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A scenario analysis of future Hong Kong age and labour force profiles and its implications

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Summary. The consequences of reduced fertility and mortality on the age-distribution are an issue for most developed countries, but especially for the "Asian tiger" economies. We use functional data analysis forecasting techniques to project the population of Hong Kong. Our projections include error estimates that allow for forecasting error as well as exogenous variations of fertility and migration numbers. We separate out the effects of pure demographic shifts from projected behavioural changes in labour force participation. This allows us to look at the kinds of changes in labour force participation that would be required to offset the aging effects that we estimate.

Some Key Words: functional data analysis; economic dependency ratio; fertility decline; labour force participation

1 Introduction

Population aging is a global challenge. It is the inevitable consequence of very high post war fertility followed by much lower fertility in an environment of steadily reducing mortality. World-wide, the proportion of adults aged 65+ increased from 5.1% in 1950 to 5.9% in 1980, but has since reached 8.3% in 2015 and is expected to increase to 15.8% by 2050. Such trends are clearest in high income countries. The starkest example is Japan where it is already 26%, and has one of the lowest fertilities and longest life expectancies in the world (United Nations, 2017).

There are several measures of the economic burden of population aging in common use. The elderly dependency ratio is the number of elderly divided by the number of productive, where productives are equated with the age range 15-64. Since this ignores the burden of the young, we will prefer to look at the number of non-productive (i.e.

young and old) per productive, which we call the *age dependency ratio* (ADR). This has been called total dependency ratio by some authors. We will point out some of the consequences of using this measure in the results section. Any measure based on equating a crude age range with productivity takes no account of changing patterns of work *in response to* aging. Indeed, in most countries where aging is a problem, labour force participation rates (LFPRs) are increasing amongst the elderly while educational credentialism is leading to lower participation in the 15-19 range. Therefore, we prefer to replace the crude age-group surrogate with actual labour force participation, and integrate across all ages to obtain the overall labour force participation. Of course, this requires data on, and projections of, age- and gender-specific labour force participation rates, which is why it is less commonly used. We call this the *economic dependency ratio* (EDR), though we note that Yip et al. (2010) used this term for the odds against participation.

Aging patterns are especially pronounced in the highly developed Asian countries, namely Japan, South Korea, Singapore, Taiwan, and Hong Kong. While Japan is 15 years ahead of the others, all are projected to have in the order of 35% aged over 65 by 2050. The pace and magnitude of aging is expected to be faster and deeper than the European experience, largely because of their common experience of extreme fertility decline The total fertility rate (TFR) in these five Asian countries dropped from around 5 children per woman to below replacement (2.1) in only 25 years and collapsed to between 1 and 1.4 thereafter. Despite pronatalist policies being in place, these Asian countries show no sign of the fertility rebound seen in Europe. Meanwhile, decreasing trends are observed in their labour force participation rates (LFPRs) among males, partly offset by increasing rates for females. (ILO, 2015).

The trend being well established, interest is moving from the extent and timing of the demographic transition to how countries can better prepare (Bouvier, 2001; Nagase and Brinton, 2017). What kinds of changes to labour force patterns are required to offset aging and to what extent can fertility recovery and immigration reverse the trend

itself?

Hong Kong is our chosen case study of the potential impact of aging in the high income Asian context. With a dense population of 7.4 million, TFR at 1.2, and life expectancy amongst the highest in the world, Hong Kong underwent a rather extreme version of demographic transition over past decades (Yip et al., 2001; Yip et al., 2009; Census and Statistics Department [C&SD], 2016). There are also two special and interesting features of Hong Kong demography.

Firstly, since the large scale refugee migrations from mainland China in the 1930s, Hong Kong has always been a "migrant metropolis" and mainland immigrants continue to be a major source of overall population growth. Currently, there is a daily intake of 150 migrants from mainland China known as "One-way Permit Holders" (OWPHs), mostly the spouse or child of a Hong Kong resident. While the main purpose is family reunion, OWPHs are eligible for permanent residency after seven years. Due to the very low fertility in Hong Kong, the One-way Permit (OWP) scheme has been the major source of population growth and has contributed to over 60% of population growth in the past decade. Most OWPHs are in the productive age range (80.5% were aged 15-64 in 2014) and are mainly female (66.6%) which mitigates the aging effects of low fertility and mortality.

Secondly, cross-border marriage is a very unique situation in Hong Kong. Since the 1997 sovereignty change, Hong Kong has become a special administrative region of the People's Republic of China (PRC) and is governed under the so-called one country two systems. There is a physical border between Hong Kong and PRC. PRC residents do not have the automatic right of abode in Hong Kong. The term "cross-border marriage" means a marriage between a Hong Kong resident and a PRC resident. It has become a substantial component of Hong Kong marriage, especially with the increasing business and social contact since 1997. At its peak, 45% marriages registered in Hong Kong involve a mainland spouse, but this has been leveling off and is now about 35%. The majority of cases involve Hong Kong men marrying mainland women, which has

imposed a shortage of local male marriage partners for local females, a point that has not been recognised or addressed in other studies.

In this paper, we provide 50 year projections of Hong Kong's total population, including particularly the age-structure and various economic dependency ratios. There are several noteworthy technical features of this work.

- We use functional data analysis (Ramsay & Silverman, 2005) to project mortality, fertility, labour force participation and net migration. This technique is currently under-utilised in demography and has several advantages. For instance, projected fertility and mortality curves are automatically smooth and the uncertainty of population projections are easily simulated.

- We address the gender imbalance constraints on the Hong Kong population due to female over-representation in immigration from PRC. We quantify the effects of this imbalance which is caused by, but can also be mitigated by, cross-border marriages and include projections of these cross-border marriages in our model.

- In assessing the effects of aging on economic dependency ratios, we separate out the effects of pure demographic shifts from projected behavioural changes in labour participation. This allows us to look at the kinds of changes in labour force that would be required to offset projected aging effects. We supplement our projections with scenario analyses where fertility and net migration are exogenously varied and find that one of these has much more impact than the other.

The plan of the paper is as follows. We give a short overview of functional data analysis. We then use this technique to model and predict fertility, mortality, labour force participation and migration flow, all treated as (smooth) functions of age for each gender. We then use these projections to project the Hong Kong population. We also generate projections under a range of plausible scenarios where fertility and migration flows are manipulated exogenously and evaluate the age burden as measured by ADR and EDR. The policy implications are discussed in the final section.

2 Projecting Functional data

Our projections involve fertility, mortality, labour force participation rates and migration, all of which depend on age. Functional data analysis (FDA) treats these demographic features as functions, generically denoted by $f(x)$, where x here represents age. We expect that $f(x)$ is a smooth function of x and that the "shape" of $f(x)$ will change smoothly over time. FDA has been available for several decades but its application to demography was first highlighted by Hyndman and Ullah (2007). A systematic review on the application of FDA identified 84 articles post 1995 (Ullah & Finch, 2013), only three in the field of demography. One was an application to Serbia (Nikitovic, 2011) and one an unpublished report on great Britain (Shang et al., 2013).

2.1 Functional data model

We have observations $f_t(x_j)$ at time points $t = 1, ..., T$ and ages $x_1, , .., x_q$. We arrange this as a $T \times q$ matrix with rows indexing time and columns age. For instance, for our mortality data we have $q = 86$ ages ranging from $x_1 = 0$ to $x_{86} = 85+$ and $T = 39$ time points from 1976 to 2014. Our goal is to make m step ahead projections $f_{T+m}(x_j)$.

A simple but naive method is to analyse each age x_j separately, i.e. take each column of the data matrix, fit a time series model to $f_t(x_j)$, and project this into the future. This leads to forecasts $\hat{f}_{T+m}(x_j)$ that quickly become a non-smooth function of x_j. The idea of functional data analysis (FDA) is to describe the systematic changes of $f_t(x_j)$ in terms of a small number (often 2 or 3) of smooth features and to project these into the future. This not only reduces statistical uncertainty because we use 2-3 forecast models instead of q models, but also generates forecasts which mirror the smoothness of the historical data. It also provides a parsimonious way to describe how the curve has changed, and will change, over time.

With functional data analysis, the basic observations are the rows $f_t(x)$ and these

functions are described with a single equation

$$f_t(x_j) = \mu(x_j) + \sum_{k=1}^{K} \beta_{t,k}\phi_k(x_j) + e_t(x_j) \tag{1}$$

for some value $K < \min(q, T)$. So the function $f_t(x_j)$ at time t is generated by a baseline mean function $\mu(x_j)$ plus a time progressing linear combination of K basis functions $\phi_k(x_j)$. The case $K = 1$ is the well-known model of Lee & Carter (1992). For applications were $f_t(x)$ is thought to be a smooth function of x, it is recommended to first pre-smooth each row of the data matrix.

2.2 Fitting

For a given K, the basis functions ϕ_k and the coefficients $\beta_{t,k}$ are estimated by singular value decomposition (SVD). Further theoretical details are in Appendix **??**.

