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Policy Options to Reduce Electricity Greenhouse Gas Emissions*

(* I am grateful for the comments of Ian McDonald and two referees on an earlier draft, and accept responsibility for this version.)

Abstract

The design and effects of different schemes to reduce greenhouse gas emissions associated with the production and consumption of electricity are modelled. The tax scheme achieves the lowest cost per unit emission reduction because it encourages both businesses and consumers to reduce emissions, and the recycled windfall revenue can meet equity objectives. Comparing the EIS, CET and RET schemes with common government revenue neutral and emissions reduction design outcomes, the EIS provides better incentives to generators to find the lower cost per unit emissions reduction.

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1. Introduction

Many government interventions have been proposed, and some implemented, to reduce greenhouse gas emissions in the production and consumption of electricity as a component of climate change mitigation policy. In Australia, interventions include regulations, such as the Renewable Energy Target (RET), placing a price on emissions, such as the carbon tax and the promised emissions trading scheme of the Gillard government (Gillard et al., 2011), and subsidies, such as grants to invest in renewable energy.

Recent policy interest and debate has been stimulated by the Finkel Review (Finkel, et al., 2017). Finkel favoured an Emissions Intensity Scheme (EIS), and discussed the more restricted Clean Energy Target (CET) and the RET. In effect, the three schemes involve a self-funding mix of a tax on fossil fuel generators and a subsidy to renewable energy generators. The EIS allows for variation of pollution per unit electricity generation across all different generator options. By comparison, the CET, and more so the RET, explicitly or implicitly assume a common pollution per unit of electricity rate across many different generators with different actual rates of pollution. Relative to the EIS, the resulting flat tax rate across some different generators with the CET, and even more the RET, removes some incentives and rewards to reduce aggregate pollution by generators at lowest cost.

The conventional recommended economic policy intervention to correct an external cost market failure dating back to Pigou (1920) is to internalise the external cost with a tax per unit of pollution. Williams (2017) provides a recent discussion specifically for greenhouse gas emissions, including choice of the tax base and tax rate, decision responses and market outcomes. A tax draws on private information across all producers and consumers of electricity to reduce the pollution at least cost by equating marginal abatement costs to reduce pollution across the many decision options. Further, the revenue windfall from the pollution tax can be recycled as approximate lump sum transfers to compensate households for the higher electricity price.

An EIS has been proposed by the Climate Change Authority (2016), Grattan Institute (Wood, et al., 2016) and others as a relatively efficient way to reduce emissions, zero cost to government, and with a relatively low cost to consumers. Retailers are required to meet a target maximum rate of CO2-e emissions per KWh of electricity sold. In practice, generators with pollution rates below the target rate receive a permit or credit proportional to the target less actual pollution, and generators with pollution above the target level are required to purchase permits or credits proportional to actual pollution less the target. A market for the limited aggregate quantity of permits to pollute generates a scarcity price. An outcome is a government budget neutral package with a tax on above target polluters to fund a subsidy to below target polluters.

The EIS explicitly recognises different pollution rates per unit electricity across all different types of generators. By contrast, the CET and RET constrain the number of categories of generators by pollution intensity. The CET would give credits to all generators with pollution below the aggregate target level proportional to the target less actual rates as for the EIS; but, unlike the EIS it would treat all generators with a pollution rate above the target rate as homogeneous polluters even though actual pollution rates vary. The RET takes a more restricted position on differentiation of generators by pollution intensity: renewable generators receive a credit; and, all other generators are treated as homogeneous polluters even though, for example, brown coal is more polluting than black coal, and both are more polluting than gas.

This paper describes the operation of the different schemes to meet a given target reduction in greenhouse emissions by electricity generators, such as the 2015 Paris Agreement, and then it assesses their comparative effects. With the EIS, CET and RET schemes characterised as a budget neutral mixed tax and subsidy system, as building blocks the paper begins with the tax only and subsidy only schemes. Comparative effects of the schemes are evaluated in terms of: changes to the mix of electricity generators and their returns; cost effectiveness in reducing emissions; changes to the market price and quantity of electricity; and, distribution of the benefits and costs across electricity consumers, different electricity generators with different pollution rates, and government revenue.[1] Section 2 provides a background on the electricity sector and current policy challenges, including a reduction of greenhouse gas emissions. A simplified model with two generator types, renewables and fossil, and an aggregate electricity demand is developed in Section 3.[2] Relative to a base case with no policy intervention, the model is used to assess the effects on market outcomes, cost efficiency in reducing emissions, and distribution of the costs and benefits of the different schemes. Section 4 extends the simple two generator model to

[1] Potential benefits of lower greenhouse gas emissions on lower costs of adaptation to climate change are not considered. These benefits are global, and their magnitude will depend on reductions across the economy and across the world.

