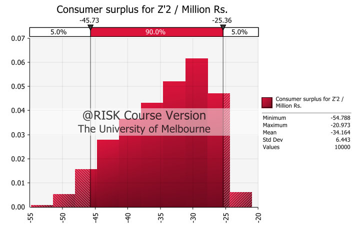
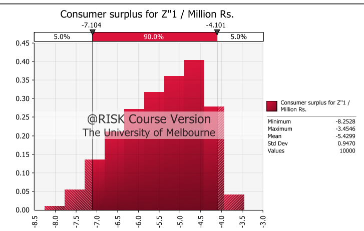
Appendix 4 – B: Surplus changes in endogenous variables resulted from 1 per cent shock of increased costs on variable inputs in private and estate tea grower sectors

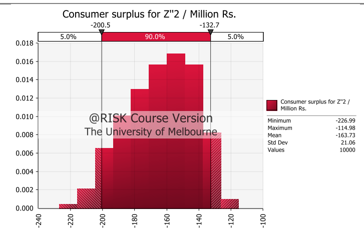
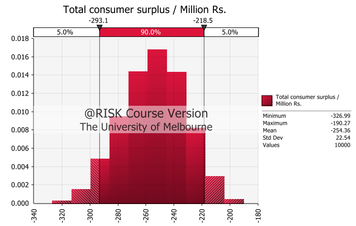
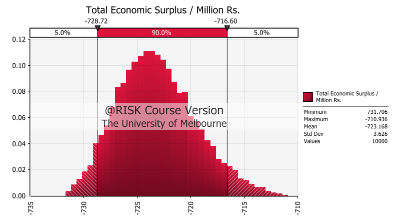
Surplus changes	Million Rs.	Distribution (%)
Producer surplus		
Green leaf production	(235.3)	32.52
Private grower sector	(175.50)	24.26
Producer surplus for variable inputs	(130.17)	17.99
Producer surplus for fixed inputs	(45.32)	6.27
Estate grower sector	(59.76)	8.26
Producer surplus for variable inputs	(39.30)	5.43
Producer surplus for fixed inputs	(20.46)	2.83
Black tea manufacturing	(97.83)	13.52
Secondary processing of tea for bulk tea exports	(37.99)	5.25
Secondary processing of tea for VAT exports	(59.04)	8.16
Secondary processing of tea for domestic consumption in loose form	(1.71)	0.24
Secondary processing of tea for VAT consumption in domestic markets	(37.83)	5.23
Total producer surplus	(469.67)	64.92
Consumer surplus		
Black tea exports in bulk form	(50.89)	7.03
Black tea exports in value-added form	(33.70)	4.66
Black tea in loose form for domestic consumption	(5.38)	0.74
Black tea in value-added form for domestic consumption	(163.77)	22.64
Total consumer surplus	(253.75)	35.07
Total Economic Surplus	(723.42)	100

Appendix 4 – C: Probability distributions of surplus changes in endogenous variables resulting from 1 per cent increase in the costs of variable inputs in both the private and estate tea grower sectors

Market level	Graph	Minimum value	Mean value	Maximum value	5%	95%	Standard deviation
Farm sector							
Private grower sector		(224.41)	(175.41)	(135.49)	(200.8)	(152.4)	14.78
Estate grower sector		(78.39)	(59.72)	(44.51)	(69.04)	(50.98)	5.63
Black tea manufacturing sector		(134.41)	(97.66)	(71.99)	(117.7)	(81.1)	11.44

Secondary processing of black tea for bulk exports		(45.39)	(37.35)	(30.20)	(41.35)	(33.54)	2.35
Secondary processing of black tea for VAT exports		(82.55)	(59.03)	(41.78)	(72.39)	(47.78)	7.68
Secondary processing of black tea for domestic marketing of loose bulk tea		(2.42)	(1.71)	(1.19)	(2.12)	(1.38)	0.23
Secondary processing of black tea for domestic marketing of VAT		(54.38)	(37.88)	(26.23)	(47.04)	(30.26)	5.28