As in other modeling contexts, fit improves with more components K, either measured by total squared error or the sum of the first K eigenvalues of the SVD. If the main aim of the decomposition is forecasting then components can also be rejected on the basis of their contribution to the forecast; for those components whose coefficients $\beta_{t,k}$ are white noise (or a random walk) the forecasts of these coefficients will be zero (or quickly decay to zero). It is common for this to occur and for only a small number of components to be retained.

2.3 Forecasting

Forecasts are generated by applying univariate time series methods to each of the k sequences $\beta_{t,k}$. By construction, these series are orthogonal and are modeled separately. Forecasting these K series is the part of analysis where art as well as science is required, though there are automatic time series algorithms available, such as `auto.arima` in `R` which we will utilise where appropriate.

It is common to measure the accuracy of a forecasting procedure conditional on model selection. In this case, model selection is deemed to include extraction of the

basis functions, so only the estimates of the future $\beta_{t,k}$ involve statistical error, measures of which are routinely output by the time series package used. Moreover, the squared standard error of the m-step ahead forecast is given by

$$\mathrm{SE}^2\left(\hat{f}_{T+m}(x)\right) = \sum_{k=1}^{K}\left(\mathrm{SE}(\hat{\beta}_{T+m,k})\phi_k(x)\right)^2. \tag{2}$$

A useful feature of FDA methods is that this standard error can be used to generate estimates of the statistical uncertainty of our final projections. To incorporate the uncertainty in our forecasts we simulate the population using $\hat{f}_{T+m}(x) + z \times \mathrm{SE}\left(\hat{f}_{T+m}(x)\right)$ where z is drawn from the standard normal distribution.

3 Fertility Rates

3.1 Historical patterns in fertility rates

We obtained data for 34 years (from 1981 to 2014) on age-specific fertility rate (ASFR), age of mother being measured to the nearest year. Fertility is measured in units of live births per 1000 females and is taken to be zero outside the age range 15-49.

Foreign domestic helpers (FDHs) are an important population component in Hong Kong, numbering more than 320,000 in 2017. They are overwhelmingly females, and come mainly from the Philippines, Indonesia and other relatively low income countries in South and Southeast Asia. The wage is relatively affordable (USD$550 per month) compared to the medium household income (USD$ 3300 in 2017). On average there is one FDH per eight households and they provide much needed elderly and child care support to Hong Kong families (C&SD, 2017). However, they have no right of abode in Hong Kong, neither do their children. For this reason, they are best considered as a separate population and fertility rates are computed after excluding them from the database.

The left panel of Figure 1 plots the ASFR functions $f_t(x)$ against age x for each year, darker lines being the most recent. The curves have been moving towards the right, representing delay of child bearing. Total fertility, which is the area under the

curve, is in the central panel and decreased steadily from 1981 to 2001. The rebound from 2002 appears impossible to anticipate from the previous data and some might argue that it is impossible to predict rates accurately in the future, since they are partly driven by social trends that are inherently complex. This is supported by the erratic behaviour of the TFR over the last three years.

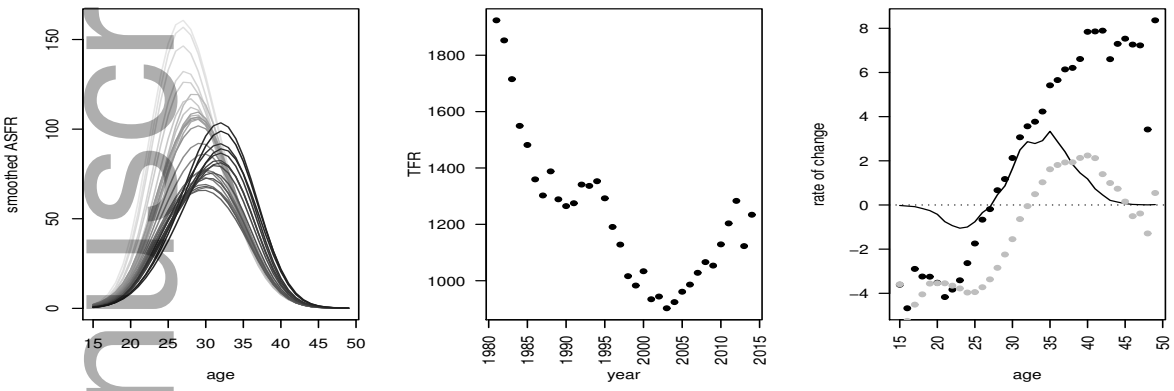

Figure 1: **Historical fertility.** *Left*: Historical ASFRs 1981-2014 (smoothed). *Centre.* TFR versus time showing rebound from 2002. *Right.* Percentage growth over past 34 years (grey) and most recent 15 years (black). Absolute growth rate over last 15 years (solid line).

The right panel shows the rate of change of fertility by age. The grey points give percentage change over the past 34 years. Rates decreased for all ages up to 32 but mostly increased at ages above 32. The dark points give percentage change over the past 15 years. It appears that fertility rates have increased even more strongly at all ages above 28 while the tendency of decreasing rates at lower ages is still apparent. These are all percentage rates of change and suppress the absolute change. The solid line shows the absolute growth in ASFR over the last 15 years. Most of the increase in TFR is attributable to higher absolute rates in the age range 30-40 (which have grown at about 3% per annum), partly offset by decreases for ages 20-25.

3.2 Functional data decomposition of fertility rates

The panel of fertility rates were log-transformed then smoothed (as recommended by Hyndman and Ullah, 2007) using a seven degrees of freedom smoothing spline. The back transformed data were earlier displayed in the left plot of Figure 1. FDA was applied to the smoothed log-data and two clear components emerged, accounting for 95% of the variation. Moreover, all subsequent components have coefficients $\beta_{t,k}$ that follow white noise or random walk and so contribute nothing to long run forecasts. Plots of these components and the time varying coefficients β_{t1} and β_{t2} are in Figure **??** of Appendix **??**.

The first component describes a tendency for higher fertility rates for mothers over 32 with a peak around 40 years of age and reduced rates at young age-groups. The coefficients β_{t1} have been increasing strongly over time, though at a reducing rate. The second can be interpreted as a combination of two effects, namely higher total fertility rates with a simultaneous shift to the right. So increasing β_{t2} will increase TFR but also skew the ASFR's towards older aged mothers. These coefficients decreased consistently from 1981 to 2002 and then strongly rebounded, a very similar pattern to what we saw in the raw historical TFR.

3.3 Functional data forecasts of fertility rates

The FDA decomposition models the historical ASFR curves using two easily interpreted components and reduces forecasting these curves to forecasting the two sequences of coefficients β_{t1} and β_{t2}.

For the first sequence β_{t1}, the forecast is based on a power model with AR(1) errors and is displayed in the upper right panel of Figure **??** in Appendix **??**. The second component is much harder to forecast. We have already noted the erratic behaviour of the TFR in the last three years of the historical data and the same variability is present in β_{t2}. Details of our ensemble forecast model are in Appendix **??**.

The left panel of Figure 2 shows historical data in grey and 50 years of FDA

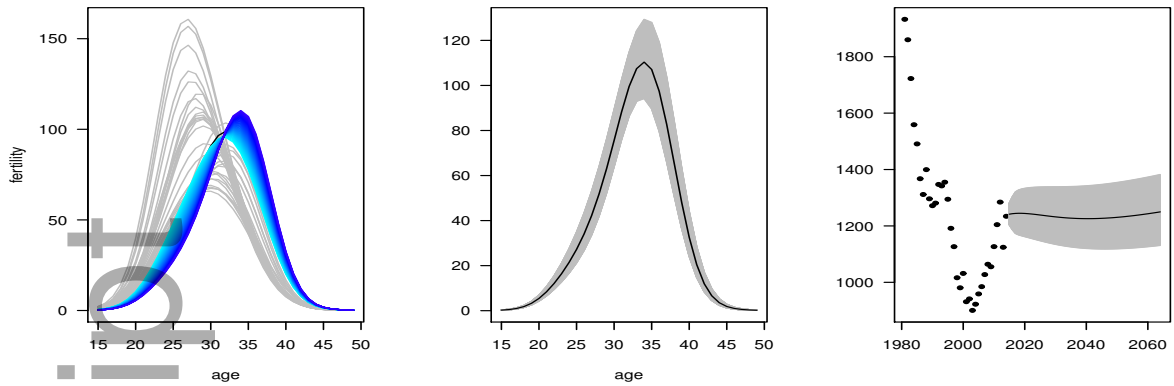

Figure 2: **Projected fertility.** *Left*: Projected ASFRs. Pale grey curves are 1981 to 2014. Forecasts are from 2015 to 2064 starting light blue and ending dark blue. *Centre*. Forecast ASFR function in 2064 with one standard error bands. *Right*. TFR from summing the projected ASFRs at left, with standard error bands.

projections in shades of blue. The centre of the ASFR curve is projected to move to the right by another 3 years over the next 50 years. The central panel shows the projection 50 years hence. The right panel shows the projections of TFR with error bands generated by simulation. The first component, which measures increases in fertility for mothers over 32, is well estimated. It is the total fertility which is less certain. These wide bands indicate that TFR is hard to estimate and in later sections we will interpret this to mean that fertility is best investigated by varying it exogenously in our simulations rather than measuring uncertainty by statistical error.