[2] A much more detailed model including individual generators and the time path of effects through to 2070 was undertaken for the Finkel Review by the Jacobs Group (2017). This modelling makes much of significant differences in the cost of capital across the different generators, and the adverse effects of policy uncertainty as embedded in the status quo scenario on the cost of capital for generators. Neither issue is considered in this paper.

include a range of fossil fuel generator types which vary by emissions intensity to highlight comparative effects of the EIS, CET and RET. A final section concludes.

2. Electricity Generation and Emissions

As discussed by Finkel et al. (2017) and others, the Australian electricity generation industry faces challenges in choosing a portfolio of generator types to best meet society objectives. Included in the social welfare function are the attributes of: low prices for business and household consumers and an appropriate or opportunity return for producers; security of supply; and, reducing greenhouse gas emissions and other forms of pollution. The different generation types have different mixes of the three attributes. Generator types include those burning fossil fuels, and then brown coal, black coal, open cycle gas, closed cycle gas and diesel, plus possible carbon capture and storage, hydro and pumped hydro, wind, solar and solar thermal, battery and other storage.

Electricity generation contributes about 35 per cent of total Australian greenhouse gas emissions (Department of the Environment and Energy, 2016). Changes in electricity generation will be vital to meeting a share of the government's commitment under the 2015 Paris Agreement to reduce CO2-e pollution by 26-28 per cent below the 2005 quantity by 2030, and a net zero in the second half of the twenty-first century. Some envisage faster and larger rates of emissions reduction, including several State governments. Most consider that electricity generation will need to carry an above average share because of lower marginal costs of abatement and the exclusion of some sectors because of administrative challenges and costs (Climate Change Authority, 2016). One way of meeting the 2030 target reduction of emissions would involve more than doubling the current share of renewables in generation of about 13 per cent.

Availability and security of supply to match demand involves a many faceted set of challenges. Demand varies by time of day, by season, and then with variations across days and seasons.[3] Costs of storage are high relative to costs of generation. Supply provided by renewables is intermittent. Long lead times are required to adjust up and down the output of coal and closed cycle gas. With current technology, both the emissions intensity and the operating costs of open cycle gas which can adjust supply at short notice are relatively high. Pumped hydro and battery storage under current technology are relatively expensive. Ideally, the optimal level of security

[3] A more general evaluation would include the option of time of use pricing to better signal social costs to electricity users as one element of a more comprehensive reform package to adjust demand and supply.

of supply to match demand should equate the marginal benefit with the marginal cost of additional security. Finding the appropriate level of security of supply remains an untested and unanswered question in the current policy discussion, including Finkel et al. (2017) and the government's proposed National Energy Guarantee.[4]

To simplify the analysis, initially the paper considers just two packages of electricity generators which meet the volatility of demand over the day and over seasons together with a common but unspecified security of supply target, namely renewables and fossil fuel. Fossil fuel includes base load coal plus open cycle gas and hydro to meet peak demand. Renewables include intermittent wind and solar plus a package of open cycle and closed cycle gas, hydro, batteries and interconnectors to ensure supply security.

For both the fossil fuel and renewables, supply cost involves more than the oft quoted "levelised cost of electricity", or LCOE. The LCOE measured as (total fixed plus operating costs in $s) / (KWh of electricity generated) has no regard to security of supply or matching of supply with fluctuations in demand. As illustrated in Appendix A of Finkel et al. (2017), providing storage for large scale solar for just 10 hours raises the LCOE by about 50 per cent, and solar thermal with 12 hours of storage is much more expensive again, and both involve higher costs than gas, including open cycle. The need for government policy intervention to reduce pollution presumes that under current technology and competitive market generator decisions, which is the base case of this paper, the reliable supply of electricity from renewables with complementary investments to meet fluctuating demand at the margin involves a higher cost than the alternative fossil fuel generation.

Although the focus of this paper is on the choice of generators of electricity, and in turn the wholesale price of electricity, the location of generators influences transmission costs. Wholesale costs are estimated to contribute 22 per cent of average household electricity bills and transmission costs 48 per cent (ACCC, 2017). For simplicity, the paper assesses effects of the policy options on the wholesale price, and it implicitly assumes a constant mark-up for transmission and retail costs to reach the consumer price.

[4] The government's proposed National Energy Guarantee (NEG) aims to meet the twin objectives of a reduction in emissions and reliability of supply. At the time of writing (March, 2018) details of the measure(s) of reliability, how they will be monitored, and so forth have not been released, including in the Draft Design Consultation Paper (Energy Security Board, 2018).