Producer sector		(527.35)	(468.80)	(402.17)	(502.0)	(432.4)	21.09
Bulk tea export sector		(75.63)	(51.04)	(34.39)	(64.84)	(40.04)	7.73
VAT export sector		(54.78)	(34.16)	(20.97)	(45.73)	(25.36)	6.44
Domestic consumption of loose bulk tea		(8.25)	(5.43)	(3.45)	(7.10)	(4.10)	0.94

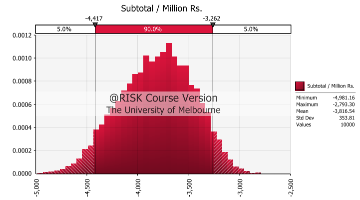
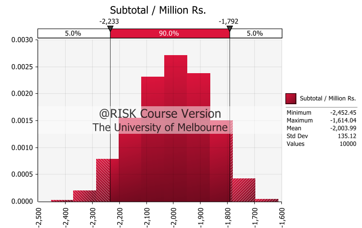
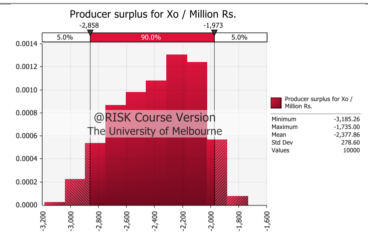
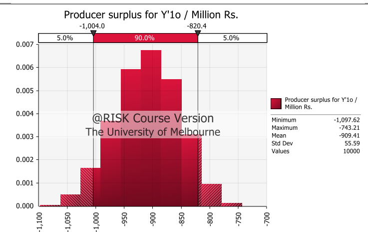
Domestic consumption of VAT		(226.99)	(163.73)	(114.98)	(200.5)	(132.7)	21.06
Consumer sector		(326.99)	(254.36)	(190.27)	(293.1)	(218.5)	22.54
Tea industry		(731.70)	(723.17)	(710.93)	(728.7)	(716.6)	3.62

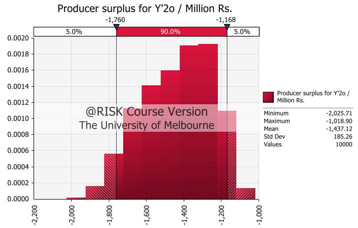
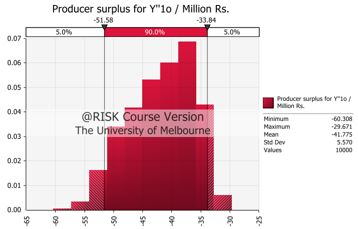
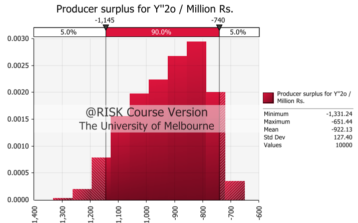
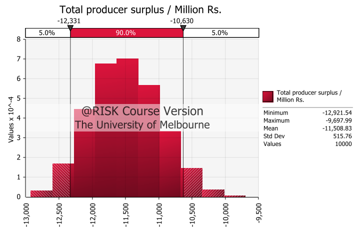
APPENDIX 5 Budget parameters of weed management decisions in the private tea grower sector

