Health externalities to labor productivity and optimal policies with endogenous fertility, labor and longevity♠

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Abstract

We explore how health externalities to labor productivity affect efficiency and optimal policies in a lifecycle-dynastic model with endogenous fertility, labor and longevity. The health externalities decrease health spending, labor productivity, longevity, savings and labor but increase fertility from the socially optimal levels. Public health subsidies through universal public health insurance or private health subsidies through employer-based health insurance increase the marginal benefit of health spending and the marginal cost of childrearing. Taxes on income and consumption reduce the benefit of health spending and the cost of childrearing. Appropriate taxes and subsidies, such as age-specific health subsidies and age-specific labor-income taxes, can fully internalize the health externalities to achieve the social optimum. Without such taxes, private health subsidies alone cannot achieve the social optimum. Calibration results suggest a larger welfare gain of optimal policies in the US with private health subsidies for workers than in Australia with universal public health subsidies.

Keywords: Health externality, Longevity, Labor productivity, Fertility, Savings

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1. Introduction

Health is an important form of human capital for our capabilities and wellbeing in life. For workers, in particular, health is a key determinant of labor productivity. Thus, achieving good health for all is an important on-going call by the United Nations to achieve the Sustainable Development Goals. However, a major challenge to achieve good health for all is the market failure arising from health externalities (Bloom and Canning, 2003). The external costs of poor health or the external benefits of health improvements through preventive and curative health spending are massive. Empirical evidence indicates that infectious diseases lead to adverse macroeconomic effects, workplace productivity losses and mortality unrecognized by individuals (e.g., Bloom et al., 2022b; de Courville at al., 2022), while influenza vaccination effectively reduces influenza-related mortality and illness-related work absences (White, 2021; Acton et al., 2022). Empirical evidence also indicates that workers' utilization of preventive healthcare services depends positively on the share of peers at work utilizing such services (e.g., Pruckner at al., 2020). Yet, it is unclear how health externalities to labor productivity affect health spending, savings, longevity and fertility and whether social policies such as public or employer-based health insurance and taxes can internalize the health externalities.

This paper investigates the consequences of health externalities to labor productivity and the roles of public or private health subsidies and taxes in internalizing the health externalities. As shown in empirical studies, health investment or health spending improves health, labor productivity and longevity.[1] The core idea of health externalities to labor productivity in this paper is that individual workers' health is private information not perfectly observed by firms (Sauermann, 2016). With asymmetric information on health, health externalities to labor productivity occur when healthier and more productive workers improve the average productivity of labor at workplaces but firms lack the information to reward the workers.

Specifically, market failure occurs when firms benefit from having healthy workers but do not pay them the wage rate that reflects their contributions to average labor productivity at workplaces. Consequently, individual workers overlook the contributions of their health investment to average labor productivity and under-invest in their health because the perceived private return to health spending is below the social return. Under-investment in health results

[1] Empirical evidence suggests a positive effect of health spending on health outcomes (Wolfe and Gabay, 1987; Hitiris and Posnett, 1992; Cremieux et al., 1999; Or, 2000; Martin et al., 2008; and Kim and Lane, 2013) and positive effects of health spending and better health on labor productivity (Rivera and Currais, 2004; Suhrcke and Urban, 2010; and Prettner et al., 2013). See Tompa (2002) for a thorough survey on the links among health, health expenditure and labor productivity.

in low levels of average labor productivity, wage rates (time cost of childrearing), interest rates, longevity, savings and output but high fertility relative to the socially optimal levels.

It is essential to measure the efficiency consequences of the health externalities for policy implications. In many developed countries such as Australia, workers are covered by universal public health insurance financed by taxes on income and consumption, while most workers in the US are covered by employer-based health insurance (EHI).[2] It is important to ask whether the public or private health subsidies can internalize the health externalities and achieve the social optimum.

To gain insight into these questions, we develop and calibrate a lifecycle-dynastic model with two-sided intergenerational transfers[3] and endogenous fertility, labor and longevity to explore the macroeconomic impacts of health externalities to labor productivity and optimal health and tax policies, both theoretically and quantitatively. Departing from lifecycle models where health spending only extends longevity and retirement lives, health spending here has external benefits for the average health and labor productivity and private benefits for longevity and working life at old age. By incorporating two-sided intergenerational transfers along with endogenous fertility and labor, the costs of raising a child in our model consist of the time cost of childrearing (forgone earnings for time-intensive childrearing) as well as bequests and inter-vivos transfers between young and old parents.[4] These features provide several novel results that have important implications for optimal health and tax policies as summarized below.

First, we show that appropriate taxes and universal public health can internalize the health externalities to achieve the social optimum. Intuitively, young-age and old-age public health subsidies increase young-age and old-age health spending, lifetime labor supply and longevity by lowering the private cost of health spending. Old-age public health subsidies also increase parental transfers to children (the transfer cost of childrearing). The transfer cost of childrearing rises further if there are public transfers to the elderly. On the contrary, taxes on young-age and old-age labor income reduce the time cost and the transfer cost of childrearing, respectively, while consumption taxes reduce the time cost, bequest cost and transfer cost of childrearing. Capital income taxes reduce the relative price of current consumption, while savings subsidies increase the relative price of current consumption and decrease the bequest cost of childrearing. Thus, appropriate public health subsidies and taxes can fully internalize the health externalities.

[2] The EHI is popular in the US where public health only covers 35% of the population (OECD, 2016).
[3] Existing evidence finds intergenerational transfers within families (Laitner and Juster, 1996; Altonji et al., 1997).
[4] For instance, altruistic parents are willing to ease the tax burdens of public transfers to the elderly on children by giving bequests as in Zhang (1995).

Second, the EHI chosen by firms to maximize profit can substitute for public health subsidies to fully internalize the health externalities when it is accompanied by appropriate taxes, with or without public health subsidies. However, without taxes, the EHI alone cannot achieve the social optimum because taxes on income and consumption and the EHI exert opposite effects on the cost of childrearing, and thus it is necessary to combine them to attain socially optimal fertility. The EHI can also ease the financial burden of universal public healthcare. Third, health subsidies and labor income taxes should have different age-specific rates to achieve the social optimum due to the age-dependent impacts on the marginal contributions of health spending and on the costs of childrearing.[5]

For quantitative assessment, we calibrate the model to Australian and US data as two interesting case studies since both countries share similar levels of economic development but have different health systems: universal public health in Australia but the EHI for most workers aged below 65 in the US. We calibrate key parameters to match certain data moments in each country, such as longevity, the investment to output ratio, fertility, health-spending shares of output, taxes, subsidies and public transfers to the elderly. We assume the same degree of health externalities to labor productivity in both countries based on the estimated range in Bloom et al. (2022a) for 133 countries.

Our model generates some interesting quantitative results as follows. The benchmark tax and health systems in both countries have lower welfare than their laissez faire and social optimum as the welfare loss of distortionary taxes outweighs the welfare gain of health subsidies, mainly due to their high income taxes. The net welfare loss is larger in the US than in Australia as US taxes on capital and labor income are relatively high.