To summarise the policy context, for a target reduction in greenhouse gas emissions and for a given security of supply to meet fluctuations in demand, and where at current technology fossil fuel generation is the dominant supply source and lower cost than renewables, the paper considers the effects of a tax on fossil, a subsidy for renewables, and a budget balance tax and subsidy mix EIS, CET and RET to achieve a similar increase in the share of renewables.

3. A Two Generator Sector Model

A simplified two generator sector electricity market model can be represented as in Figure 1 with generator supply functions

$$Qf = f(Pf, Xf) \quad (1)$$

$$Qr = f(Pr, Xr) \quad (2)$$

where, Qf is the quantity of fossil generated power, Qr is the quantity of renewables generated power, Pf is the price received for fossil and Pr is the price received for renewables, and the Xi are other variables, including technology and input costs, which are assumed to remain constant. For both (1) and (2) the Qi and Pi reflect the costs to achieve a common and policy determined level of security of supply. Both supply functions are shown as rising functions to reflect higher marginal costs for extra generation. The fossil supply curve around current output can reflect significant investment in repairs and maintenance to extend the life and/or the efficiency of existing generators rather than new plant. While it is likely that both fossil and renewables generators can be cloned consistent with a horizontal supply function, or constant average and marginal costs, a combination of different vintages of technology, differences in the availability of wind and sun, different access to and quality of coal and gas inputs, and different costs for required transmission infrastructure lie behind the assumed rising, but still high elastic, supply curves.[5] Only the fossil fuel sector is assumed to generate greenhouse gas emissions, even though the renewables may require some complementary fossil generators for security of supply.

Aggregate supply and demand is given by

$$Q = Qf + Qr = f(P, X) \quad (3)$$

[5] Jacobs Group (2017, Figure 15) provide indicative estimates of rising long run marginal cost curves for renewable supply.

where, Q is market quantity and P the wholesale electricity price. Demand while price sensitive generally is considered inelastic, with, for example, AEMO estimates of around -0.4 (as quoted in Table 4 of Jacobs Group 2017) and much less elastic than supply.

3.1 Base Case

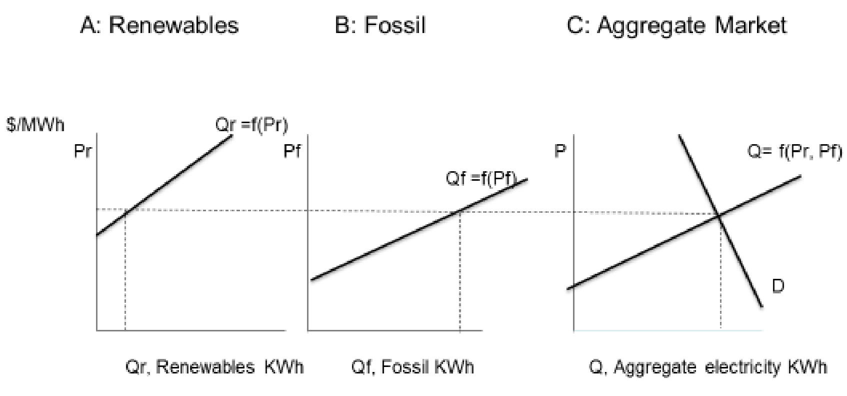
The base case scenario with no policy intervention to reduce emissions, and with an implicit zero price on emissions, sets the three prices in (1), (2) and (3) equal with

$$P = Pf = Pr \qquad (4)$$

Figure 1 shows the base case market outcome with a common price and with most electricity provided by fossil.

Against this base case, policy schemes to increase the share of renewables in the electricity generation mix to reduce emissions to meet the Paris Agreement target are compared.

Figure 1 Base Case



3.2 An Emissions Tax

In the context of the simplified model of (1) through (3) and Figure 1, a tax of T per unit of Qf (which is proportional to a tax per unit pollution) changes the pattern of prices from (4) of the base case to

$$Pf' = P' - T, \quad Pr' = P' \tag{5}$$

In Figure 1 the tax shifts upwards the fossil fuel supply curve by the tax T, no change to the renewable supply curve, and an upward shift of the aggregate supply curve by less than the tax.

Market and distribution effects of the tax, T, can be gleaned from Figure 1 with more details on magnitudes in terms of elasticities of supply and demand summarised in Table 1. The upward shift of the aggregate supply curve drives a higher electricity price and a fall in electricity consumption. The higher price attracts an increase in production of renewables. The fall of the net return for fossil causes a reduction of fossil generation. The higher share of renewables reduces the average emissions rate. In addition, the higher electricity price provides incentives and rewards for household and business consumers to improve energy efficiency and to choose less energy intensive products. Many of these electricity buyer decision changes are among the low marginal abatement cost decisions to indirectly reduce greenhouse gas emissions via smaller consumption of electricity.