The value of FDA here may appear nebulous. However, the shapes of the ASFR curves are well estimated and this is important in our projections since population dynamics will depend on how these curves integrate with the age distribution of mothers. The large standard error of the TFR warns us of the limitations of forecasting total fertility while still allowing quite precise forecasts of ASFR.

4 Mortality Rates

We obtained data on registered deaths from 1976 to 2014, broken down by age and gender, and converted these into mortality rates by dividing by the age- and gender-specific mid-year population. The single-age population data we used has an open

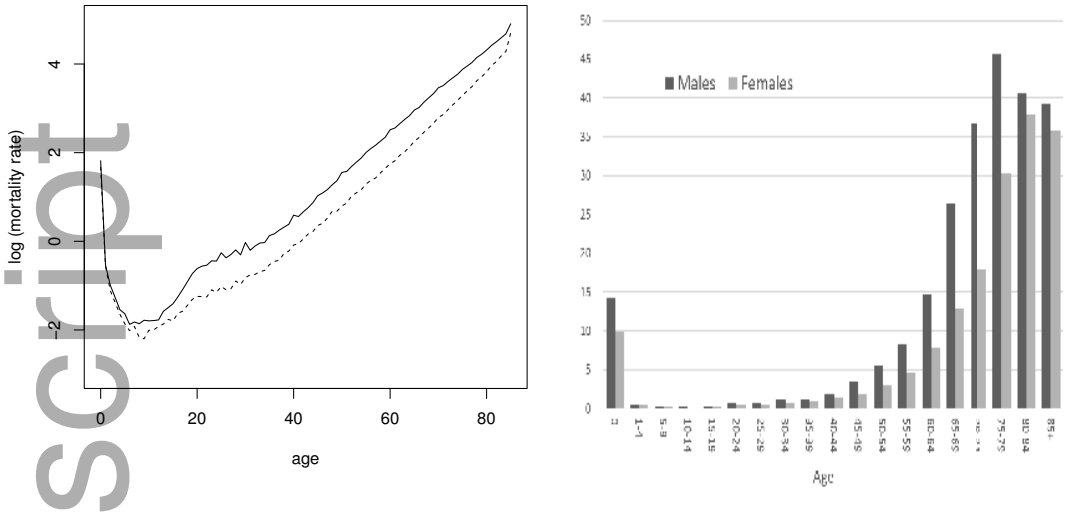

Figure 3: **Historical mortality rates per 1,000 population.** *Left*: Average age- and gender-specific mortality rates (1976-2014). LN(rates) versus age. Solid lines for males and dashed line for females. *Right*: Reduction in mortality rates from 1976 to 2014.

age-group 85+. The left panel of Figure 3 shows mortality rates averaged over the 39-year period for males (solid line) and females (dashed line), both log-transformed. The right panel shows the absolute reduction between 1976 and 2014. Further detailed data displays are in Appendix **??**.

4.1 Historical patterns in mortality rates

Males have higher mortality than females at almost all ages but mortality is reducing for both genders and at all ages, largely due to improvement in hygiene and advances in medical technology. Hong Kong has a universal and affordable healthcare system. The decreases are largest for older age-groups and for males, where there is more potential for improvement. These patterns will be detected and projected in our FDA decomposition.

Mortality rates were log-transformed and then pre-smoothed from age 1 to 84, using a smoothing spline with a fifteen degrees of freedom. Age 85+ was not included since

it represents a discontinuity and age 0 was also treated separately since it is drastically higher than age 1.

4.2 Functional data forecast of mortality rates

FDA was applied to the smoothed log-transformed data. The first component explains 90.5% and 90.1% of the variation for males and females, respectively. The variation explained by the second component drops to 3.5% and 4.1%. For both males and females, subsequent components are governed by coefficients $\beta_{t,k}$ that are either white noises or some other stationary process for which forecasts will quickly decay to zero.

The first two components are displayed in Figures **??** and **??** in Appendix **??** for males and females respectively. The decompositions are quite similar. The first basis function is uniformly negative and describes a tendency for mortality rates generally to reduce, and at a faster rate for younger than older people. The coefficients β_{t1} have steadily increased over the past 4 decades (top right panel of Figure **??**) but at a decreasing rate. The second component describes a tendency for lower mortality for ages around 20 with a simultaneous increase for children around the age of 10. For both genders, the coefficients β_{t2} were decreasing until the mid-1990s. This means that, on top of the general decreasing tendency described by the first component, mortality for children around 10 was reducing faster and for those around 20 mortality was reducing slower than the long term trend. These effects reversed in the mid-1990s, reflecting faster mortality reduction for those around 20 and slower for those around 10.

We used a two-component model for the forecast of mortality rates. The time series for β_{t1} and β_{t2} were carefully modelled (see Appendix **??**). β_{t1} is projected to continue increasing but at a decreasing rate. The second component will eventually decay but still has some effects in the following decade, suggesting additional mortality reductions in ages around 20 and less for children around 10. The smoothed historical mortality rates as well as 50-year projection on the log scale are displayed in Figure 4.

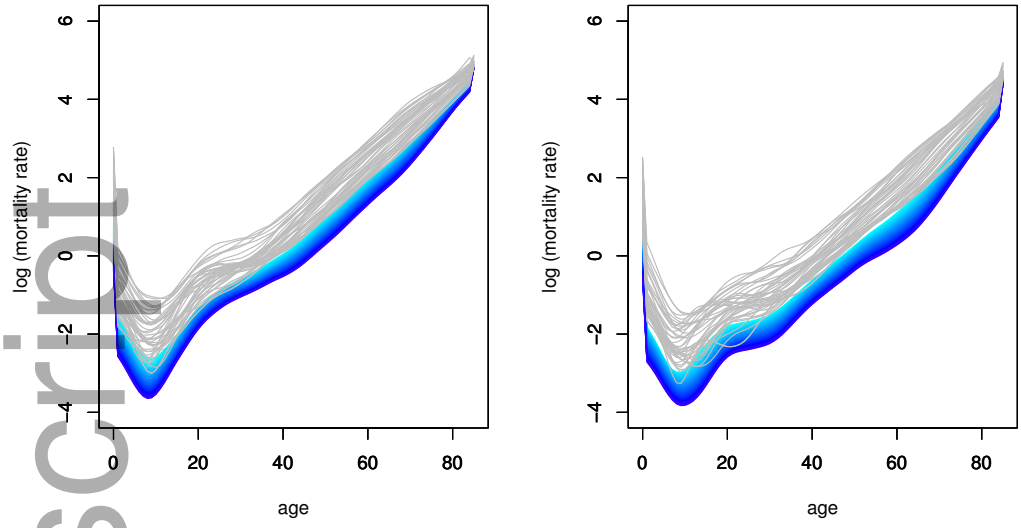

Figure 4: **Projected mortality rates for males and females.** *Left*: Historical and projected mortality rates per 1,000 for males on log scale. *Right*: Historical and projected mortality rates per 1,000 for females on log scale. Pale grey curves are 1976 to 2014 data. Forecasts from 2015 to 2064 start light blue and end dark blue.

5 Labour force participation

We obtained data on labour force participation rate (LFPR) by age-group and gender from 1994 to 2014. For reasons explained in section 3, FDHs are considered as a separate population and excluded from analysis. A summary of the main patterns in the data is displayed in Figure 5. The left panel displays male and female rates by age-group, averaged over time. The right panel shows recent growth rates for each age-group and both genders. Further data displays are in Appendix **??**.