Since the most important source of funding public health subsidies in Australia and the US is income taxes, we also compute optimal public health subsidies financed by taxes on labor and capital income by shutting down consumption taxes and public transfers. For Australia with universal public health, the optimal public health subsidy is higher for young workers than for old workers, hence young workers should pay higher labor income taxes than old workers to achieve the social optimum. On the contrary, for the US with public health subsidies to old workers (65 or above), old workers should pay higher labor income taxes than young workers to achieve the social optimum. This means that different health systems have important implications for optimal tax policies. The optimal capital income tax should be lower than the

[5] Weinzierl (2011) argues that age-dependent taxes are useful for Pareto improvements in a model with private information for earnings ability in the absence of investment in capital and health.

benchmark rate to raise savings, especially in the US, given the relatively low investment subsidy rates. If using the benchmark consumption tax, optimal health subsidies and labor income taxes would be lower in both countries (especially the optimal old-age labor income tax) as consumption taxes reduce the childrearing costs of time, bequests and transfers.

We further compute the sensitivity of the optimal allocation and optimal policies to different degrees of the health externalities when public health subsidies are financed by income taxes. Internalizing a stronger health externality increases labor productivity or the time cost of childrearing, thus reducing fertility and consumption over output per young worker at young and old ages and raising health spending at young and old ages, longevity and savings. Hence, stronger health externalities increase optimal health subsidies and income taxes. When public health is fully replaced by the universal EHI in a counterfactual experiment, internalizing a stronger health externality increases the optimal young-age and old-age EHI coverage, optimal old-age labor income tax and optimal capital income tax but reduces the optimal young-age labor income tax. That is, the intergenerational gap of income-tax rates increases with the degree of health externalities. The age-specific labor income taxes in favor of young workers under such health reform are relevant features for policy design.

The rest of this study proceeds as follows. Section 2 reviews related studies. Section 3 introduces the model. Section 4 establishes the socially optimal allocation. Section 5 characterizes equilibrium allocations and derives the socially optimal EHI, public subsidies and taxes. Section 6 characterizes equilibrium allocations and derives the socially optimal EHI, public subsidies and taxes in steady state with specific functions. Section 7 explores quantitative implications in steady state with specific functions. Section 8 concludes the study. The Appendix contains all proofs.

2. Related literature

This paper is related to several strands of the literature. The first strand is theoretical studies on health improvements and macroeconomic outcomes. Public health enhances longevity and is beneficial for economic development (Chakraborty, 2004; Aisa and Pueyo, 2006; Bhattacharya and Qiao, 2007; and Tang and Zhang, 2007). A decline in fertility can increase health investment and effective labor supply (Prettner et al., 2013).

The second strand theoretically analyzes the effects of health externalities, the welfare effect of health policies and optimal health policies. In Davies and Kuhn (1992) and Philipson and Becker (1998), longevity externalities in pension annuity returns result in overspending on health for longer life and over-savings. In Yew and Zhang (2018) with two-sided altruism and endogenous fertility, longevity externalities in annuity returns also yield overspending on health but under-savings and excessive fertility. Fang and Gavazza (2011) show that the EHI may lead to under-investments in workers' health due to labor turnover. In Zhang et al. (2006), public health subsidies financed by labor income taxes enhance longevity and welfare but reduce savings and future output. Expanding public healthcare beyond the growth-maximizing level can be Pareto superior in an R&D-based growth model (Kuhn and Prettner, 2016). Using labor income taxes to fund public pension and health subsidies, optimal health subsidies depend negatively on public pensions (Pestieau et al., 2008).

The third strand focuses on the quantitative implication of public or employer-based health insurance. In Kelly (2020), both public and private health insurance systems improve the welfare of young households at the expense of old households. In Frankovic and Kuhn (2023), the welfare gain of public health insurance in enhancing life expectancy exceeds the welfare loss in increasing health spending. Studies on health insurance against individual health shocks have explored its effects on wage, labor, welfare and income distribution (e.g., Jeske and Kitao, 2009; Feng and Zhao, 2018; Feng and Villamil, 2022; Jung and Tran, 2022; Chen et al., 2022). For example, in Jung and Tran (2022), a consumption-tax financed expansion of public health insurance leads to smaller distortions compared to an income-tax financed expansion; and a mix of public and private health insurance results in larger welfare gains. Chen et al. (2022) find that universal public health reduces the gaps in health and life expectancy among workers with different skills and is beneficial to low-skilled workers.

However, these studies abstract from health externalities to labor productivity and often ignore two-sided intergenerational transfers, endogenous fertility or endogenous old-age labor. This paper explores the effects of health externalities to labor productivity and their implications for optimal policies, both analytically and quantitatively, in a model with two-sided intergenerational transfers, endogenous fertility and endogenous old-age labor.

3. The model

The model has an infinite number of periods. Each period has three overlapping generations: children, young parents and old parents. Children make no economic decision. The length of young parenthood equals one and that of old parenthood, $T(h_{t-1}, m_t): \mathbb{R}_+^2 \to (0,1)$, increases with health spending at young age h_{t-1} and old age m_t at diminishing rates.

3.1. Households

The wellbeing of a dynastic family increases with the consumption of the young parent c_t, the consumption of the old parent adjusted for old-age longevity $d_t T(h_{t-1}, m_t)$ and the young parent's number of children n_t at diminishing rates:

(1) $\sum_{t=0}^{\infty} \alpha^t \{\beta U(T(h_{t-1}, m_t) d_t) + \alpha[U(c_t) + \rho G(n_t)]\}$,

where $\alpha \in (0,1)$ is the subjective discount factor, $\beta \in (0,1)$ is the taste for old-age consumption and $\rho > 0$ is the taste for the number of children. Raising a child needs $v \in (0,1)$ fixed units of a young parent's time that set an upper bound on fertility, $n_t \leq 1/v$. Given the wage rate w_t, each young parent allocates one unit of time endowment to rearing children vn_t and working $1 - vn_t$, receives a bequest from the old parent $b_t > 0$, or gives a gift to the old parent $b_t < 0$. The young parent allocates resources to young-age consumption c_t, health spending h_t and savings s_t as follows:

(2) $c_t = b_t + (1 - vn_t) w_t - s_t - h_t$.

Given the gross interest rate (rental price of capital) R_t, an old parent spends the wage income $T(h_{t-1}, m_t) w_t$ and capital income $R_t s_{t-1}$ on old-age consumption and health, adjusted for old-age longevity, $(d_t + m_t) T(h_{t-1}, m_t)$, respectively, and leaves a bequest to or receives a gift from each child. Thus, the budget constraint of an old parent is

(3) $d_t T(h_{t-1}, m_t) = T(h_{t-1}, m_t) w_t + R_t s_{t-1} - m_t T(h_{t-1}, m_t) - b_t n_{t-1}$.

This model abstracts from retirement at old age for simplicity as scaling down old-age labor from longevity for retirement will not change the essence of the results.