With demand for electricity less elastic than aggregate supply, consumers bear most of the tax, but not all; that is, the electricity consumer surplus loss is smaller than the tax revenue. While the higher price of electricity purchased by households would be regressive in its effects, the indirect effects of the about 70 per cent of electricity purchased by business as an intermediate input and then passed forward to households as higher product prices would be close to proportional to total expenditure (ABS, 2017, Table 3.3). Recycling the government windfall revenue gain should be sufficient to compensate consumers for the higher cost of living. Revenue recycling is justified also for an efficiency reason to offset the tax-interaction effects from the emissions tax caused increase in consumer prices and existing distortionary income and expenditure taxes which further reduce after-tax spending power and increase the efficiency costs of tax distortions to labour, investment and other decisions (Goulder, 1995, and Williams, 2017).

In terms of the generators, the renewables are clear winners with additional production and a higher price relative to the base case. By contrast, both production and the net return fall for fossil fuel generators, but the net return fall is less than the tax as much of the tax is passed forward to consumers as a higher electricity price. In aggregate, the electricity generator industry incurs a net loss with the shift to a higher private cost mix of electricity generation and with some of the tax passed back to them.

3.3 Subsidy for Renewables

In the context of the simplified base case model of (1) through (3) and Figure 1, a subsidy of S per unit of renewables output, Qr, changes the pattern of prices from the base case of (4) to

$$Pr'' = P'' + S, \quad Pf'' = P'' \tag{6}$$

In Figure 1 the subsidy shifts downwards the renewables supply curve by the subsidy S, no change to the fossil supply curve, and then a downward shift of the aggregate supply curve by a smaller amount than the subsidy. Magnitudes of effects of the subsidy on price and quantities in terms of elasticities is given in column 3 of Table 1.

The downward shift of the aggregate supply curve drives down the electricity price and increases consumption. The lower market price reduces fossil production and emissions. At the same time, the higher net return for renewables, with the subsidy larger than the market price fall, induces an increase in renewables.

Effects of the subsidy in reducing emissions, and at lowest cost are mixed. In terms of changes to the generator mix, by design the subsidy is as effective as the tax. However, the lower electricity price and associated increase in electricity consumption provides disincentives, rather than incentives under a tax, for household and business consumers of electricity to invest in more energy efficiency equipment and appliances and to shift the consumption mix to less energy intensive goods and services. These decisions are among the set of lowest cost decision changes to reduce greenhouse gas emissions. That is, the subsidy intervention is a less effective and more costly way to reduce greenhouse gas emissions in aggregate than the tax option.

A related set of market failure arguments to subsidise renewables include to internalise external benefits of R&D and the wider benefits of valuable information gained from "learning-by-doing" have dubious merit. It is not obvious that the relative importance of external benefits of R&D in renewables is markedly larger than for other areas of R&D, such as robotics and agriculture. Then, the generally available current policy interventions to assist R&D across the economy are equally available for and appropriate for R&D for renewables, including tax concessions and patents. The idea of special assistance for learning-by-doing raises risks of the discredited infant industry argument for trade assistance to all areas of the economy, including renewables. Even if these market failure arguments were given some credence, the subsidy per unit of renewable electricity generated is poorly correlated with the alleged market failure.

Much, but not all, of a subsidy to renewable generators would be passed back to buyers as lower prices with demand being less elastic than supply. For consumers, the consumer surplus gain of a lower price should be balanced against a larger increase of government expenditure on the subsidy. Funding the subsidy outlay ultimately requires a combination of higher taxes and lower other government outlays.

The renewables generators are clear winners with a higher net return, although less than the subsidy, and additional investment and sales. Fossil fuel generators lose both on the lower price and quantity.

3.4 Emissions Intensity Scheme (EIS)

In the context of the simplified model of (1) through (3) and Figure 1, a EIS involves a tax of T per unit of Qf on fossil in buying permits and a subsidy of S per unit of Qr on renewables in selling permits. Budget neutrality equates the subsidy outlay with the tax receipts. Then, the net prices facing generators relative to the base case of (4) are

$$Pr^* = P^* + S,\ Pf^* = P^* - T, \text{ and } S\,Qr = T\,Qf, \text{ or } S = (Qf/Qr)\,T \qquad (7)$$

For a given increase in the share of renewables to meet a common electricity generator emissions reduction target, the required tax rate T in (7) for the EIS will be less than for the tax only policy in (5) and the subsidy rate S in (7) will be less than for the subsidy only policy in (6).