The broad patterns are easy to summarise. For males, rates are near saturation in the 25-49 age range while female rates almost match male rates from 15-24 but then fall short, reaching a peak of 84% in the 25-29 and decreasing thereafter. Single figure estimates of trends for the last 10 years only are in the right plot. For both genders, rates have decreased strongly for 15-24, more so for males. The decrease is probably due to improving education opportunities and higher levels of training required in the modern economy. For both genders rates have increased at higher ages. However, for females this growth is much stronger (albeit off a lower base) and applies to middle

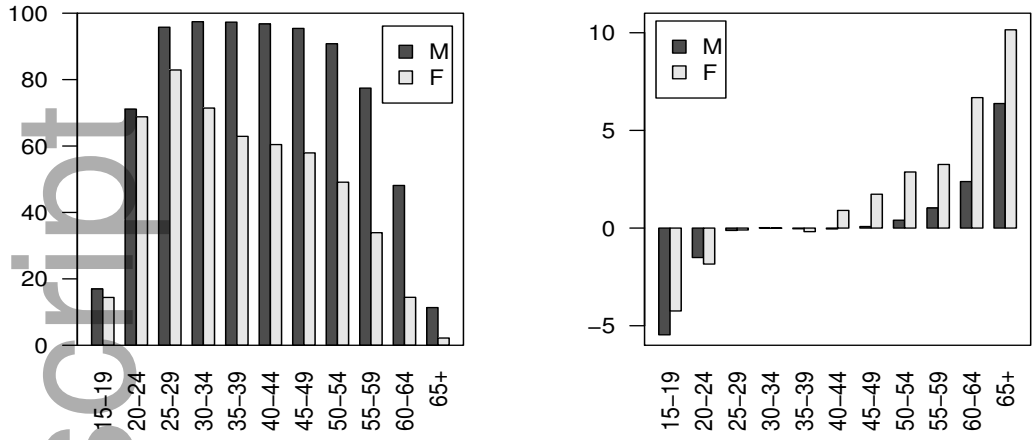

Figure 5: **Historical LFPRs.** *Left*: Average rates 1994-2014 for males and females by age-group. *Right*: Percentage growth rates from 2004 to 2014 in LFPR odds for different age-groups. Source: CS&D, Hong Kong SAR.

as well as older ages. The broad patterns are easy to summarise. For males, rates are near saturation in the 25-49 age range while female rates almost match male rates from 15-24 but then fall short, reaching a peak of 84% in the 25-29 and decreasing thereafter. Single figure estimates of trends for the last 10 years only are in the right plot. For both genders, rates have decreased strongly for 15-24, more so for males. The decrease is probably due to improving education opportunities and higher levels of training required in the modern economy. For both genders rates have increased at higher ages. However, for females this growth is much stronger (albeit off a lower base) and applies to middle as well as older ages.

To avoid extrapolating outside the range (0,1), we first applied the logit transform to all rates. We applied a seven degrees of freedom smoothing spline, and interpolated to individual ages from 15 to 70. This gives a 21×56 data matrix for each gender.

5.1 Functional data forecast of male rates

Two components account for 97.5% of the variation and for subsequent components the $\beta_{t,k}$ follow a random walk or white noise. The two chosen components are displayed in Figure **??** of Appendix **??**. In plain language, the first component describes a tendency of increasing participation for the elderly and decreasing participation for those under 45. This tendency has steadily increased over time. The second component describes a more general tendency for the LFPR curve to shift to the right. The tendency is smaller in magnitude and has mainly been increasing over the past 10 years.

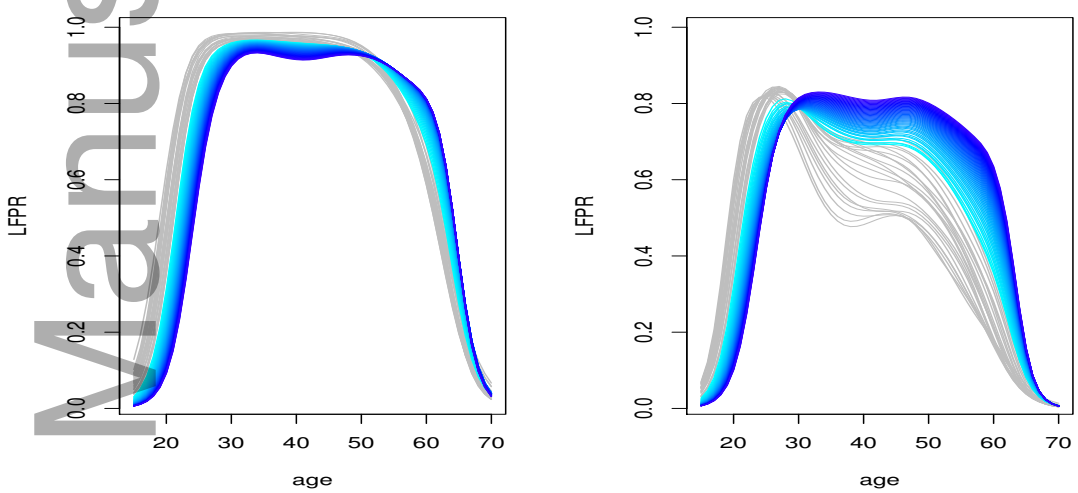

Figure 6: **Projected LFPRs for Males and Females.** *Left*: Historical and projected LFPRs for males on logit scale. *Right*: Historical and projected LFPRs for females on logit scale. Pale grey curves are 1994 to 2014 historical data. Forecasts from 2015 to 2064 start light blue and end dark blue.

The time varying coefficients β_{t1} and β_{t2} were carefully modeled (see Appendix **??**) and the projections with error bands are also indicated in the right panels of Figure **??**.

As expected from the projections and interpretations of the $\beta_{t,k}$, the male LFPR as a function of the age is projected to decrease for ages below 50 but increase for ages above 50. While total LFPR depends on the age distribution, it appears as if this will decrease. The smoothed historical data as well as 50 years of projection are displayed in Figure 6 for easy comparison with female rates, to which we now turn.

5.2 Functional data forecast of female rates

We know that female rates are strongly increasing in the central age-groups and have seen that male rates are decreasing and are projected to continue decreasing. This raises the prospect that forecasting female rates will exceed male rates and this indeed occurs for quite well supported forecast models of the female data. We considered it unlikely that total female rates will surpass total male rates, though this has already happened for the youngest ages where rates for both genders are quite low.

Figure **??** in Appendix **??** shows the historical differences between male and female rates on the logit scale (in grey). These have also been projected using FDA using a method that limits how far logit female rates may exceed logit male rates. Details are in the appendix. Combining the forecasts of the difference with the forecasts for males produces forecasts for females. These are displayed on the logit scale in the appendix and on the ordinary scale in Figure 6 above.

6 Migration

Hong Kong has two qualitatively different migration channels, namely two-way flows of Hong Kong permanent residents (HKPRs) and one-way inflow of migrants from mainland China, known as *One-way Permit Holders* (OWPHs). Their different natures result in distinct age and gender patterns. This justifies separate analyses.

HKPRs have freedom to move into and out of Hong Kong. The OWP is issued by the PRC government granting PRC residents the right to leave the Mainland permanently and move to Hong Kong or Macau. They are eligible for permanent residence after seven years. There has been a long standing daily quota of 150 people (54,750 per annum). Although the primary purpose of the scheme is family reunion instead of general immigration, OWPHs have become a significant constituent of population growth in Hong Kong. The scheme has undergone recent amendments. Since April 2011, "overage children" (aged over 18 but less than 60) of HKPRs who live in PRC may apply for OWP. Previously, this was limited to children under 18 years old.

6.1 Net movement of Hong Kong Permanent Residents

We obtained data on net movement (inflow minus outflow) of HKPRs by gender and single age (up to 85+) from 2007 to 2014. On average, net movement was $-49,332$ per annum, with slightly more males moving out than females (female-to-male ratio = 0.92). However, this is misleading: until 2013, around 64% of this net movement were babies, overwhelmingly born in Hong Kong to mainland women with non-resident fathers, known locally as type II babies. According to law, these babies were entitled to permanent residence at birth. Between 91% and 99% return to mainland China before the age of one, since their parents do not have residence right (C&SD, 2011).

Since 2003, the number of type II babies increased enormously, peaking at 35.7 thousand in 2011 and accounted for nearly 40% of all births in that year. It is estimated that over 300 thousand type II babies were born. This was driven by mainland mothers visiting Hong Kong to give birth, partly to avoid the one-child policy and more generally to take advantage of the superior healthcare services for delivery and the right of abode of becoming a Hong Kong resident. This explains the huge outflow of HKPRs aged 0 in the data. Moreover, about 50% of these babies would return to Hong Kong before age 6 for schooling (C&SD, 2011) though this has recently reduced to about 25% (Yip et al., 2017). Nonetheless, these flows ceased as a result of the zero-quota policy on obstetric services for mainlanders imposed by the Hong Kong Government in 2013, in response to severe strains on the local obstetric healthcare system. So, the earlier pattern for age zero cannot be naively projected and some adjustments to the age 0 data are required. Further details are in Appendix **??**. After adjustment, there were a net of 27,059 HKPRs moving out of Hong Kong averaged over eight years, with a female-to-male ratio of 1.08.

The data were then pre-smoothed, age 0 excluded for reasons just explained. The smoothed data were then modeled using FDA, which revealed two components accounting for 88.2% and 91.1% of total variation for males and females, respectively. However, all four sequences of coefficients $b_{t,k}$ were best modeled as white noise, con-

tributing nothing to the forecast. The top left panel of Figure 7 displays the mean functions extracted from FDA.