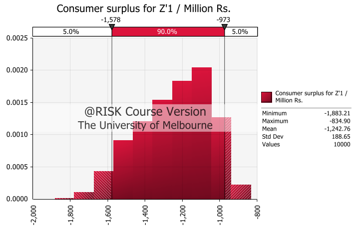
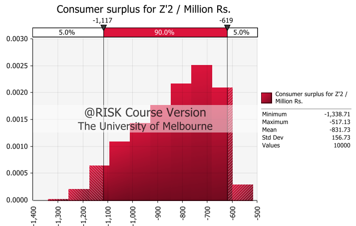
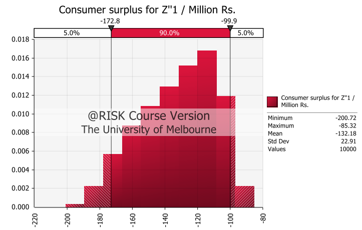
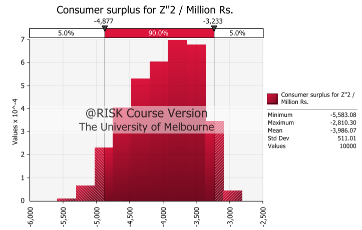
Parameters	Units	(1) Glyphos-ate only before the ban	(i) Predicted scenario: Complete substitution of Glyphosate by GA		(a) Complete substitution of Glyphosate by labour					(b) Complete substitution of Glyphosate by Diuron or Illegal Glyphosate						(c) Substitution of Glyphosate with either Diuron or Illegal Glyphosate and labour						(2) Glyphos ate and manual before the ban	(ii) Predicted scenario: Complete substitution of Glyphosate by GA and labour		(d) Continued chemical weed management with either Diuron or Illegal Glyphosate and labour					
					(wb) With the ban		(db) During the ban			(wb) With the ban		(db) During the ban				(wb) With the ban		(db) During the ban							(wb) With the ban		(db) During the ban			
			(wb) With the ban	(db) During the ban	(T) Theoretical	(A) Actual	(T) Theoretical	(A) Actual	(AF)	(AD) Actual Diuron	(AIG) Actual Illegal Glyphosate	(AD) Actual Diuron	(AIG) Actual Illegal Glyphosate	(AFD) AF-Diuron	(AFIG) AF-Illegal Glyphosate	(AD) Actual Diuron	(AIG) Actual Illegal Glyphosate	(AD) Actual Diuron	(AIG) Actual Illegal Glyphosate	(AFD) AF-Diuron	(AFIG) AF-Illegal Glyphosate		(wb) With the ban	(db) During the ban	(AD) Actual Diuron	(AIG) Actual Illegal Glyphosate	(AD) Actual Diuron	(AIG) Actual Illegal Glyphosate	(AFD) AF-Diuron	(AFIG) AF-Illegal Glyphosate
Cost on chemical weeding	Rs/ha	30,183	41,644	45,646	N/A	N/A	N/A	N/A	N/A	33,049	56,267	37,050	60,268	37,050	60,268	24,786	42,200	27,788	45,201	27,788	45,201	35,568	35,568	44,460	24,786	42,200	27,788	45,201	27,788	45,201
Cost on manual weeding	Rs/ha	N/A	N/A	N/A	180,656	73,013	225,264	90,896	90,896	N/A	N/A	N/A	N/A	N/A	N/A	47,424	47,424	59,280	59,280	59,280	59,280	21,482	31,233	34,234	59,280	59,280	74,100	74,100	74,100	74,100
Cost on weed management	Rs/ha	30,183	41,644	45,646	180,656	73,013	225,264	90,896	90,896	33,049	56,267	37,050	60,268	37,050	60,268	72,210	89,624	87,068	104,481	87,068	104,481	57,050	66,801	78,694	84,066	101,480	101,888	119,301	101,888	119,301
Total variable cost	Rs/ha	372,634	384,095	452,272	523,106	415,464	631,890	497,522	484,085	375,499	398,717	443,676	466,894	430,239	453,457	414,661	432,075	493,694	511,107	480,257	497,670	399,500	409,252	485,320	426,517	443,931	508,514	525,927	495,077	512,490
Gross income	Rs/ha	800,754	800,754	1,075,221	800,754	772,725	1,075,221	1,037,584	806,415	772,725	772,725	1,037,584	1,037,584	806,415	806,415	772,725	772,725	1,037,584	1,037,584	806,415	806,415	800,754	800,754	1,075,221	772,725	772,725	1,037,584	1,037,584	806,415	806,415
Gross margin	Rs/ha	428,120	416,659	622,949	277,648	357,261	443,330	540,062	322,330	397,226	374,008	593,908	570,690	376,176	352,958	358,064	340,651	543,891	526,477	325,159	308,745	401,254	391,502	589,900	346,208	328,795	529,071	511,657	311,339	293,925
Change in GM	Rs/ha	N/A	(11,461)	194,829	(150,472)	(70,859)	15,210	111,942	(105,790)	(30,894)	(54,112)	165,788	142,570	(51,944)	(75,162)	(70,056)	(87,470)	115,770	98,357	(101,962)	(119,375)	N/A	(9,752)	188,646	(55,046)	(72,459)	127,817	110,403	(89,915)	(107,329)
% Change in GM	%	N/A	(2.67)	45.51	(35.15)	(16.55)	3.55	26.15	(24.71)	(7.22)	(12.64)	38.72	33.30	12.13	(17.56)	(16.36)	(20.43)	27.04	22.97	(23.82)	(27.88)	N/A	(2.43)	47.01	(13.72)	(18.06)	31.85	27.51	(22.41)	(26.75)
Change in TVC	Rs/ha	N/A	11,461	79,638	150,472	42,830	259,256	124,888	111,748	2,865	26,083	71,042	94,260	57,605	80,823	42,027	59,441	121,060	138,473	107,623	125,036	N/A	9,752	85,820	27,017	44,430	109,013	126,427	95,577	112,990
% Change in TVC	%	N/A	3.07	21.37	40.38	11.50	69.57	33.51	29.98	0.77	7.00	19.06	25.30	15.45	21.69	11.28	15.95	32.49	37.16	28.88	33.55	N/A	2.44	21.48	6.76	11.12	27.29	31.65	23.92	28.28
% Change in weeding cost	%	N/A	37.97	51.23	498.53	141.90	646.32	201.15	201.15	9.50	86.42	22.75	99.67	22.75	99.67	139.24	196.93	188.46	246.15	188.46	246.15	N/A	17.09	37.94	47.36	77.88	78.59	109.12	78.59	109.12