3.2. Production

The production for a final good per young worker increases with capital per young worker k_t, effective labor per young worker $\bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t$, where l_t is the total labor time per young worker[6] and $\bar{\Omega}(\bar{h}_t, \bar{m}_t)$ is the average health of the labor force as a labor-augmenting factor: [7]

(4) $y_t = f\left(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t\right)$,

with constant returns to scale in (k_t, l_t) but increasing returns to scale in $\left(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t\right)$. In line with the aforementioned empirical evidence, the average health status of the labor force has positive external effects on average labor productivity and depends positively on the average health spending by young and old workers, $\bar{h}_t$ and $\bar{m}_t$, at diminishing rates.

[6] Total labor time per young worker is the total labor of young and old workers over the number of young workers.

[7] Results remain the same if average health of labor is modeled as a separate production factor, $y_t = f\left(k_t, \bar{\Omega}\left(\bar{h}_t, \bar{m}_t\right), l_t\right)$. Equation (4) agrees with the notion that health is a form of general human capital (e.g., Becker, 1964; Fang and Gavazza, 2011).

Since the health status of an individual worker is private information, firms cannot directly link the wage rate to the worker's health status or health investment, despite the contribution of the worker's health to the average health status of the labor force. This leads to health externalities to labor productivity. Consequently, workers overlook the contributions of their health investment to the average health of the labor force, and thus their perceived private returns to health spending are lower than the social return.

Competitive firms compensate production factors by their marginal products as follows:

(5) $w_t = f_l\big(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t\big) = f_2\big(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t\big)\bar{\Omega}(\bar{h}_t, \bar{m}_t),$

(6) $R_t = f_k(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t).$

Hence, the marginal product of capital increases with the average health status of workers. By contrast, the average health status has opposing forces on the marginal product of labor. For a Cobb-Douglas production function, the net effect of the average health status on the marginal product of labor is positive.

As one period here corresponds to 30 years, we assume that physical capital depreciates fully within one period. The size of the young generation in the economy N_t evolves via $N_{t+1} = N_t n_t$. Hence, markets clear when

$$k_{t+1} = s_t/n_t,$$

$$l_t = 1 - vn_t + T(h_{t-1}, m_t)/n_{t-1}.$$

The labor supply of all young workers $(1 - vn_t)n_{t-1}$ in a dynastic family at time t decreases with fertility n_t but increases with the number of young workers n_{t-1}. The labor supply of the old worker $T(h_{t-1}, m_t)$ increases with lifetime health investment. Feasibility for the allocation of output is

(7) $c_t = f\big(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t\big) - k_{t+1}n_t - h_t - \frac{(d_t+m_t)T(h_{t-1},m_t)}{n_{t-1}}.$

To gauge the efficiency loss of the health externalities and to explore optimal policies to attain the social optimum, the next section describes the socially optimal allocation.

4. The socially optimal allocation

Given an initial state (h_{-1}, k_0, n_{-1}), the social planner chooses $\{d_t, m_t, c_t, n_t, k_{t+1}, h_t\}_{t=0}^{\infty}$ to maximize utility in (1) subject to feasibility in (7) by internalizing health externalities $h_t = \bar{h}_t$ and $m_t = \bar{m}_t$ as follows:

$$V(k_t, h_{t-1}, n_{t-1}) = \max_{\{d_t, m_t, n_t, k_{t+1}, h_t\}} \{\beta U(T(h_{t-1}, m_t)d_t) +$$

$$\alpha U\big(f(k_t, \bar{\Omega}\big(\bar{h}_t, \bar{m}_t\big)(1 - vn_t + T(h_{t-1}, m_t)/n_{t-1})) - k_{t+1}n_t - h_t -$$

$$(d_t + m_t)T(h_{t-1}, m_t)/n_{t-1}) + \alpha\rho G(n_t) + \alpha\, V(k_{t+1}, h_t, n_t)\}.$$

The planner chooses inter-vivos transfers to equate the marginal rate of substitution between the old and young agents' consumption with old-age dependency as follows:

(8) $$\frac{\beta U'(T(h_{t-1},m_t)d_t)}{\alpha U'(c_t)} = \frac{1}{n_{t-1}}.$$

Higher health spending in the previous period h_{t-1} or in the current period m_t contributes to higher old-age labor and longevity, thus motivating transfers from old to young agents that decrease old agents' consumption but increase young agents' consumption. Higher fertility in the previous period results in lower old-age dependency, thus generating more transfers from young to old agents.

The planner chooses capital investment or bequests to children to equate the marginal rate of substitution between young-age consumption across generations with the marginal product of capital per young worker in the next period:

(9) $$\frac{U'(c_t)}{\alpha U'(c_{t+1})} = \frac{f_k(k_{t+1},\bar{\Omega}(\bar{h}_{t+1},\bar{m}_{t+1})l_{t+1})}{n_t}.$$

The average health of young and old agents in the next period contributes to the marginal product of capital, thus creating a positive substitution effect on savings or investment in capital.

By equalizing the marginal benefit and cost of young-age health spending, the planner internalizes young-age health externalities to labor productivity as follows:

(10) $$\frac{T_h(h_t,m_{t+1})\left[\beta U'(T(h_t,m_{t+1})d_{t+1})d_{t+1} + \frac{\alpha U'(c_{t+1})(f_l(k_{t+1},\bar{\Omega}(\bar{h}_{t+1},\bar{m}_{t+1})l_{t+1}) - d_{t+1} - m_{t+1})}{n_t}\right]}{U'(c_t)[1 - f_{\bar{h}}(k_t,\bar{\Omega}(\bar{h}_t,\bar{m}_t)l_t)]} = 1.$$

The marginal cost of young-age health spending is the forgone marginal utility of young-age consumption. The marginal benefit is twofold in the next period: the marginal utility of old-age consumption from extended life and the marginal utility of children's young-age consumption from the increase in bequests to children owing to the extended working life at old age. The marginal product of average young-age health spending $f_{\bar{h}}(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t)$ contributes to the internalized marginal benefit of young-age health spending.

By equalizing the marginal gain and loss of old-age health spending, the planner internalizes old-age health externalities to labor productivity as follows:

(11) $$\frac{T_m(h_{t-1},m_t)\left[\beta U'(T(h_{t-1},m_t)d_t)d_t + \frac{\alpha U'(c_t)(f_l(k_t,\bar{\Omega}(\bar{h}_t,\bar{m}_t)l_t) - d_t - m_t)}{n_{t-1}}\right]}{\beta U'(T(h_{t-1},m_t)d_t)[T(h_{t-1},m_t) - n_{t-1} f_{\bar{m}}(k_t,\bar{\Omega}(\bar{h}_t,\bar{m}_t)l_t)]} = 1.$$

The marginal cost of old-age health spending is the forgone marginal utility of old-age consumption. The marginal benefit of old-age health spending includes the marginal utility of old-age consumption from extended life and the marginal utility of children's young-age consumption from the increase in inter-vivos transfers from parents to children owing to the extended working life at old age. The marginal product of average old-age health spending $f_{\bar{m}}\big(k_t,\bar{\Omega}(\bar{h}_t,\bar{m}_t)l_t\big)$ contributes to the internalized marginal benefit of old-age health spending.