Future patterns of movement depend on numerous external factors that are hard to predict. Historical trends should play an important role but no consistent trend has been identified. Therefore, we will assume that future movement of HKPRs will stably follow the mean age-gender pattern, with a net number of 13,057 females and 11,992 males leaving Hong Kong each year. In our later projections, we vary total migration numbers exogenously.

6.2 Inflow of One-way Permit Holders

We obtained data on inflow of OWPHs by gender and single age (up to 85+) from 2007 to 2014. The top right panel of Figure 7 displays the age-gender pattern averaged over 8 years. Each year, there were an average of 44,820 PRC residents holding OWP who moved to Hong Kong, with a large 2.1 female-to-male ratio. Detailed displays of the data are in Appendix **??**. Clearly, females aged 20-50 are hugely over-represented, driven by the large gender asymmetry in cross-border marriages. Historically, Hong Kong men marrying PRC women has been 5-6 times more frequent than the reverse, though the ratio is more like 2.5 in recent years.

The data were pre-smoothed and FDA extracted two components accounting for 96.6% and 96.2% of total variation for males and females, respectively. The gender-specific mean functions revealed that the large inflow of females occurred within child-bearing ages 21 to 49. However, all time varying coefficients $\beta_{t,k}$ are white noise and therefore, as with the HKPR decomposition, have zero contribution to the forecast. Based on this, we could project the simple averages in the top right panel of Figure 7 into the future. However, we prefer a less naive approach.

Future inflow of OWPHs will be influenced by two drivers, neither of which are predictable statistically. The first is the number of families requiring reunion. This is driven by cross-border marriage which is in turn driven by the gap between quality

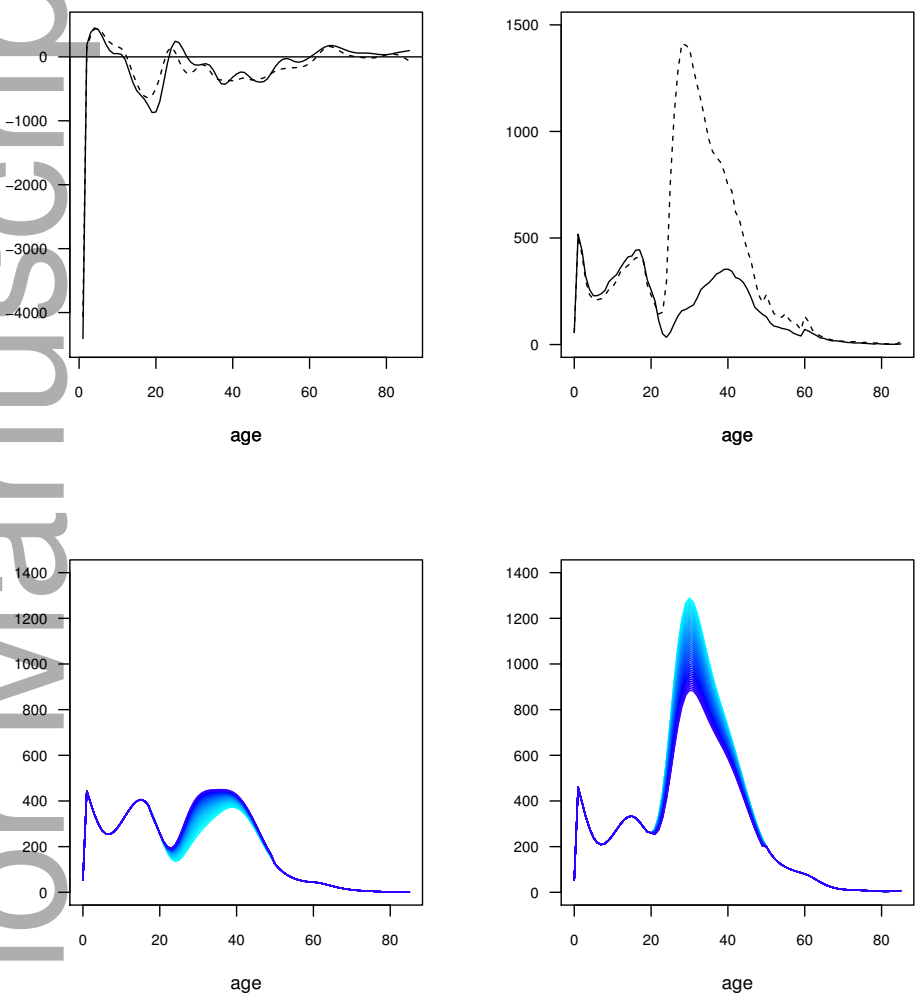

Figure 7: **Migration numbers.** *Top left*: Mean function of net movement of HKPRs. Solid line for males and dashed line for females. *Top right*: Historical average numbers of inflow of OWPHs versus age for 2007-2014. Solid line for males and dashed line for females. *Bottom*: Projected number of inflow of OWPHs versus age from 2015-2064, starting from light and ending in dark blue. Left for males and Right for females.

of life in Hong Kong compared to mainland China. Historically, this meant mainland women marrying with Hong Kong men. The number of such marriages are already diminishing as the differential in living standard reduces. It is reasonable to assume that this trend will continue and drive a decrease in the inflow of female OWPHs of childbearing age. On the other hand, the number of inflow of adults may increase due to the "overage children" policy mentioned at the start of this section. Consequently, we may observe female-to-male ratio moving towards parity in the future.

Making use of the difference of male and female mean functions $(\mu_F(x_j) - \mu_M(x_j))$ identified from FDA, we proposed a mathematical model to project the future inflow of OWPHs, considering change in gender ratio and change in age distribution at the same time. Details of the model are in Appendix **??** and projections are displayed in the bottom panel of Figure 7, with daily number ranging from 115 to 124 and gender ratio decreasing from 1.93 to 1.36. We do not have a measure of forecast error for these projections. However, migration numbers will be varied exogenously in section 8.

7 Population projections

Based on our forecasts of fertility, mortality and migration flows we project the Hong Kong population using the standard cohort component method. All projections are supplemented by estimates of statistical error.

7.1 Projection method

For each year we first apply mortality rates to each gender/age segment using random binomial generation, i.e. if n people are subject to mortality p then we generate a binomial count with these parameters. This assumes that deaths occur independently, both within and between the groups. The amount of random variation involved is typically small because of the large counts involves, but does accumulate over the 50 years of our projection.

We next apply fertility rates to females to generate births using the same binomial

method. However, we do not include every female in the 15-49 age range. Why? In 2014, the ratio of females to males was 1.07. This is forecast to increase strongly reaching 1.15 by 2030 and 1.25 by 2050. The gender skew is not driven by mortality differences, which mainly affects older age-groups, but by a strong skew towards females in net immigration. It is not clear whether or not all females in Hong Kong will find a partner when the gender ratio is 1.25. On the other hand, it might be argued that there is an effectively inexhaustible supply of males from PRC. This is an issue that has not been identified in the literature and is not easy to resolve, but it does have a non-trivial effect on projections depending on how it is handled. In Appendix **??** we detail our approach to this issue, which involves looking at trends in cross-border marriages for males and females and making reasonable projections. We also give some results on the level of difference that this whole issue can make to overall projections.

For the final steps of our projections, we apply net immigration flow excluding OWPH to each age-gender-group and lastly OWPH to each age-gender-group.

Statistical variability is accounted for by using the FDA standard errors. For each simulated projection, we perturb the forecast fertility, mortality and LFPR profiles with their standard errors multiplied by a standard normal variable. We summarise 1000 runs of this procedure using the mean and one standard deviation bands either side.

7.2 Demographic projection

Figure 8 describes our results. The left plot shows the total population for 2015 to 2064, as well as disaggregated numbers in three age-groups. Notionally, we deem the youngest age-group to be economically inactive. In the previous literature, the economically active group has often been taken to be aged 15-65 however, with increasing participation, as forecast in section 5, it seems preferable to extend this to 15-70.

