Facing Demographic Challenges:

Pension Cuts or Tax Hikes?[1,2]

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Abstract

A challenge that faces many advanced economies is how to finance age-related spending programs as the population ages. In this paper, we investigate two policy options – pension cuts and tax hikes – to mitigate fiscal pressure arising in the special context of Australia, whose population is ageing fast while growing substantially in size due to immigration. Using a computable overlapping generations model, we find that while both policy reforms can achieve a similar fiscal goal, they lead to different distributional and welfare effects across income groups over time. Future generations prefer pension cuts, whereas current generations prefer tax hikes to finance government spending commitments. Moreover, within the tax hike option taxing income or consumption results in opposing macroeconomic and welfare effects. Indeed, our opposing intra- and inter-temporal welfare outcomes highlight some political complexity when devising a more sustainable tax-transfer system.

Keywords: Demographic Transition, Fiscal Policy, Welfare, Overlapping Generations

JEL Classification: H2, J1, C68

1 Introduction

Developed countries around the world are experiencing ageing of their populations arising primarily from changes in fertility and mortality. These significant changes in the age structure of populations have important implications for the economies of the countries in question and, in particular, for the fiscal policies of their governments, since they are likely to experience budgetary stress as a consequence of having public expenditures that depend heavily upon age related public programs. Foremost amongst these are social security retirement, long term (aged) care and health programs, each of which induce greater expenditures with an ageing population. With this backdrop, policy questions arise as to how fiscal authorities can respond to prevent unsustainable expenditures. The main purpose of this paper is to investigate the efficacy of two alternative policy responses – pension cuts and tax hikes.

Our investigation of these two alternative policy approaches to fiscal sustainability of government budgets in the context of population ageing is undertaken for the Australian economy. In Australia, population ageing will accelerate in the next few decades, driven partly by falling fertility rates in the past and partly by projected mortality improvements in the future. Although almost all developed countries need to deal with similar fiscal issues associated with ageing demographics, the problems facing Australia and the policy settings are quite distinct. First, the Australian population is projected to increase significantly in size due mainly to high net migration inflows. Despite growing fast due to migration, ageing will still be a distinctive feature of the demographic trend in Australia over the next 50 years. Second, Australia's fiscal setting is different from most countries in that its government's age pension program is not funded by employee contributions and there are very limited payroll taxes. Age pension payments to retirees are funded from general tax revenue, which imposes fiscal stress as the population ages. Moreover, the age pension is means-tested and this provides additional policy instruments to the government. Accordingly, understanding the consequences of population ageing in this special

Australian context will have important implications not only for Australian fiscal policy but also for policy analyses of other ageing economies that plan reliance on their migration policies to mitigate the fiscal costs of ageing.

Changes in the age structure and size of Australia's population will place increasing demands on the government in terms of financing old-age related spending on health, aged care and pensions. Fiscal reform will inevitably form part of the overall policy response to demographic change, but formulating an optimal policy response requires a rigorous economic analysis of how much adjustment is needed and of what the consequences will be. Accordingly, it is important to quantify the macroeconomic and distributional welfare effects of the two fiscal adjustments identified above – pension cuts and tax hikes – to mitigate fiscal pressure arising from population ageing in Australia.

To that end, we construct a small open economy version of a computable, overlapping generations (OLG) model based on Auerbach and Kotlikoff (1987) with non-stationary demographic structures. This class of model has been used by many researchers worldwide to analyze the economic effects of population ageing, for example Fehr (2000), Nishiyama (2004), Kotlikoff *et al.* (2007) and Fehr *et al.* (2008). Our model comprises overlapping generations of households and production, government and foreign sectors. In addition, we use a demographic model to project future changes in the age structure and size of Australia's population, based on assumptions regarding future movements in the age profiles for fertility, longevity and immigration. Since rising fiscal costs are due not only to pensions but also to other age related government spending, our model embodies a rich fiscal structure with age profiles for public expenditures on health care, aged care, the means tested age pension as well as on education and family benefits. We discipline our benchmark economy to match key Australian macroeconomic aggregates and demographic structure in 2012 and to approximate the lifecycle behavior of Australian households, including labour supply, labour earnings and pension payments. The model is then applied to conduct policy experiments.

First, using the demographic projections derived from our demographic model, we quantify the fiscal costs of demographic transition. We maintain initial assumptions about the policy environment to focus on endogenous responses of households, firms and the government to the exogenously projected changes in the demographic structure of the population. The simulation results indicate that demographic shift in Australia with increasing (decreasing) population shares of the elderly (working cohorts) has significant implications for the future government budget position through changes in both taxation revenues and expenditures. Similarly to Kudrna *et al.* (2015), we find (*i*) significant changes in the tax base, with a shift from labour income to assets income and consumption, and (*ii*) substantial increases in age related spending on health care, aged care and the age pension, with a resulting fiscal gap of over 2 percentage points of GDP in 2050, increasing to over 4 percentage points of GDP by 2100.

Next, we examine the macroeconomic and welfare effects of two fiscal reform options to respond to demographic shift. The first policy option is a cut to government spending by reducing pension benefits - increasing the eligibility age for the pension, reducing the maximum pension benefit and increasing the taper (withdrawal) rate at which the pension benefit reduces as other income increases. The second policy option is an increase in taxation revenues through adjusting either consumption or income tax rates. These two policy options thus address different sides of the government budget constraint. It is found that, while the two fiscal reform options achieve the same goal of reducing the fiscal burden of population ageing, their macroeconomic and welfare outcomes differ greatly. In terms of the welfare effects, we find that young and future generations prefer pension cuts, but currently older and middle-age generations prefer to finance the fiscal burden through tax hikes. Furthermore, higher income households would prefer pension cuts as the age pension is not an important source of retirement income for them, whereas lower income types would prefer tax hikes with increases in progressive income tax rates. Interestingly, the indirect and regressive consumption tax hikes have opposing effects on macroeconomic aggregates and welfare across skill types to those obtained from the income tax hikes. We show that the required increases in the consumption tax rate result in positive effects on per capita labour supply, assets and output, but reduce the welfare of low income households most. Conversely, the increases in progressive income taxes result in negative effects on output but reduce the welfare of poor households least.

Related literature. Our paper is related to a growing literature that calculates the fiscal costs of population ageing and examines the implications of fiscal reforms to mitigate these costs. Attanasio *et al.* (2006) build a multi-regional world model focusing on the effects of demographic trends across regions. Diaz-Gimenez and Diaz-Saavedra (2009) simulate a reform to raise the retirement age, using a model calibrated to the Spanish economy. For the U.S., effects of social security reforms have been addressed by Imrohoroglu and Kitao (2009), while ageing has been studied by Nishiyama (2015). Kitao (2014) uses a computable OLG model to examine the effects of four pension reform options to achieve a fiscal balance for the U.S. social security system. McGrattan and Prescott (2016) analyze how to devise a transition path from the current pension system in the U.S. to a new saving-retirement system that improves welfare of all generations. We follow a similar approach, but build a dynamic, general equilibrium OLG model with a more detailed description of fiscal policy to estimate fiscal costs of population ageing in Australia. We also consider a broader plan for fiscal reforms, allowing the government to adjust not only pension benefits but also taxes to finance the fiscal deficit caused by population ageing. By comparing the implications of these two fiscal reform options, we highlight that they result in different macroeconomic and welfare outcomes.

Hansen and Imrohoroglu (2016), using a standard representative agent growth model, calculate the size of the Japanese fiscal burden, which they define as additional taxes required to maintain the promised levels of per capita public pensions and health services. Imrohoroglu *et* *al.* (2016) build a model based on micro-data to estimate the fiscal costs of population ageing in Japan. Braun and Joines (2015) and Kitao (2015) also analyze the fiscal cost of population ageing in Japan. It is important to note that the population ageing problems facing Australia are quite different from Japan and other advanced economies. As noted above, net migration inflows to Australia are relatively high, so that the size of the Australian population will double while ageing is accelerating. In contrast, Japan's ageing population is declining in size. Moreover, Australia's fiscal setting is different, with its means-tested age pension and limited payroll taxes. These differences underline the importance of paying particular attention to Australia's population ageing issues.

We also contribute directly to the literature on the economic and fiscal implications of population ageing in Australia. While the Australian Government (2010, 2015) and Productivity Commission (2013) quantify the fiscal challenges caused by demographic shift, neither of these reports take direct account of behavioural responses to population ageing that are an important component of our methodology. In addition, while the 2015 Intergenerational Report (Australian Government, 2015) includes the effects of the proposed policy changes on the government budget, it provides little guidance regarding who bears the costs of these policy changes. The analyses of population ageing by Guest and McDonald (2001, 2002) and Guest (2006) use a Ramsey model of optimal savings with no inter-generational heterogeneity among households. Kulish *et al.* (2010) apply an OLG model to study the macroeconomic effects of changes in fertility and longevity, but they do not analyze the fiscal effects of demographic change. Finally, while fiscal effects are analyzed by Kudrna *et al.* (2015), they abstract from the policy reforms required to finance the budgetary costs arising from population ageing that are the focus of the present paper.

The paper is structured as follows. In Section 2 we set up a dynamic, general equilibrium model. Section 3 provides details on the calibration of our model to the Australian economy, while Section 4 contains the discussion on the effects of demographic transition computed using the base model. In Section 5, we examine a range of policy experiments to mitigate the fiscal costs of population ageing, with the results presented in terms of macroeconomic and welfare implications. Section 6 deals with a sensitivity analysis of several modifications of the model. Section 7 offers some conclusions.[1]

2 Model

In this section, we formulate a small open economy OLG model. It is a general equilibrium model that comprises overlapping generations of heterogeneous households, a perfectly competitive representative firm, and a government sector with essentials of the Australian tax and pension policy settings.[2]

2.1 Demographics

The model economy is populated by overlapping generations of households. In every time period t, there are 101 generations aged 0 to 100 years ($j = 0, .., J = 100$). We assume that only adult households aged 21 years and over make economic decisions. Denoting $N_{j,t}$ as the size of a cohort of age j in time t, the total population is a sum of all cohorts alive in period t as $P_t = \sum_{j=0}^{J} N_{j,t}$. The cohort share of the entire population at any point in time t is given by $\phi_{j,t} = \frac{N_{j,t}}{P_t}$. The population growth rate, $n_t = \frac{P_t - P_{t-1}}{P_{t-1}}$, depends on the evolution of age-specific fertility, mortality and net immigration rates. The assumptions for these vital rates and the assumed demographic scenarios are discussed in detail in Section 3 on calibration. When the demographic structure is stationary, the population grows at a constant rate.