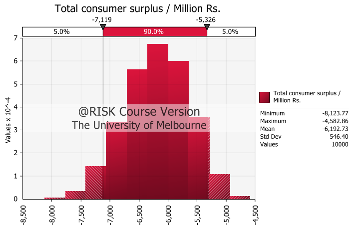
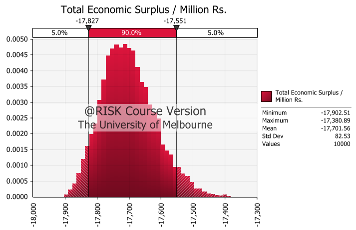
APPENDIX 6 Welfare analysis of the effects of the Glyphosate ban on the tea industry

Appendix 6 – A: Distribution of surplus changes across market levels in the scenario 'during the ban' for increased variable costs in the farm sector

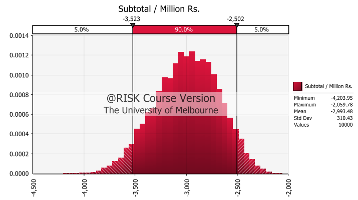
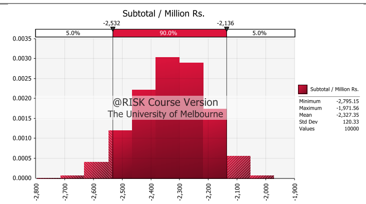
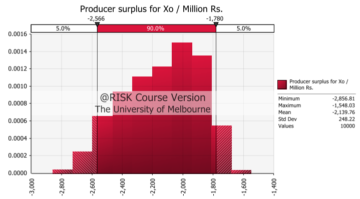
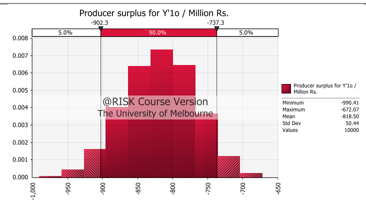
Market level	Graph	Minimum value	Mean value	Maximum value	5%	95%	Standard deviation
Farm sector							
Private grower sector		(4,981.16)	(3,816.54)	(2,793.30)	(4,417)	(3,262)	353.81
Estate grower sector		(2,452.45)	(2,003.99)	(1,614.04)	(2,233)	(1,792)	135.12
Black tea manufacturing sector		(3,185.26)	(2,377.86)	(1,735.00)	(2,858)	(1,973)	278.60
Secondary processing of black tea for bulk exports		(1,097.62)	(909.41)	(743.21)	(1,004.0)	(820.4)	55.59