The total population is projected to peak at 7.47 million in 2033. The numbers in the youngest age-group will be relative stable. The main changes will be a decrease

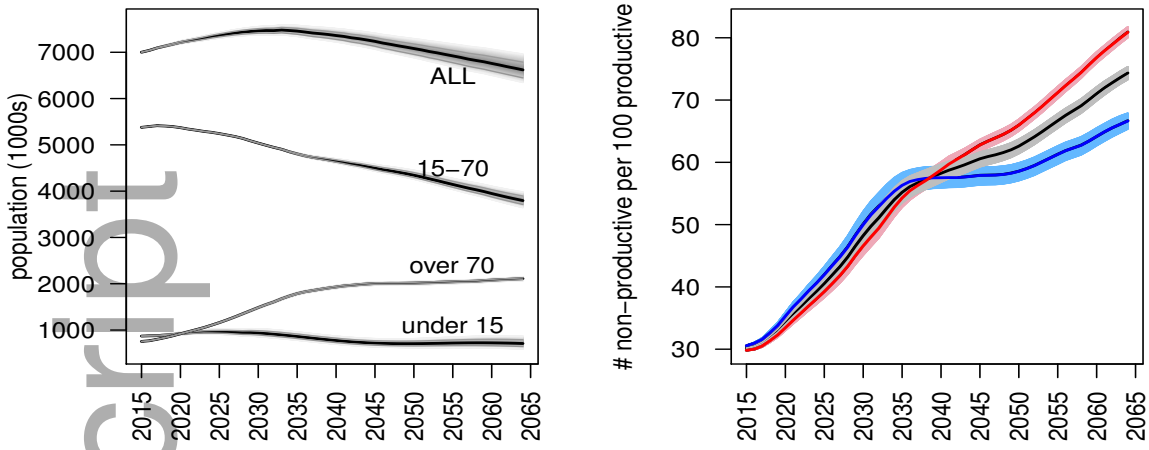

Figure 8: **Projected population counts and ADR.** *Left*: Summary of 1000 projections using best forecasts of all drivers. Dark line is mean and bands are one standard deviation. *Right*: Summary of projections of ADR. Blue is males, pink is females and grey is both genders.

in the productive age range from 5.38 million to 3.79 million at the same time as the oldest age-group increases from 0.75 million to 2.11 million. As described in the introduction, we measure age burden by the ratio of non-productive age-groups (i.e. the youngest plus the oldest) to the productive age-group, labeled ADR. Larger values indicate a larger burden. This has been displayed separately for males and females, and also overall, in the right panel. Not surprisingly, the female ratio is projected to become higher than the males ratio in around 2036, almost entirely driven by the lower mortality of females compared to males.

7.3 Economic participation projections

We combine the population projections with our forecast age- and gender-specific LFPR to investigate the effects of aging on overall labour force participation, known as EDR.

Let $L_g(x,t)$ be the LFPR at time t, conditional on age=x and gender $g = m, f$. We generated forecasts of $L_g(x,t)$ in section 5. Roughly speaking, for central ages, rates for females will tend to increase, and for males will tend to slightly decrease; the population will both age and tend to skew to females. It is not clear from this

qualitative discussion how overall participation will fare.

The EDR is obtained by integrating $L_g(x,t)$ with respect to the age distribution $\pi_g(x,t)$ at time t. We denote this $E_g(t)$, see Appendix **??** for its exact definition. We have projected $E_g(t)$ 1000 times allowing for uncertainty in the forecasts of $\pi_g(x,t)$ and $L_g(x,t)$ and summarised results by the mean. The solid line in the left panel of Figure 9 is for all genders and show that $E(t)$ will decrease from 50% to 37% by 2064. How much of this decline is due to demographic changes and how much to changes in age- and gender-specific LFPR?

We can investigate this by holding either $\pi_g(x,t)$ or $L_g(x,t)$ fixed at $t = 0$. Again, mathematical and notational details are in Appendix **??**. The dashed line shows the mean value of our projections where only the demography $\pi_g(x,t)$ changes. This is projected to fall to under 35%, slightly worse than $E(t)$ because we are not factoring in increases in LFPR, especially amongst the elderly. The dotted line shows the mean value of our projections where only $L_g(x,t)$ changes and demography is held fixed. This is projected to increase from 50% to 52%. So the short story is that underlying economic participation will increase modestly but will be easily out-weighed by the effects of aging.

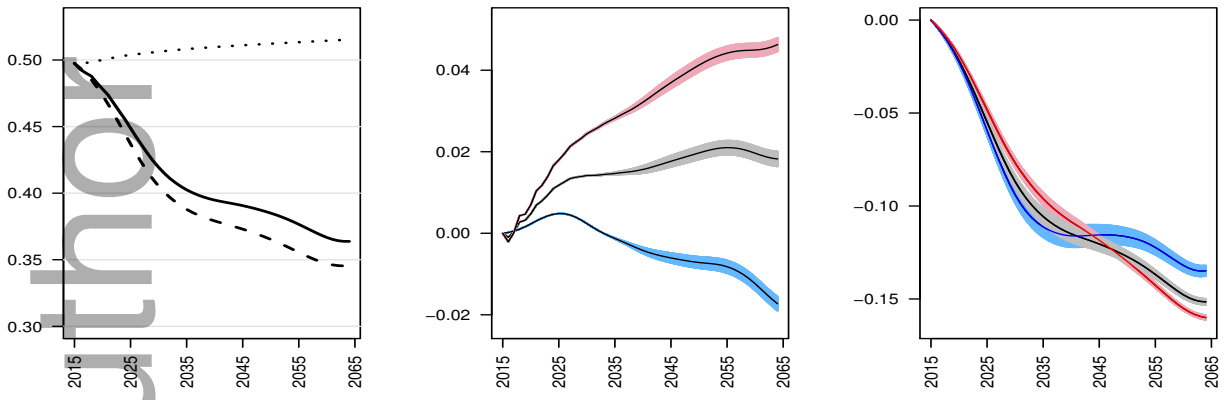

Figure 9: **Economic participation.** *Left*: Projections of $E(t)$. Solid line is baseline projection. Dashed line is projection with demographic changes only. Dotted line is projection with changes in LFPR only. *Centre.* Effect on $E(t)$ of changes in LFPR assuming fixed demographics. Females are in pink, males in blue. *Right.* Effect of demographic changes on $E(t)$ assuming fixed $L_g(x)$. Females are in pink, males in blue.

It is helpful to decompose the separate effects of demographics and LFPR by looking at the relevant differences. Formulas are again given in Appendix **??**. The pure effect of changes in $L_g(x,t)$, are displayed in the central panel of Figure 9. It shows the changes in economic participation if the age distribution was held constant at $\pi_g(x,0)$. Female participation (pink) would increase by about 0.045 and male participation (blue) would decrease by about 0.015. Overall, there would be an increase of 0.015 (grey). The right panel shows pure effects of demography. The change is –0.12 for males and –0.16 for females. This is because aging of the female population is more pronounced than for the male population. These effects are almost an order of magnitude larger than the pure economic effects. The conclusion from this analysis is that demographics effects will swamp the forecast increased participation in older age-groups and amongst females that has sometimes been touted as a solution to demographic aging.

8 Population scenarios

Our FDA decomposition of fertility and migration flows had time varying coefficients that followed random walks or white noise. This suggests that they are not statistically predictable; fertility is based on an accumulation of autonomous decisions which depend on economic and political trends; sometimes, net migration and especially OWPH flows are based on economic and political decisions. This being the case, it seems pertinent to exogenously vary these two drivers by plausible amounts to see what effect they will have on age dependency and economic ratios.

In this section we consider the effects of exogenous manipulations of fertility and migration on the age burden. This is measured by ADR, which is the ratio of non-productives to productives and EDR, which is simply the overall labour force participation rate. We remind the reader that neither of these measures makes a distinction between young and old non-productives.

8.1 Scenarios considered

Our baseline scenario and projection method is as described in the previous sections. Baseline fertility forecasts were described in section 3.3. Current government policy is to grant 50,000 one way permits per year (though not all of these are always exercised) and we described forecasts of the demographics of these in section 6.

Table 1: **Projection scenarios considered.** (s) means fertility change is introduced slowly i.e. gradually over 50 years, (f) means it is introduced fast i.e. instantly in 2015.

Scenario	fertility change	OWPH change
1	none	none
2	+ 25%(s)	none
3	+ 25%(f)	none
4	- 25%(s)	none
5	- 25%(f)	none
6	none	+25k
7	none	-25k
8	+25%(f)	-25k
9	-25%(f)	+25k
10	+25%(f)	+25k
11	-25%(f)	-25k

We will make three kinds of perturbations from the baseline forecast. The first is to multiply the whole set of fertility curves by $1+g/100$. This amounts to an instantaneous and permanent change to fertility of $g\%$ and is termed *fast*. The second method is to multiply the fertility curves for the projection m years ahead by $(1+g/100)^{m/50}$. This amounts to gradually changing fertility by $g\%$ over a period of 50 years and is termed *slow*. We chose $g = \pm 25$ which means total fertility would be around 1.5 in the high case and a little below 1 in the low case, which seems historically reasonable. The third manipulation is to vary total OWPH numbers. We consider the effects of increasing this to 75,000 or reducing it to 25,000. Note that OWPHs tend to be in the productive 15-70 age-group and are skewed towards females. Whereas, increased fertility introduces non-productive children into the population and slightly favours males. The combinations of these manipulations are summarised in table 1.

8.2 Age dependency

Figure 10 describes our results on the ADR. The first message from all of these plots is that ADR is set to drastically increase over the next 50 years, regardless of fertility or migration levels.