Market effects of an EIS relative to the base case can be gleaned from Figure 1, with a more detailed quantification shown in the last column of Table 1. Initially the tax shifts upwards the fossil supply curve and the subsidy shifts down the renewables supply curve. The net effect of these two shifts on the aggregate electricity supply curve is ambiguous, and it depends on the relative supply elasticities. From Table 1, the aggregate electricity supply curve shifts upwards (downwards) if the elasticity of fossil supply, ESf, is greater (lesser) than the elasticity of renewable supply, ESr; and there would be no electricity price or quantity change if the elasticities were equal.

To the author's knowledge, for the long run and in the model context of providing electricity with a comparable security of supply and similar aggregate pollution reduction, there are neither a priori arguments nor available empirical studies which provide convincing evidence for significant differences in the supply elasticities for fossil and renewables. Relative to the base case market price P of (4), the market price of electricity with an EIS, P* of (7), will fall below the increase for the tax only, P' of (5), and above the subsidy only, P" of (6).

In terms of reducing pollution at least cost, by design the EIS achieves a similar change in mix of electricity generators as the tax only and subsidy only options. To the extent that the electricity price change is less for the EIS than for the tax only option and that the tax only option equates marginal abatement costs across generators and electricity users, with the EIS marginal abatement costs are not equated for pollution reduction decisions by electricity users relative to electricity generation. But, the higher EIS electricity price relative to the subsidy only price means a lower pollution cost reduction than for the subsidy only policy.

Net returns to fossil fall with the tax and by less (more) than the tax if there is an electricity price rise (fall). Renewables gain with a higher net return and a larger output. Government finance by policy design is unaffected. Electricity consumers win or lose depending on the price change outcome; and, with no second-round effects associated with the neutral government budget outcome.

For the simplified model of just two sets of generators with different pollution intensities, both the clean energy target (CET) and the renewable energy target (RET) would operate alike and have the same market outcomes as the EIS. However, as will be explored in Section 4 below, expanding the simplified model for fossil with a common pollution intensity across different fossil generator types to several fossil generators with different emissions intensities brings important differences between the EIS, CET and RET.

3.5 Some Comparisons

Table 1 provides more formal comparisons of the effects of the tax, subsidy and EIS policy interventions to increase the share of renewables in electricity generation relative to a base case of business as usual. For a similar increase of renewables relative to fossil in the generator mix, and assuming a similar level of reliability of supply (implicitly captured in the supply functions), proportional changes to aggregate electricity production and consumption, electricity price, production of renewables and fossil, and government budget are compared.

Table 1 Comparative Effects of Tax on Fossil, Subsidy to Renewables, and EIS on Market Outcomes

Market Outcome	Tax on Fossil, T/P	Subsidy for Renewable, S/P	EIS with T Qf = S Qr for budget neutral, T/P
Change in wholesale electricity price, ΔP/P	(ESf s) / A	-(ESr (1-s) / A	((ESf – ESr) s) / A
Change in aggregate electricity quantity, ΔQ/Q	-(ED ESf s) / A	(ED ESr (1-s)) / A	(ED (ESf-ESr) s) /A
Change in renewable quantity, ΔQr/Q	((ESf s) (ED + ESr(1-s))/A	(ESr (1-s)) (ED+ESf s)/A	(ESr(1-s))(ED m+ESf s(m+1)) / A
Change in fossil quantity, ΔQf/Q	-((ESf s)(ED+ESr(1-s))/A	-(ESr (1-s) ESf s) /A	-((ESf s (ED+ESr(1-s)(1+m)) / A
Effect on government budget	Qf P	-Qr P	Zero

Details of derived formulas are provided in the Appendix. ED is elasticity of electricity demand, ESr is elasticity of supply of renewables, ESf is the elasticity of supply of fossil, A = (ED + ESf s + ESr (1-s))), s is share of fossil = Qf/Q, m is ratio of Qr/Qf

By policy design the three schemes are specified to have a similar effect on the mix of renewables and fossil to reduce greenhouse emissions in the generation of electricity. But, they have different effects on aggregate economy emissions and the cost per emission reduction. The tax intervention passes through the price signal to business and household consumers of electricity to choose more energy efficient equipment and appliances and to choose a less energy intensive mix of goods and services. By contrast, the subsidy by reducing electricity prices has the opposite and perverse effect to encourage more pollution intensive choices by business and household consumers of electricity. A much smaller electricity buyer price effect with the EIS lies between the tax only and subsidy only interventions.