The planner also equalizes the marginal rate of substitution between fertility and young-age consumption and their relative costs as follows:

(12) $$\frac{\rho G'(n_t)}{U'(c_t)} = vf_l\big(k_t,\bar{\Omega}\big(\bar{h}_t,\bar{m}_t\big)l_t\big) + k_{t+1} + \frac{\alpha U'(c_{t+1})T(h_t,m_{t+1})(f_l(k_{t+1},\bar{\Omega}(\bar{h}_{t+1},\bar{m}_{t+1})l_{t+1}) - d_{t+1} - m_{t+1})}{U'(c_t)n_t^2}.$$

The first term of the relative cost of fertility is the time cost of childrearing; the second term is capital per child from parental investment (bequests); and the last term is the discounted marginal cost of inter-vivos transfers from parents to children in the next period. Particularly, old-age labor relates positively with lifetime health investment and interacts with capital accumulation, inter-vivos transfers and fertility in contrast to standard overlapping-generations models that assume retirement at old age without intergenerational transfers and old-age labor.

The transversality condition is

$$\lim_{t\to\infty} \alpha^t U'(c_t) n_t k_{t+1} = 0.$$

Denoting $f_k(t) \equiv f_k(k_t,\bar{\Omega}(\bar{h}_t,\bar{m}_t)l_t)$ and combining this transversality condition with successive substitutions on $\alpha u'(c_t) = u'(c_{t-1})n_{t-1}/f_k(t)$ from condition (9), we have

$$\lim_{t\to\infty} k_{t+1} \prod_{j=0}^{t} \frac{n_j}{f_k(j)} = 0.$$

From this condition, the marginal product of capital should exceed the growth rate of aggregate capital for dynamic efficiency when time approaches infinity. This condition ensures a bounded value function of the state $V(k_t,h_{t-1},n_{t-1})$.

The socially optimal allocation from an initial state (h_{-1}, n_{-1}, k_0) is a sequence $\{c_t,d_t,h_t,m_t,n_t,k_{t+1}\}_{t=0}^{\infty}$ that satisfies technology (4), feasibility (7), first-order conditions (8) to (12) and the transversality condition. We now turn to the competitive equilibrium allocations.

5. Competitive equilibrium allocations

This section first determines the competitive equilibrium allocation without private health subsidies and government interventions for comparisons with the socially optimal allocation to reveal the effects of the health externalities. It then determines the competitive equilibrium allocation with private and public health subsidies, investment subsidies as well as taxes on income and consumption to explore their roles in internalizing the health externalities.

5.1. Laissez faire

From budget constraints (2) and (3), the dynasty faces a constraint in each period as follows:

(13) $$c_t = \frac{R_t s_{t-1}}{n_{t-1}} + \left(\frac{T(h_{t-1},m_t)}{n_{t-1}} + 1 - v n_t\right) w_t - s_t - h_t - \frac{(d_t+m_t)T(h_{t-1},m_t)}{n_{t-1}}.$$

The dynasty maximizes utility in (1) subject to (13), taking prices as given. The respective intergenerational and intertemporal substitution conditions are given as follows:

(14) $$\frac{\beta U'(T(h_{t-1},m_t)d_t)}{\alpha U'(c_t)} = \frac{1}{n_{t-1}},$$

(15) $$\frac{U'(c_t)}{\alpha U'(c_{t+1})} = \frac{R_{t+1}}{n_t}.$$

From $R_{t+1} = f_k(k_{t+1}, \bar{\Omega}(\bar{h}_{t+1}, \bar{m}_{t+1}) l_{t+1})$ in (6), conditions (14) and (15) are analogous to (8) and (9) chosen by the social planner. Yet, the health externalities affect the intertemporal substitution via the investment return $R_{t+1} = f_k(k_{t+1}, \bar{\Omega}(\bar{h}_{t+1}, \bar{m}_{t+1}) l_{t+1})$ as agents disregard the contribution of their health to average health and labor productivity in the economy.

The first-order conditions with respect to health spending h_t and m_t are

(16) $$\frac{T_h(h_t,m_{t+1})\left[\beta U'(T(h_t,m_{t+1})d_{t+1})d_{t+1} + \frac{\alpha U'(c_{t+1})(w_{t+1}-d_{t+1}-m_{t+1})}{n_t}\right]}{U'(c_t)} = 1,$$

(17) $$\frac{T_m(h_{t-1},m_t)\left[\beta U'(T(h_{t-1},m_t)d_t)d_t + \frac{\alpha U'(c_t)(w_t-d_t-m_t)}{n_{t-1}}\right]}{\frac{\alpha U'(c_t)T(h_{t-1},m_t)}{n_{t-1}}} = 1.$$

Since the perceived private returns to health spending are below the social returns, private health spending in (16) and (17) is below the optimal levels in (10) and (11).

The first-order condition with respect to the number of children is

(18) $$\frac{\rho G'(n_t)}{U'(c_t)} = v w_t + \frac{s_t}{n_t} + \frac{\alpha U'(c_{t+1})T(h_t,m_{t+1})(w_{t+1}-d_{t+1}-m_{t+1})}{U'(c_t)n_t^2},$$

where $w_t = f_l(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t)$ in (5). The health externalities result in lower health spending, lower labor productivity, and hence a lower wage rate or time cost of childrearing $v w_t$ in (18) than their socially optimal levels. Lower labor productivity implies lower returns to capital, thus leading to lower savings in (15). The decline in savings in turn reduces the bequest cost of childrearing s_t/n_t in (18). Lower health spending results in lower old-age earnings and parental transfers to children $T(h_t, m_{t+1})(w_{t+1} - d_{t+1} - m_{t+1})$ which reduce the transfer cost of childrearing in (18). Thus, fertility is higher and young-age labor is lower than the socially optimal level in (12). Thus, output per young worker is lower than the socially optimal level.

Since $s_t = n_t k_{t+1}$, the transversality condition associated with assets is the same as that for the social planner's allocation. Combining the transversality condition with successive substitutions on $\alpha u'(c_t) = u'(c_{t-1}) n_{t-1}/R_t$ from condition (15) yields binding solvency

$$\lim_{t\to\infty} k_{t+1} \prod_{j=0}^{t} \frac{n_j}{R_j} = 0.$$

From the binding solvency, the gross return to savings should exceed the growth rate of aggregate capital for dynamic efficiency, thus ensuring a bounded value function of the state when time approaches infinity.[8]

Definition 1. *A competitive equilibrium from an initial state* (h_{-1}, k_0, n_{-1}) *is a sequence of allocations* $\{b_t, c_t, d_t, h_t, m_t, n_t, s_t, l_t, k_{t+1}, y_t\}_{t=0}^{\infty}$ *and prices* $\{R_t, w_t\}_{t=0}^{\infty}$ *such that: (i) given average health and prices, firms and families optimize, satisfying budget constraints (2) and (3), technology (4), conditions (5), (6) and (14) to (18), the transversality condition, and binding solvency; (ii) all markets clear; (iii) consistency holds:* $h_t = \overline{h_t}$ *and* $m_t = \bar{m}_t$.