[1] There are also several appendices containing supporting material on the solution algorithm, results for alternative tax hikes and detailed results for the robustness checks.

[2] The model is an extended version of the small open economy, OLG model developed for Australia by Kudrna and Woodland (2011). The main extensions of the model used for the analysis in this paper include: (*i*) a detailed disaggregation of households into income quintiles; (*ii*) richer fiscal structure with age related expenditures on health care, aged care, education and family benefits; and (*iii*) non-stationary demographic transition paths.

2.2 Endowments

Agents are born with a specific skill (or income) type that determines their labor productivity over the lifecycle. Let i denote an individual's skill type and let there be I types of skill. The skill type is predetermined and unchanged over the life span. Let μ^i be a measure of each skill type relative to the population.

In each period of life, agents of a cohort of age j in time t are endowed with $h_{j,t}$ unit of time that has labor efficiency (or working ability) denoted by e_j^i. As in Kotlikoff *et al.* (2007) and Fehr *et al.* (2008), we incorporate time-augmenting technical progress by assuming that the time endowment, $h_{j,t}$, increases for every successive generation at the rate of technological progress, g, so that $h_{j,t} = (1+g)\, h_{j,t-1}$.[3] The efficiency (or productivity) unit, e_j^i, which is skill- and age-dependent, is multiplied by $(1+g)^{j-21}$ to make the longitudinal age-wage profile steeper (see Kotlikoff *et al.*, 2007). According to this specification, agents have working abilities that change with age to reflect not only the accumulation of human capital, but also the technical progress that occurs over the course of their lives.

2.3 Households

All households have identical lifetime preferences over their consumption and leisure profiles but face individual specific lifetime budget constraints. The inter-temporal utility maximization problem of an adult household of type i born at time t is to choose a sequence of consumption paths (c) and leisure paths (l) to maximize expected lifetime utility given by

$$U_t^i = E\left[\sum_{j=21}^{J} \beta^{(j-21)}\ \pi_{j,t+j-21}\ \frac{u\left(c_{j,t+j-21}^i, l_{j,t+j-21}^i\right)^{1-1/\gamma}}{1-1/\gamma}\right] \tag{1}$$

[3] The typical approach of accounting for technical progress by multiplying the labour input in the production function by a growing productivity factor would not be compatible with a long run equilibrium path in our specification with CES preferences (see Auerbach and Kotlikoff, 1987, p.35). We therefore assume the time-augmenting technological change, which implies that all aggregate variables grow at constant rate $(1+g)(1+n)$ in a steady state.

subject to a lifetime budget constraint that can be expressed as period by period asset accumulations

$$a_{j,t}^{i}+(1+\tau^{c})\,c_{j,t}^{i} = (1+r)\,a_{j-1,t-1}^{i}+(1-\tau^{l})w_{t}e_{j}^{i}(h_{j,t}-l_{j,t}^{i})+p_{j,t}^{i} + s_{j,t}^{i}+f_{j,t}^{i}+b_{j,t}^{i}-t(y_{j,t}^{i}) \tag{2}$$

and the consumption and time allocation conditions

$$c_{j,t}^{i}\geq 0,\quad 0\leq l_{j,t}^{i}\leq h_{j,t}. \tag{3}$$

In expression (1) for the objective function, the atemporal utility function u indicates the household preferences over consumption and leisure, γ is the inter-temporal elasticity of substitution, β is a constant discount factor and the term π_j denotes unconditional age-dependent survival rates. Thus, the household discounts future utility taking into account the usual discounting via β and the uncertainty of survival.

The left hand side of (2) represents the allocation of available financial resources at age j between end of year assets, $a_{j,t}^{i}$, and consumption expenditure, $(1+\tau^{c})\,c_{j,t}^{i}$, where consumption attracts a tax rate of τ^{c}. The right-hand side specifies the total financial resources available at age j, and includes asset holdings at age $j-1$, $a_{j-1,t-1}^{i}$, interest income, $ra_{j-1,t-1}^{i}$, labour earnings, $w_{t}e_{j}^{i}(h_{j,t}-l_{j,t}^{i})$, age pension payments, $p_{j,t}^{i}$, superannuation payouts denoted by $s_{j,t}^{i}$, family benefits, $f_{j,t}^{i}$, and bequest receipts, $b_{j,t}^{i}$, minus progressive income taxes given by the tax function, $t(y_{j,t}^{i})$.[4] Households pay payroll tax at the rate of τ^{l} on earnings and income tax on their taxable income, $y_{j,t}^{i}$, which comprises labour earnings net of the payroll tax, interest income and the age pension. The interest rate, r, is assumed to be constant.

[4] We follow Gokhale *et al.* (2001) by assuming that all inter-generational transfers are accidental and, hence, that there are no intended bequests. We further assume that accidental bequests are equally redistributed to surviving households of the same income type aged between 45 and 65 years ($45<j<65$), reflecting intergenerational transfers from parents to children.

The household solves this intertemporal utility maximization problem thus determining its lifetime profile of consumption, leisure (hence labour supply) and assets given by the set $\left\{\left(c^i_{j,t}, l^i_{j,t}, a^i_{j,t}\right),\ j = 1, ...J\right\}$. The quantity of effective labor supplied by a household of type i is $L^i_{j,t} = \left(h_{j,t} - l^i_{j,t}\right) e^i_j$, where $l^i_{j,t}$ is leisure and $\left(h_{j,t} - l^i_{j,t}\right)$ is labor supply of i type household at age j in time period t. According to the model specification, the household makes labour supply decisions at both the intensive and extensive margins. The labour supply is required to be non-negative, $h_{j,t} - l^i_{j,t} \geq 0$, so the choice at the intensive margin must respect this condition. The household may choose to allocate all time endowment to leisure, $l^i_{j,t} = h_{j,t}$, in which case labour supply is zero and the households is fully retired (the extensive margin choice).

2.4 Production

The production sector consists of a large number of perfectly competitive firms, which is formally equivalent to one aggregate representative producer that maximizes profits. The production technology of this firm is given by a constant returns to scale production function

$$Y_t = A \cdot F\left(K_t, L_t\right), \tag{4}$$

where K_t is the input of capital, L_t is the input of effective labor services (human capital) and A is total factor productivity, which we assume to be constant.[5] The firm is assumed to maximize profits. Specifically, the firm chooses capital, K_t, labour, L_t, and investment, I_t, to maximize the present value of all future profits subject to a capital accumulation equation, as described by

$$\begin{aligned} \max_{\{K_t,\ L_t,\ I_t\}} \quad & \sum_{t=0}^{\infty} \tfrac{1}{(1+r)^t} \left[\left(1 - \tau^f\right)\left(Y_t - C(I_t, K_t) - I_t - (1+\nu) w_t L_t\right)\right] \\ \text{s.t.} \quad & K_{t+1} = I_t + (1-\delta) K_t. \end{aligned} \tag{5}$$

[5] Assuming total factor productivity to growth at the exogenous rate g in a model with CES preferences would not be consistent with a well-defined balance growth path. Therefore, we follow Kotlikoff *et al.*, (2007) and use an alternative approach of accounting for technical progress by assuming a time-augmenting technological change.

Current after tax profit comprises revenue from the sale of output, minus the costs of capital formation and the cost of labour inputs, where τ^f denotes the effective corporation tax rate on current profits and labour costs include the mandatory superannuation contribution at rate ν on gross labour payments (discussed further below). Capital accumulation occurs when gross investment, I_t, exceeds depreciation of the existing capital stock at rate δ and the firm incurs adjustment costs associated with investment of $C(I_t, K_t)$. These adjustment cost are assumed to be quadratic in gross investment, I_t.

Given an initial capital stock, the solution to the firm's profit maximization problem determines effective labour demand, capital stock and gross investment (L_t, K_t, I_t) at each time period t, given the time profile for wage rate, w_t, and the interest rate, r.

2.5 Government

The government plays three important roles in this model. First, the government sets a whole range of tax rates that impact the decisions of households and firms. Second, it plays a pivotal role in the setting of retirement policy and in the setting of the parameters of this policy, which interact with the tax system. Finally, it determines its debt management policy.

We begin with the retirement policy settings. In Australia, the main retirement vehicles for individuals are superannuation, the age pension, and private savings.

Mandatory retirement savings. The Australian pre-funded private pension scheme, which is stipulated by the government, is called the Superannuation Guarantee. It mandates employers to make contributions into employees' superannuation accounts. Accordingly, the representative producer in our model is required to pay these contributions for working households at the after-tax contribution rate, $(1-\tau^s)\,\nu$, from their gross labour income, $w_t L^i_{j,t}$, into the superannuation fund, where ν is the mandatory contribution rate and τ^s denotes the contribution tax rate. The contributions are added to superannuation assets, $\widehat{s}^i_{j,t}$, which earn investment income at the after-tax interest rate, $(1-\tau^r)\,r$, where τ^r is the tax rate on earnings within the superannuation account. Superannuation asset accumulation can be expressed as

$$\widehat{s}^i_{j,t} = [1+(1-\tau^r)\,r]\,\widehat{s}^i_{j-1,t-1} + [(1-\tau^s)\,\nu]\,w_t L^i_{j,t}, \qquad 21 \le j \le J_S,\ \widehat{s}^i_{20,t} = 0, \tag{6}$$

where J_S denotes the eligible age from which agents can assess to their superannuation accounts. The stock of superannuation assets accumulates in the fund until age J_S, when the accumulation ceases and households are assumed to receive their accumulated balances as lump-sum payouts. We further assume that working households aged $j > J_S$ immediately withdraw mandatory contributions into their private assets accounts. Accordingly, superannuation payouts may be expressed as

$$s^i_{j,t} = \begin{cases} 0 & j < J_S \\ \widehat{s}^i_{J_S,t} & j = J_S \\ (1-\tau^s)\,\nu w_t L^i_{j,t} & j > J_S. \end{cases} \tag{7}$$

Means-tested public pension. The Australian public pension system has some distinctive features: (*i*) the age pension is means-tested and so not every retiree receives it; (*ii*) the age pension payments form part of government budget expenditure, so there is no social security tax to collect revenue from the current working population. That is, the age pension is non-contributory, funded through general tax revenues and means tested.