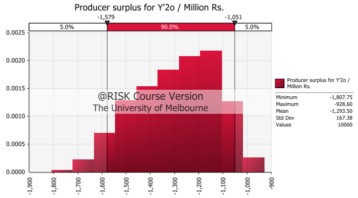
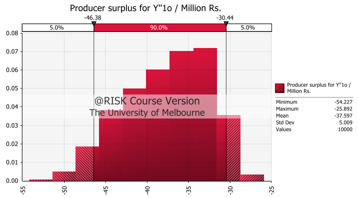
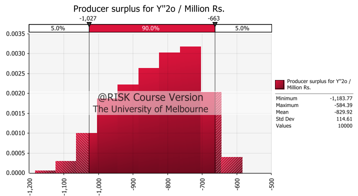
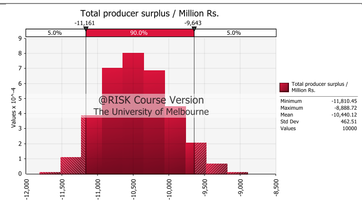
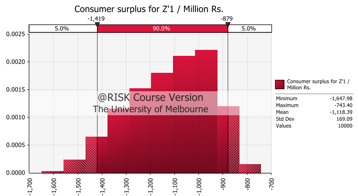
Secondary processing of black tea for VAT exports		(2,025.71)	(1,437.12)	(1,018.90)	(1,760)	(1,168)	185.26
Secondary processing of black tea for domestic marketing of loose bulk tea		(60.30)	(41.77)	(29.67)	(51.58)	(33.84)	5.57
Secondary processing of black tea for domestic marketing of VAT		(1,331.24)	(922.13)	(651.44)	(1,145)	(740)	127.40
Producer sector		(12,921.54)	(11,508.83)	(9,697.99)	(12,331)	(10,630)	515.76

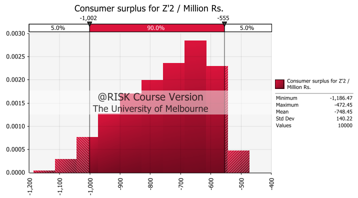
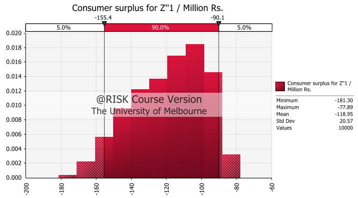
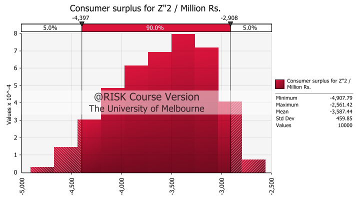
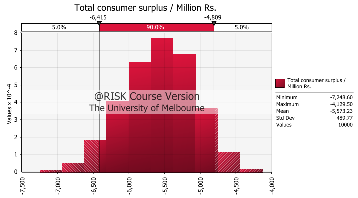
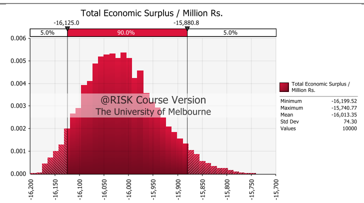
Bulk tea export sector		(1,883.21)	(1,242.76)	(834.90)	(1,578)	(973)	188.65
VAT export sector		(1,338.71)	(831.73)	(517.13)	(1,117)	(619)	156.73
Domestic consumption of loose bulk tea		(200.72)	(132.18)	(85.32)	(172.8)	(99.9)	22.91
Domestic consumption of VAT		(5,583.08)	(3,986.07)	(2,810.3)	(4,877)	(3,233)	511.01