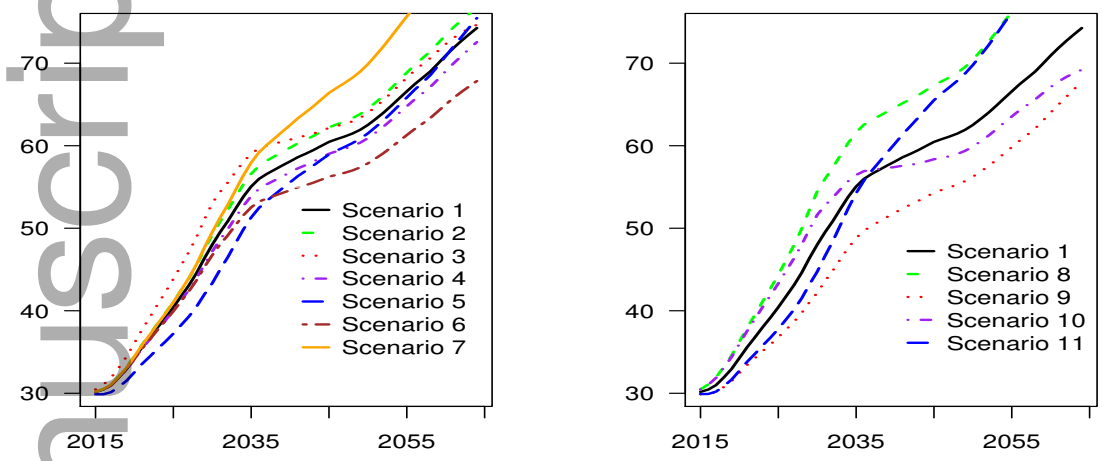

Figure 10: **Effects of fertility and netflow on age dependency ratio.** The measure is number of non-productive per 100 productive. *Left*: Baseline scenario 1 with manipulations 2-7. *Right*: Baseline scenario 1 with manipulations 8-11.

Increased fertility is, perhaps surprisingly, associated with a higher i.e. worse dependency ratio. This is because our measure includes the young as dependent. Looking at the fast increase (s3), ADR increases and then begins returning towards baseline as the children enter the productive age range. After 50 years, it has just returned to baseline. The slow increase (s2) is similar to the fast increase, but delayed by about 25 years. Eventually, the age distribution will converge to a limit, but this limit is not reached in 50 years. Nor is it clear that that the limiting ADR would be more favourable, even though the age distribution will certainly be younger, again because the young are counted as dependent.

Increasing or decreasing OWHP leads to lower/higher dependency ratios, both immediately and persistently. This is as expected since the majority of OWPH's are in the economically active age range. It is interesting to note that, by around 2035,

the dependency ratio for the increased OWHP scenario 6 falls below the fast fertility reduction scenario 5 and results in the lowest ratios into the future.

The right panel describes the effects of the fast fertility and OWHP manipulations in combination. Scenarios 9 and 10, which both have an increase in OWHP, lead to the lowest dependency ratios. The two differ in the fast fertility manipulation which has an initial effect but appears be largely swamped by the OWHP manipulation by the end of the forecast period. Scenarios 8 and 11, which both have a reduction in OWHP, lead to the highest ratios. Again the joint fertility manipulation has a strong initial effect but the curves are very close from around 2050 onwards.

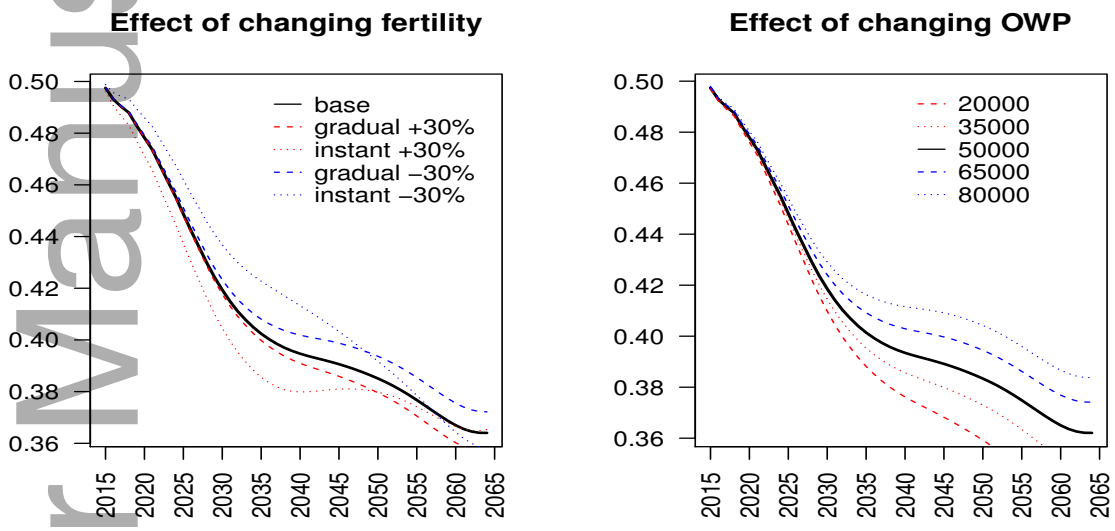

Figure 11: **Effects of fertility and netflow on EDR.** *Left*: Effect of varying fertility by ±30%.*Right*: Effect of varying LFPR in increments of 15000.

8.3 Economic dependency

The effects of fertility and OWPH manipulations on ADR do not tell the whole story, because LFPR is projected to change as well. In section 7.3 we gave projections of the EDR, obtained by integrating the LFPR forecasts with respect to the demographic forecasts. Figure 11 presents results for the effects of fertility manipulations in the left panel and OWPH manipulations in the right panel. Again, increases in fertility lead

to a lower i.e. worse EDR and the effect is faster when the increases is instant rather than gradual. In the right panel, increases/decreases in OWPH lead to higher/lower participation rates. We have also run scenarios that combine fertility and OWPH manipulations and found similar results to those for ADR. Specifically, the best outcomes are for lower fertility and higher OWHP but plausible changes in OWPH seem to have a larger effect than plausible changes in fertility.

These results are further discussed in the next conclusion section.

9 Discussion and Conclusion

In this study, we have used modern FDA method to project fertility, mortality and LFPR and used these to project two measures of age burden out to 2064. The large contribution of migration to population growth, as well as the gender skew that this is causing, are interesting complicating factors and we have attempted to model these less formally.

Our projections suggest that large increases in the age burden are seemingly inevitable for Hong Kong. There are policy discussions in Hong Kong of how best to increase fertility and attract migrants to maintain a healthy population structure, yet the ultimate effects of these changes were not well understood. This study quantifies these impacts through scenario analyses, where these two drivers are varied by plausible amounts. Our results indicate that varying fertility and migration has a modest cumulative and long-term effect on dependency ratios. The "best" outcomes follow from lower fertility and higher migration regimes. Critical to this conclusion is that we count the young as well as the elderly as dependent. The result for low fertility is not surprising, as fewer babies mean fewer dependents, who will likely not enter the labour force for at least twenty years. However, reducing fertility is obviously not a sustainable option for Hong Kong, where rates are already very low. They need to maintain a healthy demographic structure in order to maintain sustainable development into the future.

9.1 Main results

Fertility. Our projections suggest further postponement of child bearing, associated with the growing norm of delayed marriage. Fertility decisions are influenced by many factors. In Hong Kong, the major concerns are the financial burden of housing and forgone salary, and the weight of responsibility (The Family Planning Association of Hong Kong, 2014). Public policies promoting childbearing appear to have limited effect on total fertility, probably because they do not address these basic issues adequately.

There is no indication that the TFR will rise in the foreseeable future. Indeed, low fertility now being the social norm of modern Hong Kong, it has perhaps acquired its own inertia. Our modeling efforts uncovered no useful predictions of total fertility which was, instead, varied exogenously in our projections.

Mortality. Reducing mortality rates mean a longer life span, but not necessarily a longer disability-free life. Consequently, one can expect an increasing healthcare burden in the future (Kwok et al., 2017). Natural increase in population has been low for many years and will reduce to zero in around 2030.

Migration. Hong Kong has received more than 1 million OWPH migrants in the past two decades and newcomers from mainland China will account for an increasing share of annual population growth. The majority are in the working age-group and so provide an immediate and steady supply to the labour force. Again, there was no useful prediction of total numbers and we varied this my plausible amounts in our projections.

Gender balance. The proportion of females is increasing systematically, due mainly to a gender skew in OWPHs driven by a gender asymmetry in cross-border marriages. This creates a marriage squeeze for Hong Kong women. There are signs that the reducing economic gap between Hong Kong and mainland China will reduce this asymmetry and that cross-border marriages of Hong Kong women to mainland men are already starting to increase. The impact of increasing gender imbalance on fertility is unclear. While we have modeled this process, it remains an open question whether every female in Hong Kong can find a partner. Formal marriage is essential for a traditional Chinese

culture like Hong Kong, where birth out-of-wedlock is still rare (about 6%).

Labour force participation. The main patterns are decreasing rates for the young, increasing rates for the old, increasing rates for females 30-50 off a low base and decreasing rates for males 30-50 off a high base. We address these in turn.