The government pays the age pension to eligible households from the eligibility age, J_P, with the amount of pension benefits being subject to the income means test. The age pension benefit, $p^i_{j,t}$, is given by

$$p^i_{j,t} = \begin{cases} \max\left\{\min\left\{p^{\max}, p^{\max} - \theta\left(\widehat{y}^i_{j,t} - \underline{y}\right)\right\}, 0\right\}, & j \ge J_P, \\ 0 & \text{otherwise,} \end{cases} \tag{8}$$

where $p^{\max}$ is the legislated maximum pension paid to pensioners with the assessable income, $\widehat{y}^i_{j,t}$, not greater than the income free threshold, $\underline{y}$. For pensioners with $\widehat{y}^i_{j,t} > \underline{y}$, the pension payment is reduced at the income taper rate, θ, for every dollar of the assessable income above the threshold, becoming zero for those with $\widehat{y}^i_{j,t} \geq \underline{y} + p^{\max}/\theta$. The assessable income includes interest income and half of labour earnings.

Tax revenues. The government total tax revenue, T_t, consists of tax revenues from taxing household taxable income, T^Y_t, and consumption, T^C_t, payroll, T^L_t, superannuation, T^S_t, and from imposing corporate taxes, T^F_t. Specifically, these government tax revenues are given by

$$\begin{aligned}
T^Y_t &= \sum_{i \in I} \mu^i \sum_{j=21}^{100} t(y^i_{j,t}) N_{j,t}, \\
T^C_t &= \sum_{i \in I} \mu^i \sum_{j=21}^{100} \tau^c c^i_{j,t} N_{j,t}, \\
T^L_t &= \sum_{i \in I} \mu^i \sum_{j=21}^{100} \tau^l w_t L^i_{j,t} N_{j,t}, \\
T^S_t &= \sum_{i \in I} \mu^i \sum_{j=21}^{100} \left[\tau^s \nu \cdot w_t L^i_{j,t} + \tau^r r \widehat{s}^i_{j-1,t-1} \right] N_{j,t}, \\
T^F_t &= \tau^f (Y_t - \delta q_t K_t - (1+\nu) w_t L_t). \qquad (9)
\end{aligned}$$

While the tax rates $(\tau^c, \tau^l, \tau^s, \tau^r, \tau^f)$ are constant (linear), the income tax schedule denoted by $t(y^i_{j,t})$ is a nonlinear and progressive function of taxable income consisting of labour earnings net of the payroll tax, investment income and the age pension.

Fiscal policy. The government collects consumption and income (progressive income, superannuation and payroll) taxes from individuals and corporate taxes from firms, T_t, in order to finance government final consumption expenditures, G_t, interest and principal payments on its debt, $(1+r)\, D_t$, and government transfer payments to households, TR_t.[6] The government also

[6] All items of government expenditure and transfers are detailed in Section 3.

issues new debt, D_{t+1}, to finance fiscal deficits. The government budget constraint is given by

$$D_{t+1} + T_t = G_t + (1+r)\, D_t + TR_t. \tag{10}$$

2.6 Foreign sector

We employ a small open economy specification as this description fits best the Australian economy. Hence, the domestic interest rate is exogenous and equal to the world interest rate, $r = r^w$. When domestic savings fall short of the value of domestic capital, foreign capital will be employed, which adds to foreign debt. Denoting the net foreign debt as D_t^F at the beginning of period t, the international budget constraint can be expressed as

$$D_{t+1}^F = (1+r)D_t^F - X_t, \tag{11}$$

which shows that foreign debt in period $t+1$ comprises the debt in period t plus interest payments on net foreign debt, rD_t^F, minus the net trade balance, X_t.

2.7 Competitive equilibrium

Given government policy settings for the taxation and pension systems, the demographic structure and the world interest rate, a steady state competitive equilibrium is such that

(a) households make optimal consumption and leisure decisions by solving the utility maximization problem in (1) - (3);

(b) the representative firm chooses labour and capital inputs to solve the profit maximization problem in (5);

(c) the government budget constraint (10) is satisfied;

(d) the labour, capital and goods markets clear

$$\begin{aligned} L_t &= \sum_{i \in I} \mu^i \sum_{j \in J} e^i_j (h_{j,t} - l^i_{j,t}) N_{j,t}, \\ q_t K_t &= \sum_{i \in I} \mu^i \sum_{j \in J} \left(a^i_{j-1,t-1} + \widehat{s}^i_{j-1,t-1} \right) N_{j,t} - D_t - D^F_t, \\ Y_t &= \sum_{i \in I} \mu^i \sum_{j \in J} c^i_{j,t} N_{j,t} + I_t + G_t + X_t, \end{aligned} \tag{12}$$

where q_t is the price of capital, μ^i gives intra-generational shares and $N_{j,t}$ is the size of cohort age j at time t;

(e) the skill-specific bequest transfer is equal to the total amount of assets within each skill type left by the deceased agents, $b^i_t = \sum_{j \in J} d_{j,t} \left(a^i_{j,t} + \widehat{s}^i_{j,t} \right) \phi_{j,t}$, where the term $d_{j,t}$ denotes the age-specific mortality rates and $\phi_{j,t}$ denotes the cohort shares.

3 Calibration

Our benchmark economy is calibrated to target key Australian macroeconomic data averaged over the 5 year period ending in June 2012. Accordingly, the year 2012 is assumed to be the base year for our economic calculations. While some model parameters are calibrated, other parameters are either taken from related literature or match actual policy settings in 2012.

3.1 Demographics

The population dynamics in our model are driven by the sex-specific and age-dependent fertility, mortality and immigration rates. Even though we do not formally distinguish between sexes, we model the influences of sex-related factors on the dynamics of population ageing. That is, we assume that a cohort of age j in time t consists of $N^m_{j,t}$ male individuals and $N^f_{j,t}$ female individuals, so the total population is $N_{j,t} = N^m_{j,t} + N^f_{j,t}$. The size of each gender-specific cohort evolves over time. In each year t, the number of persons of gender g ($g = m, f$) at age j, $N^g_{j,t}$, is recursively given by

$$N^g_{j,t} = \begin{cases} \left(1 - d^g_{j,t}\right) N^g_{j-1,t-1} + M^g_{j,t}, & \text{for } j > 0, \\ \omega^g \sum_{j=15}^{49} N^f_{j,t}\Gamma_{j,t}, & \text{for } j = 0, \end{cases} \tag{13}$$

where the term $\left(1 - d^g_{j,t}\right) N^g_{j-1,t-1}$ denotes the last year's survivors, $d^g_{j,t}$ is the sex-specific mortality rate and $M^g_{j,t}$ denotes the number of net immigrants at age j in year t. The number of newborn males and females, $N^g_{0,t}$, is a function of age-specific fertility rates $\Gamma_{j,t}$ of females aged between 15 and 49 years in year t, with the terms ω^m and ω^f defining the birth shares of male and female newborns.[7]

The assumptions for the three age-specific demographic rates are taken from the Productivity Commission's (2013) medium population projection scenario. Figure 1 shows these age-specific rates in 2012 (actual rates) and in a future year from which the given vital rates are assumed to remain constant. The Productivity Commission (2013) further assumes (*i*) the total fertility rate (sum of the age-specific fertility rates, $\Gamma_{j,t}$) to decrease from 1.89 in 2012 to 1.85 babies per woman by 2027; (*ii*) annual net immigration (sum of age-specific net immigration, $M_{j,t}$) to decline from 236,700 people in 2012 to 180,000 people by 2018; and (*iii*) the constant decline in mortality rates to generate life expectancy at birth that increases from 80 years in 2012 to 89.1 years by 2060 for males and from 84 years in 2012 to 91.4 years by 2060 for females. These demographic factors generate an annual population growth rate n_t and an old-age dependency ratio in the model. A summary of the main aspects of the population in the base year and over the projection period is provided in Table 4, which is presented and discussed in Section 4.

Insert Figure 1 here.

Since our economic framework does not distinguish between sexes, we use average mortality

[7] This description of the population dynamics is based on Fehr and Habermann (2006). Similarly to Kotlikoff *et al.* (2007) and Fehr and Habermann (2006), our economic model does not distinguish between immigrants and the native population on the household side, meaning that the assumed economic behaviour of immigrants is the same as that of the native-born households.

rates between males and females in the utility function to determine effective rates of discount and also to calculate accidental bequests. The intra-generational cohorts shares, μ^i, are set to 0.2 for each skill or income type, based on the quintiles used by ABS (2012a).

3.2 Endowments

Households are endowed with an efficiency or earnings ability profile that is age- and skill-dependent. We consider five skill or income types of households (i.e., the lowest, second, third, fourth and highest quintiles). The earnings ability (productivity) profiles are constructed using the econometrically estimated lifetime wage function for males and females with 12 years of schooling taken from Reilly *et al.* (2005). In particular, the earnings ability profile for the third quintile is taken from Reilly *et al.* (2005) and is adjusted for technical progress in the same way as in Kotlikoff *et al.* (2007) and adjusted by income distribution shift parameters for other quintiles. The resulting growth-adjusted earnings ability profile for an individual of age j in skill quintile i takes the form

$$e_j^i = \lambda^i \left(1+g\right)^{21-j} \exp(\alpha_0 + \alpha_1 E_j + \alpha_2 E_j^2), \tag{14}$$

where parameters $\alpha_0 = 2.235$, $\alpha_1 = 0.036$ and $\alpha_2 = -0.00063$ are taken from Reilly *et al.* as averaged estimates for males and females with 12 education years, E_j represents years of potential experience ($j - 5 -$ Education years), the term $g = 0.015$ denotes the rate of technical progress and λ^i is a shift parameter for each quintile i calibrated to approximately replicate the private income distribution in Australia using ABS (2012a) data. These shift parameters are set to 0.26 for the lowest quintile, 0.55 for the second quintile, 1.0 for the third quintile, 1.52 for the fourth quintile and 2.63 for the highest quintile. The profile is normalized to unity at the entry age of 21. In addition, earnings ability after age 65 is assumed to decline at a constant rate, reaching zero at age 90 for each skill type, as Reilly *et al.* consider only workers aged $15 - 65$.

These labour productivity profiles are exogenous and unchanged over the transition path.

3.3 Preferences

The assumed atemporal utility function takes the constant elasticity of substitution (CES) form

$$u(c,l) = \left[c^{(1-1/\rho)} + \alpha l^{(1-1/\rho)}\right]^{1/(1-1/\rho)}, \tag{15}$$

where the intra-temporal elasticity of substitution, ρ, is set to 0.9 and the value for the leisure distribution parameter, α, is 1.5, as in Auerbach and Kotlikoff (1987). The remaining parameters in the lifetime utility (1) are the inter-temporal elasticity of substitution, $\gamma = 0.4$, and the subjective discount factor, $\beta = 0.99$, whose value is set to generate the capital output ratio $\frac{K}{Y}$ of 3 (ABS, 2012b). These parameter values for preferences are reported in the first block of Table 1, which also contains the values of various other parameters discussed below.

Insert Table 1 here.