Comparative assessment of the redistributive effects of the tax, subsidy and EIS schemes on households requires including second-round general equilibrium effects, including different effects on government budgets. The first-round higher electricity price effect with a tax and lower electricity price with a subsidy are less than the tax and subsidy but a larger share, respectively, given that the elasticity of supply is larger than the elasticity of demand. Taking a neutral government budget outcome constrained general equilibrium picture: for the tax option, households can be compensated for the higher electricity prices via close to lump sum increases of social security payments and income tax reductions, and some business consumers such as the energy intensive trade exposed might also receive compensation; and, for the subsidy option, more than the first-round gain to households of the lower electricity price would be eroded by higher taxation or reduced other government expenditure. Consumer price changes are much smaller with the EIS compared with the tax and subsidy, and by design there is no budget change effect.

Under each of the three schemes to increase the share of renewables in electricity generation, fossil generators lose and renewables gain, both in terms of quantities and the net return per unit output. Magnitudes of the gain and loss of net returns for the two generator types are smaller for the EIS.

4. Some Multiple Generator Sector Model Effects

This section relaxes the simplifying assumption of Section 3 of a single type of fossil generator to include several types with different emissions intensity characteristics. The different types can include brown coal, black coal, open cycle gas, closed cycle gas, each with and without carbon capture and storage, and then with different vintages and input qualities.

In the real world of multiple type fossil generators with different pollution intensities there are key similarities and differences of the EIS, RET and CET schemes to reduce emissions. The key similarity is a budget neutral system of taxes on relatively high pollution intensity generators to fund a subsidy to relatively low pollution intensity generators to drive an increase in the share of low pollution generators.

Key differences are the different scheme assumptions of pollution intensity by different types of fossil generators, and then variations of the tax rate across the different fossil generators. Unlike the CET and the RET, the EIS allows for heterogeneity of pollution intensity across all generator types, and it imposes gradated tax rates per unit electricity generated according to pollution intensity. For example, those with a higher pollution rate, including brown coal, are required to purchase more permits and face a higher effective tax than those with a lower pollution rate, including closed cycle gas, and those with carbon capture and storage would receive a credit.

The CET proposed by Finkel et al. (2017) allows for, and sets different subsidy rates for, generators with pollution below the aggregate target rate. Depending on the overall target average pollution rate, generators eligible for receipt of certificates potentially include coal with carbon capture and storage, some gas, and maybe advanced coal technology generators.[6] Unlike the EIS, the CET assumes the same pollution intensity for all generators with a pollution intensity above the required target rate; as a result, the CET imposes a similar tax rate per unit of electricity for those generators regardless of their pollution intensity.

Under the RET, all types of fossil generators are required to acquire the same quantity of pollution permits per unit of electricity. That is, they face a similar tax per unit electricity output regardless of the often very different pollution intensities across different brown coal, black coal and gas generators.

Now, consider the different effects of the EIS, CET and RET with heterogenous fossil generators in terms of emissions intensity. The EIS allows market forces to find the least cost mix across all generator types to reduce emissions per unit of electricity to the target average level. The RET by comparison allows only increases in the share of renewables as the choice variable, and rules out other choice options such as carbon capture and storage, substitution of black coal for brown coal or gas for coal, and investment to improve the thermal efficiency of existing and new fossil generators. Ironically, a RET while increasing the renewables share may induce replacement of black coal with lower cost and more polluting brown coal, or coal with gas, resulting in an increase of pollution per unit of fossil generation, and so partly offset the pollution reduction effect of a larger renewables share.

The proposed CET could include low pollution fossil generators in the decision options to reduce pollution, such as carbon capture and storage, and depending on the aggregate target maybe also some gas and high efficiency coal. In this way, the CET can be a lower cost policy intervention to reduce aggregate generator emissions than the RET.

Both the RET and the CET treat above target rate emissions fossil generators the same. This asymmetric treatment of high pollution fossil generators relative to low pollution fossil generators under both the RET and the CET contrasts with the symmetric treatment with an EIS.

The neutral pollution tax treatment of lower cost but higher pollution intensity brown coal relative to black coal lies behind the results of the Jacob Associates (2017) model estimates in comparing the CET and EIS. In the reported projections, the CET produces a higher share for brown coal and smaller

[6] Finkel et al. (2017) proposed credits only to additional capacity investment in eligible generators; reflecting the view that existing renewable generators have been recipients of other subsidies.

for black coal than the EIS. The different brown coal and black coal generator mixes result in a lower electricity price for the CET and a lower cost per emission reduction under a EIS.

The general patterns of changes to market prices and quantities and distribution effects of the EIS, RET and CET are similar, but the magnitudes of effects differ. Drawing on the first row and fourth column of Table 1, the more elastic the renewables supply curve the smaller the electricity price increase effect of the policy intervention to reduce electricity generation emissions. Because the EIS allows choices across all generator types to reduce pollution, while the CET and more so the RET reduce the choice options, the EIS will achieve a lower pollution cost reduction per unit electricity generated.