The laissez-faire allocation features low health spending, labor productivity, longevity, savings and income but high fertility as observed in developing countries.

5.2. Employer-based health insurance and public policies

This subsection considers private health subsidies through employer-based health insurance (EHI) and a set of taxes and subsidies to explore their roles in internalizing the health externalities to achieve the social optimum.

5.2.1. Employer-based health insurance

The EHI has the advantage of group insurance over individual health insurance to ease the concern of private information on an individual's health status or health spending.[9] We explore the EHI chosen by firms for profit maximization and its role in mitigating the efficiency loss of the health externalities. Let $\pi_t \in (0,1)$ and $\pi_t^o \in (0,1)$ denote the portions of young-age and old-age health spending covered by the EHI, respectively. In equilibrium with a competitive insurance market, health insurance premium per young or old worker I_t or I_t^o equals the insurance coverage of health spending per young worker, $I_t = \bar{h}_t \pi_t$, or per old worker, $I_t^o = \bar{T}(\bar{h}_{t-1}, \bar{m}_t)\bar{m}_t \pi_t^o$.

With the EHI, we rewrite the production function as

(19) $y_t = f\left(k_t, \bar{\Omega}(I_t + \bar{H}_t, \frac{I_t^o + \bar{M}_t}{\bar{T}(\bar{h}_{t-1}, \bar{m}_t)}) l_t\right)$,

where $\bar{H}_t \equiv \bar{h}_t(1 - \pi_t)$ is average out-of-pocket health spending per young worker, and $\bar{M}_t \equiv \bar{T}(\bar{h}_{t-1}, \bar{m}_t)\bar{m}_t(1 - \pi_t^o)$ is average out-of-pocket health spending per old worker. Firms

[8] Otherwise, the marginal product of capital would be too low to compensate for capital depreciation, thus causing dynamic inefficiency, a scenario coined as over-savings, which can be ruled out by binding solvency in the dynastic model.

[9] Based on this advantage of group insurance, we focus on the EHI and abstract from individual health insurance. In practice, the EHI is much more popular than individual health insurance. As indicated by data from the US Bureau of Statistics, the EHI covers almost 85% of the population with private health insurance.

observe health insurance premium (I_t, I_t^o) but do not observe individual health spending (h_t, m_t) and old-age longevity $T(h_{t-1}, m_t)$.

Firms' profit function becomes

$$f\left(k_t, \overline{\Omega}\left(I_t + \overline{H}_t, \frac{I_t^o + \overline{M}_t}{\overline{T}(\overline{h}_{t-1}, \overline{m}_t)}\right) l_t\right) - R_t k_t - w_t l_t - \lambda_t I_t - \lambda_t^o I_t^o / n_{t-1},$$

where $\lambda_t \in (0,1)$ and $\lambda_t^o \in (0,1)$ are the firms' subsidy rates on young-age insurance I_t and old-age insurance per young worker I_t^o / n_{t-1}, respectively. Profit maximization yields

(20) $w_t = f_l\left(k_t, \overline{\Omega}\left(I_t + \overline{H}_t, \frac{I_t^o + \overline{M}_t}{\overline{T}(\overline{h}_{t-1}, \overline{m}_t)}\right) l_t\right) = f_l(k_t, \overline{\Omega}(\overline{h}_t, \overline{m}_t) l_t),$

(21) $R_t = f_k\left(k_t, \overline{\Omega}\left(I_t + \overline{H}_t, \frac{I_t^o + \overline{M}_t}{\overline{T}(\overline{h}_{t-1}, \overline{m}_t)}\right) l_t\right) = f_k(k_t, \overline{\Omega}(\overline{h}_t, \overline{m}_t) l_t),$

(22) $\lambda_t = f_I\left(k_t, \overline{\Omega}\left(I_t + \overline{H}_t, \frac{I_t^o + \overline{M}_t}{\overline{T}(\overline{h}_{t-1}, \overline{m}_t)}\right) l_t\right) = f_{\overline{h}}\left(k_t, \overline{\Omega}(\overline{h}_t, \overline{m}_t) l_t\right),$

(23) $\frac{\lambda_t^o}{n_{t-1}} = f_{I^o}\left(k_t, \overline{\Omega}\left(I_t + \overline{H}_t, \frac{I_t^o + \overline{M}_t}{\overline{T}(\overline{h}_{t-1}, \overline{m}_t)}\right) l_t\right) = \frac{f_{\overline{m}}(k_t, \overline{\Omega}(\overline{h}_t, \overline{m}_t) l_t)}{\overline{T}(\overline{h}_{t-1}, \overline{m}_t)}.$

In (20) and (21), the marginal products or rental prices depend on the EHI. In (22) and (23), firms' subsidies on health insurance for young and old workers depend positively on the marginal product of average health spending by young and old workers, respectively.

5.2.2. Public policies

Government spending includes lump-sum transfers to the young and elderly, P_t and P_t^o, respectively, and subsidies on savings at rate ξ_t^s and on health spending at young and old age at respective rates ξ_t and ξ_t^o. Government revenue is from taxes on young-age and old-age labor income at respective rates τ_t and τ_t^o, on consumption at rate τ_t^c, and on capital income $r_t = R_t - 1$ at rate τ_t^s, where $r_t > 0$ under the binding solvency for dynamic efficiency. The government balances its budget in every period:

$$\xi_t \overline{h}_t + \xi_t^s \overline{s}_t + \overline{P}_t + \frac{\xi_t^o \overline{T}(\overline{h}_{t-1}, \overline{m}_t)\overline{m}_t + \overline{P}_t^o}{\overline{n}_{t-1}} = \tau_t (1 - v\overline{n}_t) w_t +$$
$$\tau_t^c \overline{c}_t + \frac{(\tau_t^o w_t + \tau_t^c \overline{d}_t)\overline{T}(\overline{h}_{t-1}, \overline{m}_t) + \tau_t^s \overline{s}_{t-1}(R_t - 1)}{\overline{n}_{t-1}}.$$

5.2.3. Equilibrium allocations with EHI and public policies

With the EHI and public policies, household budget constraints become

$$c_t(1 + \tau_t^c) = b_t + (1 - vn_t) w_t (1 - \tau_t) + P_t - s_t(1 - \xi_t^s) -$$
$$h_t(1 - \pi_t - \xi_t) - I_t(1 - \lambda_t),$$
$$T(h_{t-1}, m_t) d_t (1 + \tau_t^c) = T(h_{t-1}, m_t) w_t (1 - \tau_t^o) + [R_t - (R_t - 1)\tau_t^s] s_{t-1} + P_t^o -$$
$$T(h_{t-1}, m_t) m_t (1 - \pi_t^o - \xi_t^o) - I_t^o (1 - \lambda_t^o) - b_t n_{t-1}.$$

Combining these budget constraints into a single constraint for the dynasty yields