3.4 Technology

The technology is described by the CES production function

$$AF(K_t, L_t) = A\left[\varepsilon K_t^{(1-1/\sigma)} + (1-\varepsilon)L_t^{(1-1/\sigma)}\right]^{[1/(1-1/\sigma)]}, \tag{16}$$

where the technology constant, $A = 0.893$, is calibrated to reproduce the market wage rate, w, which is normalized to one in 2012. The elasticity of substitution in production, $\sigma = 0.896$, and the capital intensity parameter, $\varepsilon = 0.45$, are calibrated via the producer's first order conditions to match the interest rate and national account data for factor shares. Following Fehr *et al.*

(2008), the adjustment cost function is assumed to be quadratic in net investment and given by

$$C(I_t, K_t) = 0.5\psi I_t^2/K_t, \tag{17}$$

with the adjustment cost parameter, $\psi = 2.168$, calibrated such that the adjustment costs account for about 10 percent of investment in 2012. The capital stock depreciates at rate $\delta = 0.06$, which is set to target the investment rate $\frac{I}{K}$ of 0.09 (ABS, 2012b). The rate of technological progress, g, is set at 1.5 percent per year based data from the Productivity Commission (2013).[8]

3.5 Government

Age-specific government expenditures. The average age-specific public expenditures on health care, κ_j^h, aged care, κ_j^a, education, κ_j^e, and family benefits, FB_j, which are exogenous in our model, are plotted in Figure 2. The figure shows that education expenditures are concentrated at ages below 20, that family benefits apply in middle ages and that health and aged care expenditures rise rapidly at older ages as expected. The age-profiles of public health care, aged care and education expenditures are taken from Productivity Commission (2013), while the age-profile of family benefits is derived from the 2010 HILDA survey. Family benefits are further disaggregated so that they differ across the five household types with more family benefits allocated to low income types. The family benefit for a household of age j in quintile i being $f_j^i = \eta^i FB_j$, where η^i is the quintile-specific redistribution parameter.[9]

Insert Figure 2 here.

Government consumption. Final government consumption, G_t, consists of expenditures on education, health care, aged care and government purchases of other goods and services.

[8] The chosen values for production function parameters result in a steady state q-value (i.e., the price of capital) of 1.15, which is very close to an equilibrium q-value of 1.13 found in the empirical study by Oliner *et al.* (1995).

[9] The values of η^i are based on ABS (2012a) that also provides the share of social welfare in gross income for each quintile. These shares (η^i) are 0.44 for the lowest quintile, 0.3 for the second quintile, 0.15 for the third quintile, 0.06 for the fourth quintile and zero for the top quintile.

Government purchases of goods and services that are non-age related are denoted as $\overline{G}_t$. The government's final consumption expenditures can be expressed as

$$G_t = \overline{G}_t + \sum_{j=0}^{20} \kappa_j^e N_{j,t} + \sum_{j=0}^{100} \kappa_j^h N_{j,t} + \sum_{j=65}^{100} \kappa_j^a N_{j,t}. \tag{18}$$

We assume that non-age related expenditures, $\overline{G}_t$, are held fixed per capita with an adjustment for annual technological change. The average age-specific expenditures on education, health care and aged care are also held fixed over time with the same adjustment for technological change.

Government transfers. There are two government transfer programs: age pension payments and family benefits. The age pension expenditures are endogenously determined for households aged 65 and older. The values for the age pension parameters (i.e., the maximum pension rate, $p^{\max}$, the income threshold, $\underline{y}$, and the income taper rate, θ) match the actual values in 2012 and are shown in the third block of Table 1. The age, skill and time specific family benefits, $f_{j,t}^i$, are assumed to be exogenous and received by households between ages 21 and 60 years as discussed further above.[10] The total transfer payments are

$$TR_t = \sum_{i \in I} \mu^i \sum_{j=65}^{100} p_{j,t}^i N_{j,t} + \sum_{i \in I} \mu^i \sum_{j=21}^{60} f_{j,t}^i N_{j,t}. \tag{19}$$

Tax rates. The tax rates and transfer payments that appear in the model are effective tax rates and transfer payments facing the households and firms. These effective rates are the products of statutory rates and corresponding adjustment parameters, which are calibrated to ensure that the model solutions for tax payments and expenditures match the ABS (2013a, 2013b) data. The values of these calibrated parameters together with the calibration targets are reported in Table 2, while the statutory rates appear in the middle block of Table 1.

Insert Table 2 here.

[10] We assume that the aggregate spending on family benefits also depends on the changes in the ratio of children (0-20) to adults (21-60) that is set to one in 2012.

To explain the role of the adjustment parameters further, the effective consumption tax rate in the household budget constraint (2) is given by $\tau^c = \underline{\tau}^c * f^c$ and equals 14.6 percent, generating the tax revenue that includes not only the GST revenue due to the statutory GST rate of $\underline{\tau}^c = 0.1$ but also receipts from other indirect taxes. The estimated progressive income tax function, $\underline{t}(y_j^i)$ is scaled down by $f^t = 0.83$, as the model does not account for any tax offsets available mainly for lower income earners. Given the superannuation adjustment parameter of $f^s = 0.58$, the effective superannuation tax rates (τ^s and τ^r) are lower than the statutory ones ($\underline{\tau}^s$ and $\underline{\tau}^r$) as the superannuation guarantee system is fully mature in our model, whereas it has yet to achieve full maturity in Australia. In Australia, the payroll taxes are collected by state governments only from businesses with payroll exceeding a threshold. The tax rates and thresholds differ across the states. The model abstracts from any threshold and assumes the payroll tax to be imposed on household's labour income at the effective rate of $\tau^l = 0.024$. This effective rate is given by the statutory rate of $\underline{\tau}^l = 0.0545$ in the state of New South Wales and the calibrated adjustment parameter of $f^l = 0.44$ to match the observed payroll tax revenue to GDP ratio. The pension benefits in the household's budget constraint (2) are given by $p_j^i = \underline{p}_j^i * f^p$, with $f^p = 0.95$ reflecting the use of the maximum pension for single pensioners in the model (whereas a lower pension is paid to many couples in Australia).

Income taxes are imposed on taxable income consisting of labour earnings net of the payroll tax, investment income and the age pension. The tax schedule is progressive and we use a differentiable approximation function of the 2010-11 Australian personal income tax schedule in the model.[11]

Government debt and deficit. The consolidated Australian government budget was in a deficit of about 3 percent of GDP in 2012 and net government debt was 10.6 percent of GDP in the same year. We calibrate the model to target the debt to GDP ratio $\frac{D}{GDP} = 0.106$ and

[11] The approximated income tax function used in the model is very similar to the actual personal income tax schedule. The function, the estimation procedure and the comparison with the actual income tax schedule are available from the authors.

let non-age related government expenditures in 2012, $\overline{G}_{2012}$, adjust endogenously to balance the government budget in (10). The steady state ratio of the government deficit to GDP then can be derived from (10) as $\frac{D}{GDP}(n+g+gn)$. Over the transition path, net government debt, D_t, is held fixed per capita with an adjustment for annual technological change.

3.6 Foreign sector

The small open economy framework implies that the domestic interest rate is exogenous and equal to the world interest rate. The world interest rate, r^w, is assumed to be 5 percent. We also set the equilibrium condition for the capital market such that 81 percent of the domestic capital stock comes from household savings, with the remaining 19 percent funded through net foreign debt. This reflects the net foreign ownership of about 19 percent of Australia's capital stock (i.e., $\frac{D^F}{K} = 0.19$), averaged over five years ending in June 2012 (ABS, 2012b). The steady state current account deficit and trade balance then can be derived from (11) as $CAD = (n+g+gn)D^F$ and $X = (r-(n+g+ng))D^F$. Over the transition path, net foreign debt is calculated from the capital market equilibrium condition in (12) and the trade balance is derived from the international budget constraint (11).

3.7 Benchmark solution and performance

The benchmark solution, which is the platform from which our policy simulations are developed, is obtained by numerically solving the model for an artificial steady state for the year 2012 (as in Fehr, 2000). We use the values of the model parameters, the policy settings and the demographic structure specified earlier to numerically solve the model for this artificial steady state, in order to calibrate the benchmark economy to obtain initial asset holdings for each age cohort and skill type in 2012. Our algorithm for the solution of the model applies the iterative Gauss–Seidel computational method (Auerbach and Kotlikoff, 1987, p.47), which involves choosing initial values for some endogenous variables and then updating them by iterating between the production, household and government sectors until convergence. A more detailed description of the computational technique and the software used to solve for steady states and the transition paths is provided in Appendix A.

To facilitate understanding of the working of the model, various aspects of the benchmark steady state solution are presented in Table 3 and Figure 3 below. First, the life cycle profiles for labour supply, labour earnings and age pension payments for three of the five skill types – the lowest, third and highest income quintiles – are depicted in Figure 3. Both the labour supply and earnings age profiles for each income quintile exhibit the standard hump shapes, rising at early ages with increasing labour productivity and then declining with age. As shown in Figure 3c, the lowest quintile gets the full (maximum) pension from age 65 onwards, while the third quintile receives a part age pension at early age pension ages and households in the highest quintile do not receive any pension until age 78 due to the means test. Importantly, the depicted model-generated age profile averaged across the five income groups reasonably approximate average cross-sectional data derived from the 2010 HILDA data set based on a survey of Australian households (Wooden *et al.*, 2002).[12]

Insert Figure 3 here.

Second, the benchmark solution for key macroeconomic ratios and household net income variables is presented in Table 3, which also provides a comparison with Australian data taken from ABS (2012b, 2013c) and reported as averages over the five-year period of 2008-12. As shown, the distribution of net income and the Gini coefficient measured in net income closely match the ABS (2013c) data. Similarly, the results for the components of aggregate demand reveal that the model replicates the Australian economy fairly well, apart from the trade balance.[13] The

[12] Our model abstracts from bequest motives, thus requiring households to completely exhaust their savings if they survive until the assumed maximum age of 100 years. Hence, the model underestimates average asset holdings at older ages.

[13] In this respect, it is noteworthy that each of the model generated tax revenues and government expenditures match exactly the actual data expressed as a percentage of GDP.

positive trade balance generated by the model in 2012 is due to the targeted negative foreign assets (i.e., positive foreign debt) and our assumption of dynamic efficiency with $r > n + g + ng$. The reason for calibrating the model to target net foreign asset is that it is clearly negative in the data, while the Australian trade balance has sometimes been positive during the last decade.

Insert Table 3 here.

4 Quantifying the effects of demographic transition

The fiscal costs of demographic transition are now examined using the model specified in Section 2, fitted with demographic projections described below. We first present key population statistics of the baseline demographic transition and then discuss the implications of this demographic transition for the main macroeconomic and fiscal aggregates.