Consumer sector		(8,123.77)	(6,192.73)	(4,582.86)	(7,119)	(5,326)	546.40
Tea industry		(17,902.51)	(17,701.56)	(17,380.89)	(17,827)	(17,551)	82.53

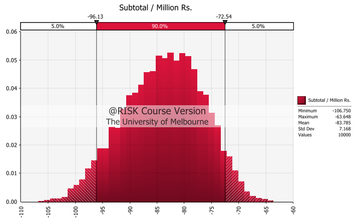
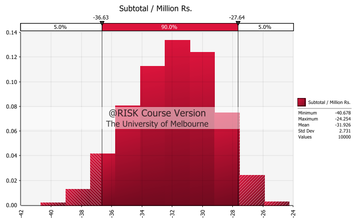
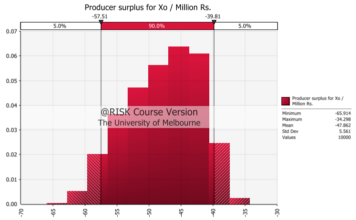
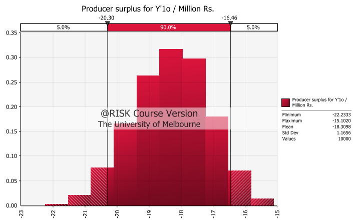
Appendix 6 – B: Distribution of surplus changes across market levels in the scenario 'during the ban with cash voucher system in place' for increased variable costs in the farm sector

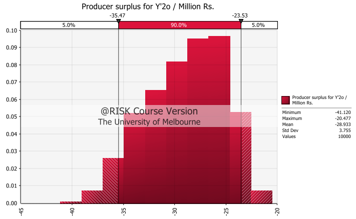
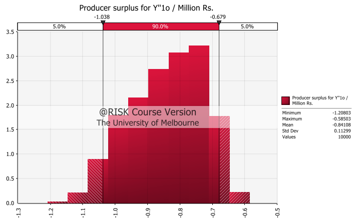
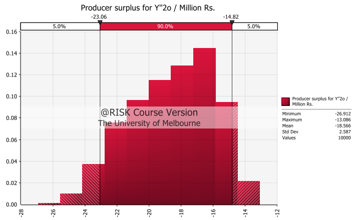
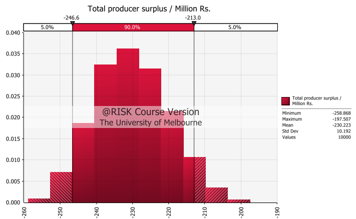
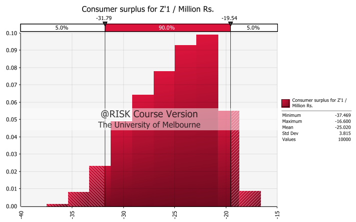
Market level	Graph	Minimum value	Mean value	Maximum value	5%	95%	Standard deviation
Farm sector							
Private grower sector		(4,203.95)	(2,993.48)	(2,059.78)	(3,523)	(2,502)	310.43
Estate grower sector		(2,795.15)	(2,327.35)	(1,971.56)	(2,532)	(2,136)	120.33
Black tea manufacturing sector		(2,856.81)	(2,139.76)	(1548.03)	(2,566)	(1780)	248.22
Secondary processing of black tea for bulk exports		(990.41)	(818.50)	(672.07)	(902.3)	(737.3)	50.44