Across the EIS, CET and RET schemes, fossil generators with above target pollution levels lose net returns and quantity, and renewables gain higher returns and output. The EIS and CET options provide opportunities for fossil generators with below target pollution levels to win and expand, while they lose with the RET. By design, the three schemes are government budget neutral.

5. Conclusions

The operation of, and the comparative effects of, an emissions tax, a subsidy, and then an Emissions Intensity Scheme (EIS), Renewable Energy Target (RET) and Clean Energy Target (CET) policy schemes to increase the share of renewables relative to fossil electricity generators have been explored. The EIS, RET and CET schemes were modelled as a government budget neutral package involving a tax on pollution by fossil generators to fund a subsidy to renewables generators. Initially, a simplified world with two homogenous generator types was examined, renewables and fossil. In this world, the EIS, CET and RET have identical effects. Then, a more realistic model with several types of fossil generators with different pollution intensities was examined. Here, the EIS recognises different pollution intensities across brown coal, black coal and gas fossil generators, and imposes a common tax per unit of pollution. Relative to the EIS, the CET provides a subsidy for all types of generators with a pollution intensity below a target rate and a common tax on different types of fossil generators with a pollution rate above the target rate; and, the RET imposes the same tax on all fossil generators regardless of differences in pollution intensity.

By design, the different policy schemes considered increase the share of renewables in electricity generation by a similar quantity. The emissions tax and EIS schemes which impose a tax rate according to differences in pollution intensity across all different generator types would achieve lower costs per aggregate unit of pollution reduction than the CET and RET with their common tax rate on different fossil generators with different pollution intensities. The subsidy does not alter the relative private costs of different fossil generators.

The flow-through of the emissions tax to higher electricity prices provides incentives and rewards for relatively low marginal abatement cost decision changes by business and household electricity consumers to reduce pollution by adopting more energy efficient technologies and to purchase less energy intensive goods and services. The subsidy with its effect of reducing the price of electricity and increasing the consumption of electricity has the opposite and costly effect. The electricity price effect with each of the EIS, CET and RET lies between the tax and subsidy schemes, with the result that these schemes fail to equate marginal abatement costs across all decision options to reduce pollution associated with the production and consumption of electricity.

Comparative redistribution effects of the different schemes for electricity consumers should include the government budget changes as well as changes to the price of electricity. Most of the first-round effect of the tax and subsidy options will be passed forward to electricity consumers as price changes given that demand is less elastic than supply. With the tax only scheme, the first-round higher electricity price effect should be offset for equity and efficiency reasons by recycling most of the government revenue windfall to households. For the subsidy, the first-round apparent gain of lower electricity prices to consumers will be more than cancelled by the higher taxes or lower other government expenditures to fund the subsidy.

By design, the EIS, CET and RET are government budget neutral. While the direction of change of the electricity price with these schemes was found to be ambiguous and depending on the generator type relative supply elasticities, the magnitude of the price and consumer surplus changes likely will be small.

Within the electricity generator industry, the different schemes to reduce pollution have common direction of redistribution effects. Fossil lose with a lower net return and a smaller output. Renewables gain with a higher net return and a larger quantity. With less than perfectly elastic supply curves, in aggregate some of the tax and some of the subsidy ends up with the generation industry.

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Appendix

Base Case

For linear equations for supply (1) and (2) and demand (3) of text

$$Qr = ar + br\ Pr \quad (1)$$

$$Qf = af + bf\ Pf \quad (2)$$

$$Q = Qr + Qf = c - d\ P \quad (3)$$

For market equilibrium set $P = Pr = Pf$ (4)

With (1) through (4), solve for P

$$P = (c - ar - af) / (d + br + bf) \quad (5)$$

Then substitute P from (5) into (1), (2) and (3) to obtain functions for Qr, Qf and Q

Tax, T, on fossil

Applying T to reduce fossil returns changes the set of equilibrium prices to solve (1) through (3)

$Pf' = P' - T$, $Pr' = P'$ to replace (4) (6)

Solve for P' using (1), (2), (3) and (6)

$P' = (c - ar - af + bf\ T) / (d + br + bf)$, or

$\Delta P' = P' - P = (bf\ T) / (d + br + bf) > 0$ and $< T$, and (7)

$\Delta Pf' = - ((d + br)\ T) / (d + br + bf) < 0$ and $> -T$ (8)