4.1 Demographic projections

We generate demographic projections for the Australian population in the following way. The starting point of our population projections is the age structure of the Australian population (i.e., actual cohort sizes) in 2012. We then use the future fertility, survival and net immigration rates assumed in the Productivity Commission's (2013) medium population projection scenario, as detailed in Section 3 above, to generate the future cohort sizes and cohort shares in the total population over the next 300 years.[14]

The key population statistics for this demographic transition path are provided in Table 4, which shows that by 2050 *a*) the total population increases to over 35 million, *b*) the old-age dependency ratio exceeds 37 percent, and *c*) the total dependency ratio (that includes the youth dependency ratio) increases above 65 percent. Furthermore, the proportion of 65+ year holds in

[14] The transition period spans the future until 2300. In addition to the demographic projection period from 2013 to 2100 for which the results are presented, there is the adjustment period from 2101 to 2200 to reach a stable population and an additional 100 year period from 2201 to 2300 for the model reach a final steady state.

the population will increase from 14 percent in 2012 to over 22 percent in 2050, demonstrating an ageing trend in Australia's population, and beyond.

Insert Table 4 here.

We simulate our model using the baseline calibrated parameter values and the baseline demographic transition. We keep all policy variables unchanged as in the baseline model, except for non-age related expenditures. That is, the government budget is balanced each year by adjustments in non-age related expenditures. Note that households in our framework are not affected by this government budget balance assumption. This assumption allows us to eliminate fiscal distortions caused by adjusting taxes. The required cuts in these non-age related expenditures to finance expected increases in age-related government spending will give us a measure of the fiscal cost of the future changes in the population structure in Australia.

We quantify the implications for key macroeconomic aggregates and for the budgetary situation of the government. These aggregate effects are driven to a large extent directly by the demographic changes (i.e., future changes in the age structure of the population briefly described above), but also to some extent by behavioural responses of households to these demographic changes. We report both transitional and long-run results, but since it takes several hundred years to reach a new steady state in our model, we focus more on the effects along the transition path up to 2100.

4.2 Macroeconomic effects

The simulation results of the baseline demographic transition for the key macroeconomic variables are provided in Table 5. The effects are reported as percentage changes in the selected de-trended per capita variables relative to their benchmark values in 2012.

Insert Table 5 here.

Starting with the effects on labour supply, our results show an initial increase in per capita labour of 4.36 percent by 2015, as the working population work longer hours to respond to unanticipated improvements in mortality rates and longevity. However, in the medium and long terms, direct demographic effects with smaller shares of the working-age population cause per capita labour supply to decline 6.51 percent by 2050 and 10.77 percent by 2100. The labour supply effects are negatively correlated with the implications for the wage rate, which is somewhat higher for most of the transition path, due to capital deepening. The effects on the wage rate are small in our open economy framework with the exogenous interest rate.

The effects on domestic total assets are significantly positive. Table 5 shows that domestic total assets are 38.6 percent higher in 2050 and almost 42 percent in 2100 relative to the base year of our calculations in 2012. Both the direct demographic effects with an increasing proportion of the elderly holding large assets and indirect behavioural effects with increased lifecycle savings are behind these aggregate increases in domestic assets.[15] In contrast, the domestic capital stock decreases over the transition (due predominantly to reduced per capita labour supply, which to a large extent determines the implications for other production variables), implying that the increase in domestic assets is used to reduce net foreign debt. As found in related literature (Fehr *et al.*, 2008), we observe declining asset prices as the population ages. The effects on average consumption are mostly positive, with per capita consumption increasing by 1.02 percent in 2050 relative to its 2012 value. However, the increases in per capita consumption (the largest expenditure on GDP) are not large enough to prevent the economy from contracting, with a decrease of 5.96 percent in de-trended GDP per capita by 2050. The implications for national product or GNP, which includes interest payments on foreign debt, are positive compared to GDP because of large decreases in foreign debt.[16]

[15] The effects of population ageing on domestic assets or wealth resulting from the simulations by Kotlikoff *et al.* (2007) for the US and Fehr *et al.* (2008) for Europe and Japan are much smaller or even negative. The key difference is the presence of distortive payroll taxes, which are high in these countries and need to be increased further to finance growing old-age related government spending programs. Our model includes a payroll tax rate, which only collects 5 percent of the total tax revenues and is unchanged over the transition (as the other tax rates).

[16] Our interest is in the effects of population ageing on per capita variables. All aggregate variables in absolute level increase significantly over the transition path due to high net immigration resulting in a growing total

4.3 Fiscal effects

Table 6 reports the fiscal implications of the baseline demographic transition as percentage changes in government tax revenues and expenditures (all measured in per capita terms and de-trended) relative to their benchmark values in 2012. The results for the government revenues show an increase of 2.79 percent in the total tax revenues by 2050. More interestingly, the projected demographic changes lead to a structural change in tax revenues, with a shift in the tax base from labour earnings to asset incomes and consumption. Hence, the tax revenue from payroll taxes declines significantly, while consumption tax revenue increases during the demographic transition.

Insert Table 6 here.

On the expenditure side of the government budget, old-age expenditures are shown to increase significantly due to a growing proportion of older cohorts in the population, causing the overall age-related spending to increase to almost 22 percent of GDP by 2050 (from 17.4 percent of GDP in 2012). In particular, our results (that only account for the effects of the changes in demographic factors) indicate that the increases in health care, aged care and pension expenditures in 2050, relative to 2012, are 27.3, 111.85 and 37.32 percent, respectively.

Insert Figure 4 here.

Figure 4 depicts government expenditures expressed in percent of GDP, the other expenditures decrease by around 2 percentage points of GDP to 5.5 percent of GDP in 2050 and by additional 2 percentage points of GDP to 3.56 percent of GDP in 2100. In other words, the other (non-age related) government expenditure needing to decline significantly by 29.36 percent by 2050 and by almost 56 percent by 2100 to close the fiscal gap. These required cuts give us a rough measure of the fiscal cost due to the ageing demographic structure in Australia. This finding indicates significant fiscal challenge Australia faces by the mid of 21st century.

population.

5 Quantifying the effects of fiscal reforms

So far we have assumed that non-age related expenditure adjusts to clear the government budget. Under this assumption, households are not affected by the government budget balance rule. This simplified assumption allows us to eliminate fiscal distortions due to the adjustment of taxes or transfers to get a clean estimate of the age-related fiscal cost. We now relax that assumption by allowing the government to use other fiscal options to finance some or all of the fiscal costs of population ageing that we have documented. In our benchmark policy experiments, we consider two fiscal reform options: (*i*) pension cuts and (*ii*) tax hikes. The main objective is to quantify the consequences of each of these reforms for the economy and for the welfare of households.

5.1 Pension cuts

We start with an experiment in which the government implements several changes in the age pension policy settings to cut pension benefits and thus to limit future growth in overall pension expenditures. In a means-tested pension system, there are three policy variables that the government can adjust to reduce the pension benefit payments: (*i*) increase the pension access age, (*ii*) decrease the level of maximum pension benefits and (*iii*) increase the taper rate of the pension means test.

In our experiment, we implement the following changes. First, the government gradually increases the age pension access age from 65 years to 66 years in 2018 for cohorts aged between 59 and 55 years in 2012, and to 67 years in 2023 for generations aged 54 years and younger in 2012. Second, the government announces cuts to the maximum pension in 2018 by 5 percent and by an additional 5 percent in 2023. Third, the government raises the income taper rate from the current rate of 0.5 to 0.625 in 2018, with a further increase to 0.75 in 2023.[17] Finally,

[17] We assume that the government implements each policy change gradually over the period 2012 to 2023. Gradual policy changes are politically palatable and our assumed changes closely follow Australia's 2010 legislated increase in the pension access age over the period up until 2023.

since cutting pension benefits is not sufficient to cover the increased fiscal cost of all aged related expenditures, we let non-age related government expenditure adjust to balance the government budget.

We first discuss the macroeconomic and welfare effects of the aggregate pension cut, containing all three aforementioned changes to the current pension policy rules. We then examine the effects of each of the separate components of the assumed aggregate pension cut.

Aggregate pension cut. The macroeconomic implications of all three pension policy changes (labeled as the aggregate pension cut) in Table 7 are reported as percentage changes in the main per capita variables relative to the effects obtained from the baseline demographic transition. The displayed improvements in other (non-age related) expenditures give the reduction in the fiscal gap (or costs). As a result of the aggregate pension cut, non-age related expenditures increase 31.9 percent by 2050 and over 58.9 percent by 2100 relative to the baseline demographic solution. However, these budget-equilibrating expenditures are still significantly lower along the demographic transition path than they were in the base year of 2012. Furthermore, the reduced age pension expenditures (over 33 percent by 2050) contribute only a 6.39 percent decrease in overall age-related government expenditures. Hence, the cuts in age pension payments alone cannot fully eliminate the fiscal costs of population ageing, which are driven to a large extent by projected increases in other old-age related public spending such as on health and aged care programs.

Insert Table 7 here.

The fiscal gap narrows not only because of lower age-related government spending, but also due to increased taxation revenues. It is well known that public pensions may reduce life cycle labour supply and savings as they act as substitute for private income in retirement. The simulated pension cuts provide an incentive for households to work and save more over the lifecycle. Table 7 shows an increase in per capita labour supply and domestic total assets by

2050 of 1.61 percent and 7.27 percent, respectively. As households work longer hours and save more, their labour earnings and investment income increase thus generating higher revenues from progressive income and payroll taxes.

The pension cuts also have positive effects on GDP per capita, driven by higher labour supply. The effects on per capita consumption, however, are negative and more significant in the short run as consumption of some older households with reduced pension benefits declines.

The distributional (both inter- and intra-generational) welfare effects of the aggregate pension cut are displayed in Figure 5. The effects are depicted for income quintiles and average welfare as a function of each generation's age at the time of the pension reform announcement in 2012.[18] Following Auerbach and Kotlikoff (1987, p.87), the calculation of welfare effects is based on the concept of the standard equivalent variation, which, for a particular generation, measures the percentage change in consumption needed in the benchmark scenario (i.e., baseline demographic transition) to produce a similar utility level under the policy change (i.e., baseline demographic transition with the aggregate pension cut).

Insert Figure 5 here.

The inter-generational effects on average welfare across the income quintiles depicted by the dotted line in Figure 4 indicate that generations between 40 and 80 years of ages in 2012 experience particularly large welfare losses.[19] The losses for these generations are caused by the cuts in their future pension payments phased in after 2018, which have negative implications for their consumption. The effects on average welfare of future adult generations (i.e., those aged 20 years and younger at the time of the reform announcement) are still negative, but the losses are significantly smaller in comparison with those attained by older and middle age cohorts.