(24) $$c_t = \frac{(1-vn_t)w_t(1-\tau_t)+P_t-s_t(1-\xi_t^s)-h_t(1-\pi_t-\xi_t)-I_t(1-\lambda_t)}{(1+\tau_t^c)} +$$
$$\frac{T(h_{t-1},m_t)[w_t(1-\tau_t^o)-m_t(1-\pi_t^o-\xi_t^o)-d_t(1+\tau_t^c)]+P_t^o+[R_t-(R_t-1)\tau_t^s]s_{t-1}-I_t^o(1-\lambda_t^o)}{n_{t-1}(1+\tau_t^c)}.$$

The dynasty maximizes utility subject to household budget constraints, taking prices, EHI coverage rates, private health subsidies and public policies as given. The first-order condition with respect to d_t is similar to (8) in the social optimum or (14) in the laissez faire; and those with respect to s_t, h_t, m_t and n_t are given as follows:

(25) $$\frac{U'(c_t)}{\alpha U'(c_{t+1})} = \frac{(1+\tau_t^c)[R_{t+1}-(R_{t+1}-1)\tau_{t+1}^s]}{n_t(1-\xi_t^s)(1+\tau_{t+1}^c)},$$

(26) $$\frac{T_h(h_t,m_{t+1})\beta U'(T(h_t,m_{t+1})d_{t+1})d_{t+1}}{\frac{U'(c_t)(1-\pi_t-\xi_t)}{(1+\tau_t^c)}} +$$
$$\frac{T_h(h_t,m_{t+1})\left[\frac{\alpha U'(c_{t+1})(w_{t+1}(1-\tau_{t+1}^o)-d_{t+1}(1+\tau_{t+1}^c)-m_{t+1}(1-\pi_{t+1}^o-\xi_{t+1}^o))}{n_t(1+\tau_{t+1}^c)}\right]}{\frac{U'(c_t)(1-\pi_t-\xi_t)}{(1+\tau_t^c)}} = 1,$$

(27) $$\frac{T_m(h_{t-1},m_t)\left[\beta U'(T(h_{t-1},m_t)d_t)d_t + \frac{\alpha U'(c_t)(w_t(1-\tau_t^o)-d_t(1+\tau_t^c)-m_t(1-\pi_t^o-\xi_t^o))}{n_{t-1}(1+\tau_t^c)}\right]}{\frac{\alpha U'(c_t)T(h_{t-1},m_t)(1-\pi_t^o-\xi_t^o)}{n_{t-1}(1+\tau_t^c)}} = 1,$$

(28) $$\frac{\rho G'(n_t)}{U'(c_t)} = \frac{v w_t(1-\tau_t)}{(1+\tau_t^c)} + \frac{s_t(1-\xi_t^s)}{n_t(1+\tau_t^c)} + \frac{\alpha U'(c_{t+1})P_{t+1}^o}{U'(c_t)n_t^2(1+\tau_{t+1}^c)} + \frac{\alpha U'(c_{t+1})I_{t+1}^o\lambda_{t+1}^o}{U'(c_t)n_t^2(1+\tau_{t+1}^c)} +$$
$$\frac{\alpha U'(c_{t+1})T(h_t,m_{t+1})[w_{t+1}(1-\tau_{t+1}^o)-d_{t+1}(1+\tau_{t+1}^c)-m_{t+1}(1-\xi_{t+1}^o)]}{U'(c_t)n_t^2(1+\tau_{t+1}^c)},$$

where $w_t = f_l(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t)$ and $R_t = f_k(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t)l_t)$.

In (25), the marginal rate of substitution between young-age consumption across generations equals the after-tax private return to savings (net of the subsidy) over the number of children. A rise in capital income tax τ_{t+1}^s reduces the relative price of current consumption, thus generating a negative substitution effect on savings. Conversely, a rise in the savings subsidy rate ξ_t^s creates a positive substitution effect on savings. If consumption tax rates are constant $\tau_t^c = \tau_{t+1}^c$ to cancel out their wedge in the intertemporal substitution, then capital income tax τ_{t+1}^s and savings subsidy ξ_t^s move in the same direction for optimal savings.

In (26) and (27), public health subsidies on young-age and old-age health spending ($\xi_t, \xi_t^o, \xi_{t+1}^o$) and EHI coverage rates on young-age and old-age health spending (π_t, π_t^o, π_{t+1}^o) increase health spending by reducing the marginal costs of private health spending. This suggests that public health subsidies or private health subsidies through the EHI are useful to internalize the health externalities. Since public health subsidies ($\xi_t, \xi_t^o, \xi_{t+1}^o$) and EHI coverage rates on health spending (π_t, π_t^o, π_{t+1}^o) are substitutable, there is a key role of the EHI in easing the financial pressure of funding public healthcare. By lowering the after-tax earnings at old age, old-age labor income taxes (τ_t^o, τ_{t+1}^o) reduce the marginal benefits of health spending, thus lowering health spending. Consumption taxes (τ_t^c, τ_{t+1}^c) reduce the costs and benefits of health spending. If consumption tax rates are constant $\tau_t^c = \tau_{t+1}^c$, then their effects on health spending fully cancel out when substituting (14) into (26) and (27).

In (28), young-age labor income tax τ_t reduces the time cost of childrearing, while old-age labor income tax τ_{t+1}^o reduces after-tax earnings at old age and the transfer cost of childrearing. Consumption tax τ_t^c reduces the time cost, bequest cost and transfer cost of childrearing. A rise in savings subsidy ξ_t^s lowers the bequest cost of childrearing, whereas a rise in public transfer to the elderly P_{t+1}^o raises the transfer cost by increasing parental transfers to children. Moreover, public and private health subsidies for the elderly ($\xi_{t+1}^o, I_{t+1}^o \lambda_{t+1}^o$) decrease old-age health costs and increase inter-vivos transfers to children (the transfer cost of childrearing). As a result, without appropriate taxes that generate positive effects on fertility, the EHI tend to reduce fertility from its socially optimal level in (12), and thus the EHI alone cannot achieve the social optimum when individuals choose the number of children. Since public and private health subsidies are substitutable, appropriate health subsidies along with appropriate taxes can achieve the social optimum as shown by the next subsection.

5.2.4. Optimal EHI, optimal public health subsidies and optimal taxes

For notational ease, we denote $f_k(t) \equiv f_k(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t)$, $f_l(t) \equiv f_l(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t)$, $f_{\bar{h}}(t) \equiv f_{\bar{h}}(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t)$ and $f_{\bar{m}}(t) \equiv f_{\bar{m}}(k_t, \bar{\Omega}(\bar{h}_t, \bar{m}_t) l_t)$. Among the policy instruments commonly used in developed countries, we treat some instruments as given and use the other instruments to achieve the optimal outcome. Equating the equilibrium conditions derived in Subsection 5.2.3 with the optimal conditions of the social planner yields the following optimal policies that eliminate the efficiency loss of the health externalities and achieve the social optimum in an economy with both the EHI and public health subsidies.