Using (7) and (8) and the supply and demand functions (1), (2) and (3), changes in quantities with the tax relative to the base case are

$$\Delta Qr' = ((br\ bf)\ T) / (d + br + bf) > 0 \quad (9)$$

$$\Delta Qf' = - (bf\ (d + br)\ T) / (d + br + bf) < 0 \quad (10)$$

$$\Delta Q' = -(d\ bf\ T) / (d + br + bf) < 0 \quad (11)$$

Using the relationship between the price slopes of (1), (2) and (3) and elasticities of renewable supply, $ESr = br\ Pr / Qr$, fossil supply, $ESf = bf\ Pf / Qf$, and demand, $ED = -c\ P / Q$, equations (7) through (11) can be expressed in terms of the elasticities and the fossil share, $s = Qf / Qr$, as

$\Delta P' / P = ((ESf\ s)\ T / P) / (ED + ESf\ s + ESr\ (1 - s))$ (7')

$\Delta Qr' / Q = ((ESf\ s)\ (ESr\ (1 - s)))\ (T / P) / (ED + ESf\ s + ESr\ (1-s))$ (9')

$\Delta Qf' / Q = -\ ((ESf\ s)\ (ED + ESr\ (1 - s))\ (T/P) / (ED + ESf\ s + ESr\ (1-s))$ (10')

$\Delta Q / Q = -\ (ED\ ESf\ s)\ (T/P) / (ED + ESf\ s + ESr\ (1-s))$ (11')

Subsidy, S, for Renewables

Applying S to increase returns to renewables, $Pr'' = P'' + S$ for (1), and the new scenario prices for electricity and for fossil generators, $Pf'' = P''$ (12)

Using (12) and (1) through (3) solve for P"

$P'' = (c - ar - af - br\ S) / (d + br + bf)$, or

$\Delta P'' = P'' - P = -br\ S / (d + br + bf) < 0$ and $< S$, and (13)

$\Delta Pr'' = (d + bf)\ S / (d + br + bf) > 0$ and $< S$ (14)

Substituting the price changes of (14) into the supply and demand equations (1), (2) and (3), changes in quantities are

$\Delta Qr'' = br\ (d + bf)\ S / (d + br + bf) > 0$ (15)

$\Delta Qf'' = -(\ bf\ br)\ S / (d + br + bf) < 0$ (16)

$\Delta Q'' = (d\ br)\ S / (d + br + bf) > 0$ (17)

As for the tax, the price and quantity changes of (13) through (17) for the subsidy S relative to the base case can be expressed in terms of elasticities and the fossil share

$\Delta P''/P = -\ (ESr\ (1-s)\ S/P) / (ED + ESr(1-s) + ESf\ s)$ (13')

$\Delta Pr''/P = ((ED + ESf\ s)\ S/P) / (ED + ESr\ (1-s) + ESf\ s)$ (14')

$\Delta Qr''\ /Q = ((ESr\ (1-s)\ (Ed + ESf\ s)\ S/P) / (ED + ESf\ s + ESr\ (1-s))$ (15')

$\Delta Qf''\ /Q = -\ ((ESr\ (1-s)\ ESf\ s)\ S/P) / (ED + ESf\ s + ESr\ (1-s))$ (16')

$\Delta Q''\ /Q = ((ED\ ESr\ (1-s))\ S/P) / (ED + ESf\ s + ESr\ (1-s))$ (17')

EIS, or Break-even Tax and Subsidy

The set of market prices of (4) are replaced with

$Pf^* = P^* - T$, $Pr^* = P^* + S$, and revenue neutral requires (18)

$T\ Qf = S\ Qr$, or $S = T\ m$ with $m = Qr/ Qf = s/(1-s)$ (19)

Then, use (18) and (19) to solve for P* using (1), (2) and (3) gives

$P^* = (c - (ar + af) - T\ (br\ m - br)) / (d + br + bf)$, and (20)

$\Delta P^* = P^* - P = -T\ (br\ m - bf) / (c + br + bf)$, and (21)

$\Delta P^*/ P = ((ESf - ESr)\ s\ (T/P)) / (ED + ESf\ s + ESr\ (1-s))$ (21')

Now, ΔP^* is < 0 or > 0 if $(br\ m - bf) = (Qf / P)\ (ESr - ESf)$ is < 0 or > 0 (22)

Following the same methods as for the tax and subsidy policy options, substituting the price change ΔP^* (21) with (18) back into (1), (2) and (3), and then using elasticities, gives changes in quantities

$\Delta Qr^* / Q = (ESr\ (1-s)\ ((m\ ED + ESf\ s\ (m + 1))\ (T /P) / (ED + ESf\ s + ESr\ (1-s))$ (23')

$\Delta Q^* / Q = (ED\ (ESf - ESr)\ s)\ (T/P) / (Ed + ESf\ s + ESr\ (1 - s))$ (24')

$\Delta Qf^* / Q = -ESf\ s\ (ED + ESr\ (1-s)\ (1+m))\ (T/P) / (ED + ESf\ s + ESr\ (1-s))$ (25')