[18] Recall that the oldest generations in our model are aged 100 years and that the youngest adult generations are aged 21 years, with all younger generations than 21 years of age assumed to enter the economic model in the succeeding years of the demographic transition (i.e., future adult generations).

[19] Our model over-estimates the welfare losses as households are assumed to derive utility only from private consumption and hence the improvements in non-age related government expenditures (i.e., public consumption) reported in Table 7 have no effect on household behaviour and welfare. Accordingly, the focus should be on relative wefare effects across generations and skill types.

Although these future generations face the same changes in the pension policy settings, they have the whole lifecycle to adjust their behaviour in terms of labour supply and savings to these policy changes.

Comparing across different skill types in Figure 5 highlights that lower income types attain significantly greater welfare losses than higher income types. For these lower income households, the age pension represents by far the main source of retirement income and, in particular, the 10 percent reduction in the maximum pension and the higher pension access age policy lead to large decreases in their life cycle consumption. As shown in Figure 5, there are two significant reductions in welfare of the lowest and second quintiles aged 59 and 54 years at the time of the reform announcement. These are the first generations affected by the higher pension ages of 66 and 67, respectively. As mentioned, future adult generations of all income types adjust their life cycle behaviour by accumulating large private savings to fund retirement consumption, thus, to a some extent, limiting the negative welfare effects of pension cuts. The welfare losses for future generations of well-off households are minimal (with the highest quintile in fact gaining in welfare in the longer term) as for them the age pension is not as important.

Components of aggregate pension cut. To deepen our understanding of the effects of pension cuts, we separately examine the effects of each of the three measures to cut pension benefits – higher pension access age, reduced maximum pension and increased taper rate. To do so, we start from the baseline model and introduce a pension cut with each of the three measures one at a time, while keep the other two measures unchanged. We compare the macroeconomic and distributional welfare effects of the three policy experiments in Table 8.

Insert Table 8 here.

Table 8 shows positive effects of each of the three pension cut measures on per capita labour supply, assets, output and overall taxation revenue, as well as reduced age pension expenditures, with an improved fiscal position for the government depicted by higher non-age related expenditures. Although the effects of each pension cut measure are qualitatively similar with the same direction of the impacts, the sizes of these effects differ to a some degree. The most effective of these policy measures in terms of reducing pension expenditures and fiscal costs is the cut to the maximum pension by 10 percent after 2023. This cut reduces age pension expenditures by 17.2 percent and increases other (budget-equilibrating) expenditures by 16.7 percent, which is more than double the increase reported for the higher access age reform in 2050. The main reason for this difference is that the reduced maximum pension is broader and affects all households. Meanwhile, the increased pension eligibility age mainly affects low income households.

Interestingly, the reduced maximum pension increases labour supply and reduces average consumption upon the policy announcement, whereas the other two pension policy changes have the most significant effects on these variables when they are actually implemented. The reduced maximum pension represents a pure negative income effect, with per capita labour supply increasing and average consumption decreasing by 1 percent and 0.92 percent in 2015, respectively. In the succeeding years of the demographic transition, households accumulate larger assets, thus effectively replacing public pensions with private income in retirement. The transitional growth in domestic assets allows for reductions in per capita labour supply and improvements in average consumption relative to the short run results. By contrast, the announcement effects of the other two pension policy changes are smaller for per capita labour supply compared to the two years (2018 and 2023) when the eligibility age and the income taper rate are actually increased.

The distributional welfare effects of each of the three cut pension measures are depicted in Figure 6. Starting with the gradual increases in the age pension eligibility age, Figure 6a shows than only the third income quintile and the two lower income quintiles aged 59 years and younger at the time of the policy announcement have their welfare affected. The welfare of all generations aged 60 years and over in 2012 is unchanged as their pensions are treated under the current pension rules with the access age at 65 years, while higher income households younger than 60 years do not qualify for any pension at early age pension ages because of the means test. However, the welfare implications for lower income households are quite negative, with two significant welfare reductions for lower income cohorts aged 59 and 54 years in 2012 - the first generations of pensioners that must wait to receive a pension at ages 66 and 67, respectively.

Insert Figure 6 here.

The reduced maximum pension measure has particularly negative effects on the welfare of lower income types approaching the current pension access age, with the largest loss of almost 2 percent in remaining welfare experienced by the lowest income households.[20] Welfare of younger and future generations improves due to increased savings and self-funding in retirement, but only future generations of the highest skill type gain in welfare.

Tightening the pension means test by lifting the income taper rate has no impact on welfare of lower income households, as demonstrated by Figure 6c. These households receive the full age pension regardless whether the taper rate is 0.5 (as in benchmark) or 0.75 (as under this reform). While the lowest income households are unaffected by this policy change, most generations of the other income quintiles attain lower welfare as the more binding income test lowers their pension benefits. The largest welfare losses due to the increased taper rate for the third and fourth income quintiles are about half of the losses attained by the lowest income quintile under the higher access age and reduced maximum pension changes.

The opposite welfare effects of pension cuts between low and high skills and between current and future generations suggests the political complexity for any pension reform proposal that favors future generations while hurting current generations. The political economy aspect of pension reforms has been discussed in Cremer and Pestieau (2000) and surveyed Galasso and Profeta (2002). Our results highlight the political economy issues by noting the policy challenge of how to devise a transition path to move from the current means-tested pension system to a

[20]Because the policy change (as for the other two pension changes) is phased in from 2018, which is six years after the policy announcement, some very old generations have their pension payments and welfare unchanged.

more sustainable pension system, while compensating for the welfare losses of current retirees and the working poor.

5.2 Tax hikes

Attention is now turned to the effects of tax hikes on mitigating the fiscal costs arising from the population ageing along the demographic transition path. We focus on two particular tax instruments: (*i*) the consumption tax and (*ii*) progressive income taxation (proportional changes in average/marginal income tax rates).[21] In these experiments, we assume that there is no change in the economy except for demographics and one tax rate that is adjusted in order to produce the same reduction in the fiscal costs of population ageing as under the aggregate pension cut.[22] This allows us to compare not only the effects between the two different tax hikes, but also their effects with those discussed above for the aggregate pension cut.

Macroeconomic effects. The macroeconomic implications of the two tax hikes are provided in Table 9 as percentage changes in the selected per capita variables relative to the effects of the baseline demographic transition (included in Tables 5 and 6). As expected, all budget-equilibrating tax policy changes require higher taxes to reduce the fiscal burden of population ageing. However, the size of increases in each tax rate varies significantly, due partly to differences in the amount of revenues collected by each tax and also to the different effects of each tax increase on the underlying tax base. Interestingly, the percentage increases in the consumption tax rate required to balance the government budget are smaller than the required increases in the average income tax rate. Although the income tax revenue is larger by almost 3 percentage points of GDP than the consumption tax revenue (as shown in Table 2 for 2012), the income tax rates are required to increase 28.10 percent by 2050, compared to a 23.93 percent increase

[21] The reason of why we focus on consumption and progressive income tax hikes is that these two taxes represent by far the main sources of the government tax revenue. Nevertheless, we also examine the effects of alternative tax hikes in payroll and capital income tax rates, which are briefly discussed at the end of this subsection.

[22] In other words, each of these tax hikes produces the same increases in other non-age related expenditures as those obtained under the aggregate pension cut and reported in Table 7.

in the consumption tax rate by that year. The reason is that the increases in progressive income taxation are more distortive for household behaviour than the consumption tax hike, thus negatively affecting life cycle labour supply and savings and so reducing the income tax base.

Insert Table 9 here.

The consumption tax hike has quite distinctive impacts on key macroeconomic variables compared to those produced by the progressive income hike. Specifically, the consumption tax hike results in positive effects on per capita labour supply, assets and output, while the required increases in progressive income taxes, which to a large extent mainly impact young and middle-age working households, have negative effects on the economy. Table 9 shows that, using the progressive tax adjustment policy, the reductions in average labour supply and domestic assets are 2.02 percent and 8.18 percent by 2050, respectively. Even the decrease in consumption per capita in 2050 is almost double the consumption reduction under the consumption tax hike. This demonstrates the highly distortive nature of progressive income taxes for household behaviour.

Welfare implications. The distributional welfare effects of the two tax hikes are plotted in Figure 7. The welfare effects of the tax changes are presented as percentage changes in the remaining utility for each income quintile of every generation relative to the remaining utility level under the baseline demographic transition.

Insert Figure 7 here.

Several interesting observations can be drawn from these results. First, the welfare losses of younger and future generations are much larger than the effects on welfare of older generations. This is particularly the case for the progressive income tax hike. In contrast, recall the large welfare losses attained by retired generations and those approaching retirement that were displayed in Figure 5 for the aggregate pension cut. Second, although the two tax hikes reduce welfare along the demographic transition path, the size of the losses for future generations differs greatly. The least distortive consumption tax hike generates smaller average welfare losses for future generations compared to those attained by these generations under the income tax hike.

Finally, the policies of taxing consumption and income through progressive taxes have opposite intra-generational welfare implications. In particular, the direct income tax hike reduces the welfare of higher income households more than the welfare of lower income types, with the largest welfare loss of 3.56 percent experienced by the highest income quintile of future generations. In contrast, the consumption tax hike produces larger welfare losses for future generations of lower income households because of the regressive nature of the flat consumption tax rate. Moreover, under the consumption tax hike the differences in the welfare effects among the five income types are much smaller in comparison with the effects resulting from the progressive income tax hike, with a 2.7 percentage point range between the minimum and maximum welfare losses for future generations.

Thus, the results imply that the effects of the two tax hikes are rather complex. There are trade-offs between macroeconomic aggregates and welfare outcomes. In addition, the welfare effects are non-linear and vary across both households and generations over time.

Alternative tax hikes. The government has a wide range of tax instruments available to mitigate the fiscal burden of population ageing. Here, we consider two additional tax policy options: payroll tax or capital income tax hikes. The former only applies to labour earnings as the tax is collected at a flat rate from labour earnings of the working population, which is different from the progressive income tax hikes applied to both labour earnings and asset incomes of the entire population. The latter introduces an extra levy that is collected at a flat rate from total assets income. These two taxes distort households differently. The payroll tax tends to affect households' incentives to work or retire, while the capital income tax levy tends to affect households' incentives to save. To keep our result comparable, the tax adjustments are constructed to produce the same reduction in the fiscal costs, measured in terms of improvements in non-age related government expenditures, as under the aggregate pension cut. The main effects of the two alternative tax hikes are now discussed, with more detailed results being presented and discussed in Appendix B.