Proposition 1. *Given the socially optimal allocation with $h_t = \bar{h}_t$ and $m_t = \bar{m}_t$ and public policies $\{P_t, P_t^o, \xi_t, \xi_t^o, \xi_t^s, \tau_t^c\}_{t=0}^{\infty}$, the optimal taxes on capital income and labor income to the young and elderly $\{\tau_t^s, \tau_t, \tau_t^o\}_{t=0}^{\infty}$ and optimal employer-based health insurance $\{\pi_t, \pi_t^o, I_t, I_t^o, \lambda_t, \lambda_t^o\}_{t=0}^{\infty}$ from the conditions for utility and profit maximization under feasibility and a balanced government budget are determined as follows*

(i) $$\frac{v f_l(t)(\tau_t+\tau_t^c)+k_{t+1}(\tau_t^c+\xi_t^s)}{(1+\tau_t^c)} = \frac{T(h_t, m_{t+1})[m_{t+1}(\xi_{t+1}^o+\tau_{t+1}^c)-f_l(t+1)(\tau_{t+1}^o+\tau_{t+1}^c)]+P_{t+1}^o+I_{t+1}^o\lambda_{t+1}^o}{n_t f_k(t+1)(1+\tau_{t+1}^c)},$$

(ii) $$f_{\bar{h}}(t) = 1 - \frac{[1-(\xi_t+\pi_t)](1+\tau_{t+1}^c)[f_l(t+1)-m_{t+1}]}{(1+\tau_t^c)\{(1-\tau_{t+1}^o)f_l(t+1)-[1-(\xi_{t+1}^o+\pi_{t+1}^o)]m_{t+1}\}},$$

(iii) $f_{\bar{m}}(t) = \frac{T(h_{t-1},m_t)f_l(t)[(\xi_t^o+\pi_t^o)-\tau_t^o]}{n_{t-1}\{f_l(t)(1-\tau_t^o)-m_t[1-(\xi_t^o+\pi_t^o)]\}}$,

(iv) $f_k(t+1) = \frac{\tau_{t+1}^s(1+\tau_t^c)}{(\tau_{t+1}^c+\tau_{t+1}^s)(1+\tau_t^c)-(\xi_t^s+\tau_t^c)(1+\tau_{t+1}^c)}$,

(v) $\xi_t h_t + \xi_t^s k_{t+1} n_t + P_t + \frac{\xi_t^o T(h_{t-1},m_t)m_t + P_t^o}{n_{t-1}} = f_l(t)\left[\tau_t(1-vn_t) + \frac{\tau_t^o T(h_{t-1},m_t)}{n_{t-1}}\right] +$

$\tau_t^c\left[c_t + \frac{d_t T(h_{t-1},m_t)}{n_{t-1}}\right] + \tau_t^s k_t[f_k(t)-1]$,

(vi) $I_t = \bar{h}_t \pi_t$,

(vii) $I_t^o = \bar{T}(\bar{h}_{t-1},\bar{m}_t)\bar{m}_t\pi_t^o$,

(viii) $\lambda_t = f_{\bar{h}}(t)$,

(ix) $\lambda_t^o = \frac{n_{t-1}f_{\bar{m}}(t)}{\bar{T}(\bar{h}_{t-1},\bar{m}_t)}$.

Proof. See Appendix A.

In condition (i), the positive effects of public transfers to the elderly P_{t+1}^o, old-age public health subsidy ξ_{t+1}^o and old-age private health subsidy $I_{t+1}^o\lambda_{t+1}^o$ on the costs of childrearing counteract the negative effects of young-age and old-age labor income taxes (τ_t, τ_{t+1}^o) and savings subsidy ξ_t^s on the costs of childrearing.

Condition (ii) internalizes the marginal product of average young-age health spending through young-age public health subsidy ξ_t, young-age EHI coverage π_t, old-age public health subsidy ξ_{t+1}^o and old-age EHI coverage π_{t+1}^o. When the health externalities are stronger, $f_{\bar{h}}(t)$ is higher, thus requiring a higher public health subsidy or a higher EHI coverage to internalize the marginal product of average young-age health spending to achieve the social optimum.

Condition (iii) internalizes the marginal product of average old-age health spending through old-age public health subsidy ξ_t^o and old-age EHI coverage π_t^o net of old-age labor income taxes τ_t^o. Under a stationary consumption tax rate $\tau_t^c = \tau_{t+1}^c$, conditions (ii) and (iii) suggest that age-specific health subsidies either from the government or firms are essential to internalize the health externalities.

When consumption tax rates are constant, condition (iv) implies the same sign for savings subsidy ξ_t^s and capital income tax τ_{t+1}^s to remove their wedge in intertemporal substitution. Condition (v) balances the government budget. Conditions (vi) and (vii) show an actuarially fair EHI policy. Conditions (viii) and (ix) internalize the health externalities by equating private health subsidies to young workers and old workers (λ, λ^o) with the marginal products of average young-age health spending and average old-age health spending, respectively.

Proposition 1 suggests that with appropriate taxes, the mixture of public and private health subsidies can co-exist to achieve the social optimum. This result is relevant to countries like the US where young workers are primarily covered by the EHI, while old workers are covered by the public health program, such as the Medicare.

Consistent with our earlier discussion for (28), firms' subsidies on old-age health insurance $I_{t+1}^o \lambda_{t+1}^o$ increase the transfer cost of childrearing, tending to reduce fertility from its socially optimal level. As a result, without having appropriate taxes, private health subsidies through the EHI alone cannot fully internalize health externalities to labor productivity when individuals choose the number of children. However, if the EHI is absent, all the conditions in Proposition 1 can still hold. These results are summarized in Corollary 1, which derives optimal public policies to eliminate the efficiency loss of health externalities in an economy by introducing universal public health in the healthcare system without the EHI. This case is relevant for many OECD countries such as Australia that have only universal public health.

Corollary 1. *Given the socially optimal allocation with $h_t = \bar{h}_t$ and $m_t = \bar{m}_t$ and public policies $\{P_t, P_t^o, \xi_t^s, \tau_t^c,\}_{t=0}^{\infty}$, the government can determine optimal public health subsidies and optimal taxes on capital and labor income $\{\xi_t, \xi_t^o, \tau_t^s, \tau_t, \tau_t^o\}_{t=0}^{\infty}$ in the absence of employer-based health insurance.*

When universal public health is absent, we can also derive the optimal EHI and optimal taxes to eliminate the efficiency loss of health externalities in an economy. This case is relevant for health reform that replaces the universal public health with the universal EHI to ease the financial burden of universal public health.

Corollary 2. *Given the socially optimal allocation with $h_t = \bar{h}_t$ and $m_t = \bar{m}_t$ and public policies $\{P_t, P_t^o, \xi_t^s, \tau_t^c,\}_{t=0}^{\infty}$, the government can determine optimal taxes on capital and labor income $\{\tau_t^s, \tau_t, \tau_t^o\}_{t=0}^{\infty}$ to support optimal employer-based health insurance $\{\pi_t, \pi_t^o, I_t, I_t^o, \lambda_t, \lambda_t^o\}_{t=0}^{\infty}$ in the absence of universal public health.*

The next section shows qualitative results in the steady state with specific functional forms.