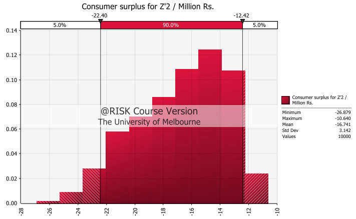
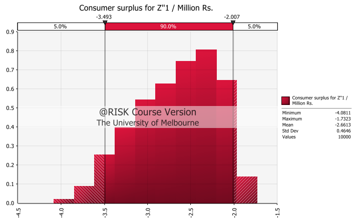
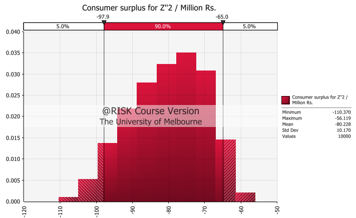
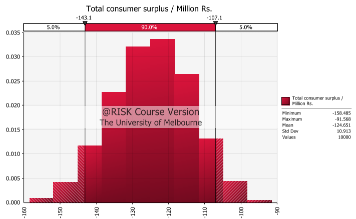
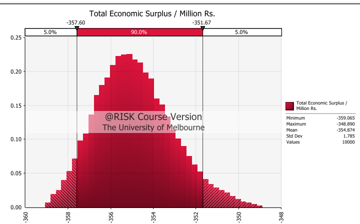
Secondary processing of black tea for VAT exports		(1,807.75)	(1,293.50)	(928.60)	(1,579)	(1,051)	167.38
Secondary processing of black tea for domestic marketing of loose bulk tea		(54.22)	(37.59)	(25.89)	(46.38)	(30.44)	5.00
Secondary processing of black tea for domestic marketing of VAT		(1,183.77)	(829.92)	(584.39)	(1,027)	(663)	114.61
Producer sector		(11,810.45)	(10,440.12)	(8,888.72)	(11,161)	(9,643)	462.51
Bulk tea export sector		(1,647.98)	(1,118.39)	(743.40)	(1,419)	(879)	169.09

VAT export sector		(1,186.47)	(748.45)	(472.45)	(1,002)	(555)	140.22
Domestic consumption of loose bulk tea		(181.30)	(118.95)	(77.89)	(155.4)	(90.1)	20.57
Domestic consumption of VAT		(4,907.79)	(3587.44)	(2,561.42)	(4,397)	(2,908)	459.85
Consumer sector		(7,248.60)	(5,573.23)	(4,129.50)	(6,415)	(4,809)	489.77
Tea industry		(16,199.52)	(16,013.35)	(15,740.7 7)	(16,125)	(15,880)	74.30

Appendix 6 – C: Distribution of surplus changes across market levels for decline in demand for bulk tea exports

Market level	Graph	Minimum value	Mean value	Maximum value	5%	95%	Standard deviation
Farm sector							
Private grower sector		(106.75)	(83.78)	(63.64)	(96.13)	(72.54)	7.16
Estate grower sector		(40.67)	(31.92)	(24.25)	(36.63)	(27.64)	2.73
Black tea manufacturing sector		(65.91)	(47.86)	(34.29)	(57.51)	(39.81)	5.56
Secondary processing of black tea for bulk exports		(22.23)	(18.30)	(15.10)	(20.30)	(16.45)	1.16

Secondary processing of black tea for VAT exports		(41.12)	(28.93)	(20.47)	(35.47)	(23.53)	3.75
Secondary processing of black tea for domestic marketing of loose bulk tea		(1.20)	(0.84)	(0.58)	(1.03)	(0.67)	0.11
Secondary processing of black tea for domestic marketing of VAT		(26.91)	(18.56)	(13.08)	(23.06)	(14.82)	2.58
Producer sector		(258.86)	(230.22)	(197.50)	(246.6)	(213.0)	10.19
Bulk tea export sector		(37.46)	(25.02)	(16.60)	(31.79)	(19.54)	3.81

VAT export sector		(26.87)	(16.74)	(10.64)	(22.40)	(12.42)	3.14
Domestic consumption of loose bulk tea		(4.08)	(2.66)	(1.73)	(3.49)	(2.00)	0.46
Domestic consumption of VAT		(110.37)	(80.22)	(56.11)	(97.9)	(65.0)	10.17
Consumer sector		(158.48)	(124.65)	(91.56)	(143.1)	(107.1)	10.91
Tea industry		(359.06)	(354.87)	(348.89)	(357.60)	(351.67)	1.78