As expected, all budget-equilibrating tax policy changes require higher taxes to reduce the fiscal burden of population ageing. However, the size of increases in each tax rate varies significantly, which is due partly to differences in the amount of revenues collected by each tax and also because of different effects of each tax increase on the underlying tax base. Specifically, the effective payroll tax rate needs to increase from 2.4 percent in 2012 to 9 percent by 2050, while a capital income levy of 14 percent in 2050 is required to generate the same reduction in fiscal costs as the aggregate pension cut. The two tax hikes have distinct macroeconomic effects. Under the payroll tax experiment (similarly to the progressive income tax hikes), effective labour supply initially increases due predominantly to increased labour supply of existing households anticipating a significantly higher payroll tax rate in near future. While this negative income/wealth effect is dominant in the short run, over the transition path and in the long run the increased payroll tax rate causes effective labour supply (and domestic assets) to decline. This implies that the substitution effect becomes a dominant force. In contrast, under the capital income tax experiment, households initially demand more leisure and consumption, with both effective labour supply and aggregate consumption shown to increase in 2015. During the transition path, the significant capital income levy (increasing to 20 percent in the long run) results in large reductions in domestic assets (by over 26 percent in the long run). Indeed, the capital levy has large impacts on wealth accumulation in the long run. This negative wealth effect leads to a higher effective labour supply with an increase by 4.47 percent.

6 Sensitivity analysis

Several analyses were undertaken to check the sensitivity of the main results to alternative assumptions of the model. The sensitivity checks include the following three alterations of the base model: (*i*) different immigration scenario; (*ii*) different productivity growth (or technological progress) scenario, and (*iii*) imperfect capital mobility with an endogenous domestic interest rate. The results are summarized in Table 10 for the demographic transition path only (without any fiscal reform) and for the demographic transition with the aggregate pension cut and consumption tax hikes.[23] The results are presented as percentage point deviations in selected macroeconomic variables under the given alternative simulation from those derived for the base model and presented in Sections 4 and 5.

Insert Table 10 here.

6.1 High immigration scenario

We first investigate to what extent increased immigration mitigates the negative macroeconomic and fiscal effects of population ageing. To do this, we consider the high immigration scenario assumed by Productivity Commission (2013) and derive new demographic projections using our demographic model. This scenario assumes a small increase in annual net immigration from $236,700$ people in 2012 to $240,000$ people by 2018.[24] The age distribution and the number of net immigrants are assumed to remain unchanged (as in 2018) over the entire demographic transition. Note that, throughout the paper, the economic behaviour of immigrants is assumed to be the same as that of native-born Australian households, which is a standard assumption (see, e.g., Kotlikoff *et al.*, 2007).

The macroeconomic results for this robustness check reported in Table 10 are similar to those presented above, with the direction of the changes unchanged. Quantitative differences, due mainly to demographic change only (comparable to the effects of demographic projections

[23] Detailed macroeconomic and welfare results for all the robustness checks are reported in Appendix C, which is available upon request from the authors. Here, we only discuss the main macroeconomic effects, since the welfare effects (of both the aggregate pension cut and the consumption tax hike) are very similar to those derived from the base model and reported in Section 5.

[24] The baseline demographic projections used in the previous sections assumed a gradual decline in the number of net immigrants to $180,000$ people by 2018.

with medium baseline immigration) can be summarized as follows. First, as migrants are concentrated in the $20-30$ age group, the high immigration scenario increases population shares of young and middle-age working cohorts. As a result, effective labour supply per capita increases relative to the baseline demographic transition path with medium immigration. Second, domestic assets decreases somewhat because of smaller population shares of older cohorts with large asset holdings. Third, non-age related government expenditures that measure the fiscal burden of population ageing increase due to lower spending on the elderly. However, all of these effects are relatively small, indicating that increased immigration would do little to alter the negative effects of population ageing with falling labour supply and increasing fiscal pressure.

6.2 High productivity growth

This sensitivity check assumes a higher rate of economic growth as a potential mechanism to mitigate the negative effects of population ageing. Specifically, we consider a scenario in which the economy has a higher rate of technical progress of $g = 0.02$ per year, compared to the annual technical change of $g = 0.015$ assumed in the base model.

Table 10 shows significant differences in the selected macroeconomic and fiscal variables due to the demographic transition with high and baseline rates of productivity growth. The higher assumed rate of growth generates increases in long run labour supply, consumption, tax revenues and non-age related expenditures (all de-trended and expressed in per capita terms). These effects are driven mainly by the increased productivity profile of each skill type of household, noting that effective labour supply increases directly by higher life cycle productivity (see the labour market equilibrium condition in (12)), which also causes the capital stock and output to increase. Interestingly, the stock of domestic assets is shown to decline compared to the base model. The intuition behind this result is that younger households save less due to higher expected future earnings, generating lower average domestic assets. In retirement, however, total assets are higher compared to those in the economy with $g = 0.015$, resulting in reduced age pension expenditures. Nevertheless, the non-age related expenditures increase significantly compared to those derived from the base model, due to large increases in the total tax revenues. Given the higher level of the non-age related expenditures in the economy with $g = 0.02$, the pension cut then generates smaller improvements in these expenditures, with a relative decline of 35 percentage points in the long run.

6.3 Imperfect capital mobility

The small open economy assumption is now relaxed by assuming imperfect capital mobility with a domestic interest rate different from the world interest rate. In this setting, the domestic interest rate is determined as $r = r^w + \varkappa \left(D_t^F / Y_t - \overline{D}^F / \overline{Y} \right)$, where $r^w = 0.05$ is the exogenous world interest rate, D_t^F / Y_t is the ratio of net foreign assets to GDP, and $\overline{D}^F / \overline{Y}$ is the initial steady state level. Accordingly, the domestic interest rate will fall (increase) if the ratio of net foreign debt to GDP decreases (increases). The parameter $\varkappa$ governs how the domestic interest rate responds to the changes in D_t^F / Y_t. We set $\varkappa$ to 0.02 as in Guest (2006).

We repeat our experiments and present the results in Table 10. The comparison of the demographic transitions under the two assumptions reveals declining domestic interest rates (as net foreign debt falls) under the relaxed interest rate scenario. This means a lower cost of capital, having positive effects on investment demand and the capital stock. The capital stock increases by over 20 percentage points in the long run relative to the baseline simulation with the exogenous interest rate. As a result, there are further increases in the wage rate (as shown in Appendix C, which is available upon request from the authors), which raises per capita labour supply. However, the increases in domestic assets per capita are not as large as under the baseline simulation because of the decreasing interest rate. The non-age related government expenditure is shown to increase due mainly to improved tax revenues, indicating a lower fiscal burden in the economy with an endogenous interest rate. The pension cut generates similar qualitative effects in the main macroeconomic variables, with further reductions in the domestic interest rate, increased long run capital and labour inputs relative to baseline model. However, increases in non-age related expenditure due to the aggregate pension cut are smaller than those derived from the base model because of relatively lower total assets and implied relatively higher pension expenditures.

The effects discussed in this section for the demographic transition and the pension cut would be similar to those derived in a closed economy model. In a closed model, population ageing with increased longevity (as well as pension cuts with incentives to increase self-funding in retirement) would lead to higher asset accumulations matched by an increased capital stock. The resulting capital deepening would alter factor prices (lower interest rate and higher market wage rate) in a similar way as in our imperfect capital mobility framework (e.g., see closed economy simulations of demographic change by Kulish *et al.*, 2010).

6.4 Mix of pension cuts and tax hikes

In the fiscal policy adjustments examined in Section 5, households were only partially responsible for the fiscal costs of population ageing as the government was allowed to reduce its non-age related spending to balance its budget with either pension cuts or tax hikes. We now consider experiments in which the government not only cuts the pension benefits, but also increases taxes to fully cover the fiscal costs arising from the demographic shift. More specifically, we implement the following two experiments: (*i*) the aggregate pension cut with a consumption tax hike, and (*ii*) the aggregate pension cut with a progressive income tax hike. In both experiments, the non-age related government expenditure is assumed to be unchanged at the 2012 level over the demographic transition path.

Table 11 reports the changes in macroeconomic variables between 2015 and the long run under these two fiscal reform scenarios, with population ageing and rising age-related public spending financed by the pension cuts and adjustments in either the consumption tax rate or the average income tax rate.

Insert Table 11 here.

The tax rate reported in Table 11 is either the effective consumption tax rate or the average income tax rate that maintains a balanced government budget, which is also impacted by the aggregate pension cut. The tax rate initially declines, partly due to the demographics (with increased tax revenues and reduced expenditures on education and family benefits) but largely due to pension cuts (with reduced pension expenditures). However, in the longer term the effective tax rate needs to increase to close the fiscal gap, with the average income tax rate in particular rising substantially to 25 percent by 2100.

The initial decline in either the consumption or income tax rates has positive effects on the economy, with per capita labour supply, assets and output increasing more that under the aggregate pension cut alone. For instance, the aggregate pension cut with the progressive income tax adjustments increases per capita assets by 11.7 percent by 2030, compared to 5 percent increase displayed in Table 7 for the aggregate pension cut alone. Pension cuts reduce retirement income provided by the government, inducing households to work and save more to replace lower pension benefits with higher private income in retirement. The income tax rate reductions provide further incentives to work and save. In contrast, the increases in the progressive income tax rates after 2050 negatively affect the selected macroeconomic variables. As shown in Table 11, the decrease in per capita labour supply, assets and consumption by 2100 is 1.3 percent, 4.6 percent and 7.6 percent, respectively.

Table 11 also demonstrates important differences between the two tax adjustments, with increases in consumption or income tax rates leading to opposite effects on the economy in the long run. An increase in the income tax rate directly reduces the effective wage rate (i.e., the price of leisure), generating a substitution effect and leading to lower labour supply. In contrast, an increase in the consumption tax rate leads to higher consumption expenditures, making households work more to meet these expenditures.

7 Conclusion

In this paper, we analyze the fiscal costs caused by population ageing in Australia, and study the effects of two main structural fiscal reform proposals designed to mitigate such fiscal challenges. The analysis is based on a computable dynamic general equilibrium, overlapping generations model calibrated to match the demographic developments, policy settings and macroeconomic data in Australia. Three age-related fiscal programs are identified as the main sources of fiscal instability in Australia – health care, age pension and aged care programs financed by government. The model is used to quantify the contribution of each of these programs to government expenditures in the long-run and during the transition path resulting from Australia's changing demographic structure. It is then used to quantify the macroeconomic and welfare implications of two fiscal reform options: pension cuts and tax hikes.