The decreasing rates for the young reflect time spent in higher education. Skills training is important for those eschewing tertiary level education, so that they still have an entry into the productive workforce. Labour participation rates among older adults in Hong Kong are the lowest in the region (Chief Secretary for Administration's Office, 2015) but are strongly increasing. Taken together, the patterns for the old and the young mean that the LFPR age-profile is moving to the right i.e. the labour pool becomes older, partly in response to demographics.

Female rates are increasing at ages over 30, from an historical pattern where rates dropped from the age of 25, due to family duties. While rates are moving in the right direction, the projected increases in female rates are only projections and will need family-friendly employment policy support to be realised. Male rates in the productive years have reduced from 98% to 96%, possibly due to increasing affluence.

Age burden. Our two metrics of age burden, namely ADR and EDR, treat young and old non-productives as equally burdensome. It is more common to only consider the burden of the elderly which automatically leads to recommendations of increased fertility. Indeed, the higher the fertility the lower the proportion of elderly will be in the limit. Yet, anyone who has had children knows that they are a cost, as well as a joy.

Thus our results show that increasing fertility will increase the total economic burden (as measured by ADR or EDR) both in the short and medium terms. In the very long term, increased fertility means a younger average age but this can mean a higher or lower ADR/EDR, depending on the exact shape of the population and the labour force patterns.

Without doubt, ADR and EDR are set to deteriorate drastically over the next

50 years, regardless of fertility or migration settings. It is the latter that will have the greatest mitigating effect based on plausibly policy changes, though such changes are politically difficult. It is worth noting also that increases in migration from the Mainland will not lead to over-population but rather to a population equilibrium.

9.2 Some specific policy issues

Since total population in Hong Kong will peak in around 2030 under current projections, increased migration quota is a possible response to demographic burdens. However, the migration policy lever might be limited by negative local sentiments if the local carrying capacity is not improved accordingly.

The younger a mainland child is admitted, the easier they can adapt to Hong Kong's education system and local community (Bacon-Shone et al., 2008; Yip & Lee, 2000). A flexible management scheme of the OWPH quota could avoid long waiting times for family reunions and facilitate the supply of labour. Infrastructure needs to be built to remove barriers to settlement so that this human capital can be unleashed into the capacity building of the community.

There are encouraging signs that females and the elderly are increasing their labour force participation. Most advanced countries have already extended their retirement age, supplementing this with flexible working hours, re-training, and initiation of some re-employment plans with affordable medical insurance coverage. The challenge for Hong Kong, therefore, will be to support physically and cognitively fit older people to remain or even return to the workforce.

Pursuing a career and raising children are not necessarily incompatible. Some OECD countries (e.g. Norway and Sweden) have maintained fertility rates at around 1.8, while female participation has shown large increases, going from about 50% to 75% during the period of 1975-2015. In France, both the TFR (about 1.7-1.8) and the female LFPR (about 70 per cent) remain at high levels. Koppen (2004) shows that compatibility between work and family life is high in France, where highly educated

women are more likely to have a second child than less-educated women. The increase in female labour force participation could generate further gains in income per capita and lessen the acute labour shortage, and the example of other countries demonstrate that this is achievable. Child care service for local working women in Hong Kong is severely lacking and unaffordable to many.

9.3 Conclusion

The demographic window of opportunity will soon close in Hong Kong, as in many other high income Asian countries, such as Singapore, Taiwan and South Korea. Hong Kong's population growth will slow, the workforce will inevitably shrink, and the gender balance will become skewed towards females. Policies that attract outside talent and which promote fertility may slow these trends, but only at the margin. The poor ADR and EDR in 50 years, which is the result of sharp fertility decline in the past and consistent mortality decline, remains similar under all plausible scenarios. To tackle the impact of population aging, simple demographic inputs are necessary but just not sufficient.

A highly skilled, educated and sufficiently numerous workforce is vital if Hong Kong seeks to become a successful knowledge-based and service-oriented economy. Hong Kong needs a forward looking, integrated and evidence-based population, education, labour and migration policy to achieve a sustainable and diversified economy. Training and education opportunities should be provided to all the young people of age 15-24. Policies targeting specific ages and levels of education, where the impact will be greatest, should be considered. Labour policy should focus on facilitating the participation of women and those in older age-groups. Migration should focus on those in the productive ages and reversing the gender skew. A key task will be to tune policy to utilize the human capital from mainland migrants.

Embracing and understanding demographic challenges and economic burdens is among the highest priorities of the Hong Kong Government today. This has largely

motivated our analysis, which will also have a bearing on other societies which have undergone a similar rapid demographic transition.

References.

Bacon-Shone, J., Lam, L. & Yip, P. S. F. (2008). *The Role of the One Way Permit Scheme in the population policy of Hong Kong.* Hong Kong: Bauhinia Foundation Research Centre.

Bouvier, L. F. (2001). Replacement migration: Is it a solution to declining and aging populations? *Population & Environment*, **22**(4), 377–381.

Census and Statistics Department. (2011). *Hong Kong monthly digest of statistics: Babies born in Hong Kong to mainland women.* Hong Kong Special Administrative Region.

Census and Statistics Department. (2016). *Women and men in Hong Kong - Key statistics (2016 Edition).* Hong Kong Special Administrative Region.

Census and Statistics Department. (2017). *Quarterly report on General Household Survey (fourth quarter 2016).* Hong Kong Special Administrative Region.

Chief Secretary for Administration's Office. (2015). *Population policy: Strategies and Initiatives.* Hong Kong Special Administrative Region.

Hyndman, R. & Ullah, M. S. (2007) Robust forecasting of mortality and fertility rates: A functional data approach. *Computat. Stat. Data. Anal.* **51**, 4942–4956.

International Labour Organization. (2015). Labour force participation rate – ILO modelled estimates, July 2015.

Koppen, K. (2004). *The compatibility between work and family Life – An empirical study of second birth risks in West Germany and France.* MPIDR Working Paper WP-2004-015. Rostock: Max Planck Institute for Demographic Research.

Kwok, C. L., Lee, C. K. M., Lo, W. T. L., & Yip, P. S. F. (2017). The Contribution of Ageing to Hospitalisation Days in Hong Kong: A Decomposition Analysis. *International Journal of Health Policy and Management*, **6**(3), 155-164. doi:

10.15171/ijhpm.2016.108

Lee, R.D., & Carter, L.R. (1992). Modeling and forecasting U.S. mortality. *J. Amer. Statist. Assoc.* **87**, 659-675.

Nagase, N., & Brinton, M. C. (2017). The gender division of labor and second births: Labor market institutions and fertility in Japan. *Demographic Research*, **36**, 339–370.

Nikitovic, V. (2011). Functional data analysis in forecasting Serbian fertility. *Stanovnistvo*, **49**(2), 73–89.

Ramsay, J. & Silverman, B. W. (2005). *Functional Data Analysis*. Springer Series in Statistics.

Shang, H. L., Smith, P. W. F., Bijak, J., & Wisniowski A. (2013). *A functional data analysis approach for forecasting population: a case study for the United Kingdom*. Working Paper Series, 41. UL: Southampton, GB ESRC Centre for Population Change.

The Family Planning Association of Hong Kong. (2014). *Report on the Survey of Family Planning Knowledge, Attitude and Practice in Hong Kong 2012.* Hong Kong Special Administrative Region.

Ullah, S., & Finch, C. F. (2013). Applications of functional data analysis: A systematic review. *BMC Medical Research Methodology*, **13**(1), 43. doi: 10.1186/1471-2288-13-43

United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*.

Yip, P. S., Cheung, K. S., Law, S. C., Chi, I., & Robine, J.-M. (2010). The demographic window and economic dependency ratio in the Hong Kong SAR. *Asian Population Studies*, **6**(2), 241–260.

Yip, P. S. F., Kwok, C. L., Lam, K.F., Soleymani, M., & Wat, K. P. (2017). *Follow-up study on movement of Type A and Type B babies in Hong Kong.* The University of Hong Kong, Hong Kong SAR.

Yip, P. S. F., Law, C. K. & Cheung, S. L. K. (2009). Ultra-low fertility in Hong Kong: A review of related demographic transitions, social issues, and policies to encourage childbirth. In G. Jones, P. T. Straughan & A. Chan (Eds.), *Ultra-low Fertility in*

Pacific Asia: Trends, Causes and Policy Issues (pp. 132–159). New York: Routledge.

Yip, P. S. F. & LEE, J. (2000). The effects of migration on the population distribution in Hong Kong. *Asian Journal of Public Administration*, **22**(1),90–104.

Yip, P. S. F., Lee, J., Chan, B., & Au, J. (2001). A study of demographic changes under sustained below-replacement fertility in Hong Kong SAR. *Soc Sci Med*, **53**(8), 1003-1009. doi: Doi 10.1016/S0277-9536(00)00395-6

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