We find that, while the pension cut and tax hike options achieve the same fiscal goal, the macroeconomic and welfare outcomes differ significantly. Under the first policy scenario of making cuts to the age pension program, the simulations show that people receiving the pension and those approaching the pension access age experience significant welfare losses, especially households in lower income groups. We compare the effects of the aggregate pension cut to that of several options to increase taxes. Young and future generations prefer pension cuts to mitigate the fiscal pressure, because they are worse off by having to pay higher taxes over their entire life cycle. Meanwhile, the current retiring and working generations prefer no pension cuts and increases in future taxes.

The simulation results from the second policy scenario of raising tax rates suggest interesting outcomes when choosing between consumption and income tax policies. Taxing consumption or income results in opposite effects on the economy and on welfare across different income groups of households. Specifically, the required increases in consumption tax rate result in positive effects on per capita labour supply, assets and output, but reduce the welfare of lowest income households most. Conversely, the required increases in progressive income tax rates result in negative effects on output but reduce the welfare of poor households least.

These findings have important policy implications. Even though the costs of population ageing in the coming decades are inevitable, the transitional cost on aggregate economy and welfare can be minimized by the choice of fiscal policy option and the timing of policy implementation. Reforms that allow individuals to have enough time to adjust and those that minimize the fiscal distortion on labor supply stand out as the best policy options. However, none of these policy reform options is likely to gain strong political support as each policy results in welfare losses for the current retiring and working generations. The opposite welfare effects between current and future generations suggests political complexity for any structural fiscal reforms that are in favor of the future generations while hurting the current generations. Evidently, politically feasible policy responses will necessarily involve significant welfare trade-offs in the absence of compensation schemes.

The results also suggest that a gradual shift from the retirement income support scheme that relies heavily on a means-tested pension system (e.g., an unfunded public pension scheme) towards a superannuation system (e.g., a self-financed private pension scheme) may effectively help control fiscal cost of demographic transition while allowing individuals to adjust labor supply and savings for retirement. How to design a means-tested pension system to exploit interactions between these two retirement systems is an interesting issue that needs further exploration. We leave this question for our future research.

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Appendix A: Algorithm to solve the model

The GAMS software is used to solve for the steady state equilibria and the transition paths for our nonlinear model. Our algorithm applies the iterative Gauss–Seidel computational method suggested by Auerbach and Kotlikoff (1987), pp. 46-50.

Steady state. The algorithm involves choosing initial values for some endogenous variables and then updating them by iterating between the production, household and government sectors until convergence. The following steps are carried out to solve for the benchmark steady state of our small open economy model with exogenous interest rate, r.

1. Choose initial values for the accidental bequest, b, the non-age related government expenditure, $\overline{G}$, and the labour input, L.[25]

2. Given L, calculate the market clearing wage rate, w, capital stock, K, output, Y, price of capital, q, and investment, I, using the first order necessary conditions derived from the profit maximization problem (5).[26]

3. Given w and b, solve the household optimization problem in (1) for each income group, using Nonlinear Programming with Discontinuous Derivatives (DNLP) solver CONOPT, to obtain household optimal consumption, labour supply and assets profiles.

4. Given these household optimization solutions, update values of b, L and $\overline{G}$, using the bequest allocation rule, the government budget constraint and setting L equal to aggregate

[25] When we examine the tax hikes to mitigate the fiscal costs, $\overline{G}$ becomes exogenous and we adjust/endogenize the given tax rate(s) to balance the government budget in (10).

[26] The production sector includes the following five equations to solve for Y, w, q, K and I in the steady state:

$$\begin{aligned} Y &= F(K,L) - 0.5\psi I^2/K, \\ w &= F_L/(1+\nu), \\ q &= 1 + (1-\tau^f)\psi I/K, \\ rq &= (1-\tau^f) * [F_K + 0.5\psi (I/K)^2 - \delta q], \\ I &= (n+g+gn+\delta)K. \end{aligned}$$

This system of non-linear equations is numerically solved in GAMS, using Mixed Complementarity Problem (MCP) solver, PATH.

household labour supply.

5. The second through fourth steps are iterated until the solutions for b, L and $\overline{G}$ converge.

The solution of the household optimization problems is complicated by the fact that the means test for the age pension causes the budget set to be non-convex, as is well known. While the DNLP solver, CONOPT, efficiently handles inequalities such as the time (or retirement) constraint, it is not guaranteed to yield a globally optimal solution for the inter-temporal expected utility maximization problem when the budget constraint is non-convex. To deal with this potential computational issue, we undertake careful checks on the validity of our steady state solutions for the benchmark case and each of the policy settings considered in the paper. These checks involve examining the solutions for leisure, consumption and assets for each household at ages over 60 years for whom a potentially non-convex budget constraint arises. In every case, we have confirmed that the solution provided by our computer program does, in fact, constitute a global optimum for each such household.

Transition path. Computing the transition path from one steady state equilibrium to another involves the same steps. However, there is the following important difference that makes the computation of the transition path more involved than solving for the steady state. On the household side, the generations of the five income classes alive at the time the policy change is announced must be treated differently from the steady state simulation. In contrast with the steady state computation, which solves the optimization problems of just five households types, the transition path program requires the solution of household optimization problems of those households already alive in the first year of the transition (over their remaining life cycle) and of all future born generations (over their whole life cycle). At the time of the policy announcement, existing generations solve their optimization problems again but over shorter lifetimes given their ordinary private and superannuation assets accumulated prior to the policy announcement. The initial distribution of assets for these generations is obtained from the benchmark steady state simulation.

Initial steady state and demographic transition. Following Fehr (2000) and Fehr and Habermann (2006), we assume that the benchmark economy is in a steady state equilibrium. We compute this artificial steady state equilibrium to match key Australian macro data and to derive the initial distribution of assets across the generations alive in 2012 (i.e., the base year for our calculations), making use of the observed age distribution of Australia's population and age-dependent mortality rates for 2012.

Given the initial asset distribution, we then use the model that is fitted with demographic projections based on Productivity Commission's (2013) demographic assumptions to numerically solve for the transition path to a new steady state. Each transition path spans the period from 2013 to 2300 and includes: (*i*) the demographic projection period from 2013 to 2100; (*ii*) the adjustment period from 2101 to 2200 to reach a stable population by setting the number of births to be constant after 2100 (implying that the population growth rate converges to zero from 2200 onwards); and (*iii*) an additional 100 years from 2201 to 2300 for the model reach a final steady state. The long run macroeconomic results provided in the paper are those for year 2300 with zero population growth.

Appendix B: Alternative tax hikes

In this Appendix, we present and discuss the macroeconomic and welfare effects of two alternative tax hikes to mitigate the fiscal pressure due to population ageing. As briefly outlined in the paper, we consider alternative tax experiments in which the government uses either payroll tax or capital income tax hikes to balance the government budget. The payroll tax is collected at a flat rate from labour earnings of the working age population. Meanwhile, the capital income tax experiment introduces a flat rate levy on investment income generated by domestic assets.[27]

Table $B1$ summarizes the changes in macroeconomic variables between 2015 and the long run under the two fiscal reform scenarios. The tax rate reported in the table is either the effective payroll tax rate or the capital income levy that maintains a balanced government budget with the same improvements in non-age related government expenditures as under the aggregate pension cut. As expected, each tax rate is required to increase significantly to mitigate the fiscal costs measured in terms of improvements in non-age related government expenditures. In the long run, the effective payroll tax rate is 13 percent (compared to 2.6 percent rate in 2012) and the capital income tax levy is 20 percent (compared to 0 percent in 2012).

Insert Table $B1$ here.

The implications for effective labour supply, domestic assets, GDP and consumption are shown to vary greatly over time between the two alternative tax measures. Under the payroll tax experiment, effective labour supply initially increases, which is due to (*i*) an initial decline in the effective payroll tax rate to 2 percent and (*ii*) initial increased hours worked by households anticipating a significantly higher payroll tax rate in the near future. However, the required increases in the payroll tax rate during the transition generate negative effects on labour supply and domestic assets, which in the long run decline by 0.14 percent and over 11 percent, respectively. In contrast, under the capital income tax experiment, labour supply falls by 1.35 percent in 2015 and households demand not only more leisure but also more consumption, with aggregate consumption increasing by 0.96 percent in 2015. The required increases in the capital income levy during the transition result in large reductions in domestic assets that fall by over 26 percent in the long run. The resulting negative income effect then leads to higher aggregate labour supply, which increases by 4.47 percent in the long run.

[27] In Australia there is no separate capital income tax as investment income generated by asset holdings is taxed together with labour earnings under the progressive income taxation. Thus, this capital income tax or levy is set to zero in the base year of the model and is only introduced in this hypothetical fiscal policy experiment.

The distributional and average welfare effects of the investigated fiscal policy reforms for selected cohorts are depicted by Table $B2$. We first discuss the welfare effects of the two alternative tax hikes and then provide a brief comparison of the welfare effects among all the investigated fiscal reforms.

Insert Table $B2$ here.

There are several observations that one can drawn from the welfare effects of the two alternative tax hikes in Table $B2$. First, while the payroll tax hikes have no effect on older cohorts (depicted by those aged 80 years in 2012) as these households already retired from work, the capital income levy results in welfare losses for older cohorts. Specifically, the cohorts aged 80 years loose, on average, 0.11 percent of their remaining resources as a result of introducing this additional capital income tax. Second, the average welfare loss by the cohort aged 40 in 2012 is more than twice as large under the capital income tax hikes than that due to the payroll tax hikes. Third, the increased payroll tax rate generates larger welfare losses for future generations that, on average, loose 2.36 percent of initial resources compared to 1.28 percent average loss under the capital income levy. Finally, the welfare losses across all (old, young and future) generations are greater for higher income quintiles as they earn more and hold larger assets relative to lower income types.

The comparison of the welfare effects across all the investigated fiscal reforms reveals that only the pension cut reduces welfare of current generations more than future born generations. The tax hikes and particularly the income tax hikes (i.e., progressive income, payroll and capital income tax hikes) generate significant welfare losses of future generations. The payroll tax hike results in the largest average welfare loss of 2.36 percent for future generations, followed by the aggregate pension cut with 2 percent average welfare loss for the cohort aged 54 in 2012 (first cohort eligible for the pension from age 67). In terms of intra-generational (or distributional) welfare implications, the pension cut and the regressive consumption tax hike reduce the welfare of lower income types more than higher income types, whereas the opposite is true for the income tax hikes. The progressive income tax hike generates the largest welfare loss of 3.56 percent for the higher quintile of future generations, followed by 3.41 percent loss attained by the lowest quintile of the cohort aged 54 in 2012 due to the pension cut.