6. Steady state with specific functions

We assume a Cobb-Douglas production function as

$$(29) \quad y = Ak^{\theta}\left[\left(\bar{h}^{\phi}\bar{m}^{1-\phi}\right)^{\mu} l\right]^{1-\theta},$$

with $A > 0, 0 < \theta, \mu < 1$, $\overline{\Omega}(\overline{h}, \overline{m}) = (\overline{h}^{\phi}\overline{m}^{1-\phi})^{\mu}$, and $\phi \in (0,1)$, where μ measures the degree of health externalities to labor productivity and ϕ measures the relative role of average young-age health spending in determining the health externalities.

The utility function has a constant elasticity of intertemporal substitution for consumption and fertility, measured by $1/\sigma_1 > 0$ and $1/\sigma_2 > 0$, respectively, as follows:

(30) $$U(x) = \frac{x^{1-\sigma_1}-1}{1-\sigma_1}, G(n) = \frac{n^{1-\sigma_2}-1}{1-\sigma_2},$$

where $x = c, T(h,m)d$. The longevity function is:

(31) $$T(h,m) = D\left(\frac{z(h,m)}{\delta+\epsilon z(h,m)}\right)^{\psi},$$

which increases with health spending at young and old age at diminishing rates under restrictions $D \in (0,1]$, $\delta > 0$, $\epsilon \geq 1$, $\psi \in (0,1)$, and $z(h,m) = h^{\phi}m^{1-\phi}$. Appendix B gives the socially optimal allocation at the steady state.

The next subsection presents qualitative results for the optimal EHI and optimal public policies using the specific functions in the steady state.

6.1. Optimal EHI, optimal public health subsidies and optimal taxes

We define the following expressions for optimal policies:

$$\Lambda_1 \equiv \frac{T(h,m)d}{n} + c + (1-vn)\left[\frac{T(h,m)\alpha(m-f_l(k,\Omega(h,m)l))}{vn^2} - f_l(k,\Omega(h,m)l) - \frac{k}{v}\right],$$

$$\Lambda_2 \equiv \frac{(1-vn)\alpha m f_m(k,\Omega(h,m)l)}{vn} + \frac{mT(h,m)[vn-\alpha(1-vn)]}{vn^2},$$

$$\Lambda_3 \equiv f_l(k,\Omega(h,m)l)\left[\frac{T(h,m)(vn-\alpha(1-vn))}{vn^2} + \frac{\alpha m(1-vn)f_m(k,\Omega(h,m)l)T_m(h,m)}{vn(T_m(h,m)m+T)}\right].$$

The optimal public health subsidies and optimal EHI supported by optimal taxes with the specific functions in the steady state are given as follows:

Proposition 2. *Given the social planner's allocation with the specific functions, $h = \overline{h}$ and $m = \overline{m}$ and public policies $(P, P^o, \xi, \xi^o, \xi^s, \tau^c)$, optimal taxes on capital income and labor income of the young and elderly (τ^s, τ, τ^o) and optimal employer-based health insurance $(\pi, \pi^o, I, I^o, \lambda, \lambda^o)$ in the steady state from the conditions for utility and profit maximization under feasibility and a balanced government budget are determined as follows:*

(i) $$\tau^s = \frac{\xi^s n}{(n-\alpha)},$$

(ii) $$\tau^o = \frac{h\xi + P - \Lambda_1\tau^c + \Lambda_2\xi^o + \frac{k(\alpha-vn)\xi^s}{\alpha v} + \frac{(vn-\alpha(1-vn))P^o}{vn^2} - \frac{\alpha m(1-vn)f_m(k,\Omega(h,m)l)^2}{v(T_m(h,m)m+T)}}{\Lambda_3},$$

(iii) $$\pi^o = \frac{nf_m(k,\Omega(h,m)l)[(1-\tau^o)f_l(k,\Omega(h,m)l)-m] + \tau^o T(h,m)f_l(k,\Omega(h,m)l)}{T(h,m)f_l(k,\Omega(h,m)l) - mnf_m(k,\Omega(h,m)l)} - \xi^o,$$

(iv) $\tau = \left(\frac{1}{v f_l(k,\Omega(h,m)l)}\right)\left\{\frac{\alpha[T(h,m)(m\xi^o - f_l(k,\Omega(h,m)l)\tau^o) + P^o + mnf_m(k,\Omega(h,m)l)\pi^o]}{n^2} + \right.$

$$\left. \tau^c \left[\frac{T(h,m)\alpha(m - f_l(k,\Omega(h,m)l))}{n^2} - vf_l(k,\Omega(h,m)l) - k\right] - k\xi^s\right\},$$

(v) $\pi = 1 - \xi - \frac{(1 - f_h(k,\Omega(h,m)l))[(1-\tau^o)f_l(k,\Omega(h,m)l) - (1 - \pi^o - \xi^o)m]}{f_l(k,\Omega(h,m)l) - m}$,

(vi) $I = h\pi$,

(vii) $I^o = mT(h,m)\pi^o$

(viii) $\lambda = f_h(k,\Omega(h,m)l)$,

(ix) $\lambda^o = \frac{nf_m(k,\Omega(h,m)l)}{T(h,m)}$.

Proof. See Appendix C.

In condition (i), the optimal capital income tax τ^s and savings subsidy ξ^s share the same sign because dynamic efficiency or binding solvency requires $f_k(k,\Omega(h,m)l) = n/\alpha > 1$ (see Appendix B). The condition for dynamic efficiency or binding solvency implies that fertility must exceed the subjective discount factor $n > \alpha$. Intuitively, a high subjective discount factor leads to high savings (hence a low marginal product of capital), whereas high fertility leads to a high marginal product of capital. A high subjective discount factor may also lead to low fertility as it attaches a high current value to future welfare in the dynasty. This lower bound on fertility is novel in its own right.

Without health externalities $(\mu = 0)$, $f_h(k,\Omega(h,m)l) = 0$ and $f_m(k,\Omega(h,m)l) = 0$ (see Appendix B). Then, conditions (iii), (v), (viii) and (ix) in Proposition 2 imply that $\pi^o = \tau^o - \xi^o$, $\pi = \tau^o - \xi$ and $\lambda = \lambda^o = 0$, respectively. In this sense, setting all taxes, public subsidies, public transfers and private health subsidies at zero yields the socially optimal outcome. In other words, when health externalities are absent, the laissez-faire allocation without the EHI would be the same as the planner's allocation in this lifecycle-dynastic model (the First Welfare Theorem). This feature is absent in lifecycle models with overlapping generations that abstract from intergenerational transfers.

By contrast, in the presence of health externalities to labor productivity $\mu > 0$, the marginal products of health spending at young and old ages are positive, $f_h(k,\Omega(h,m)l) > 0$ and $f_m(k,\Omega(h,m)l) > 0$, and increase with μ (see Appendix B). In this sense, age-specific labor income taxes and age-specific health subsidies are necessary to internalize the health externalities. Specifically, taking public transfers, public health subsidies, savings subsidies and consumption taxes $(P, P^o, \xi, \xi^o, \xi^s, \tau^c)$ as given, stronger health externalities may increase or decrease optimal young-age and old-age labor income taxes in conditions (ii) and (iv), and may raise optimal private health subsidies for young and old workers through the EHI $(\pi, \pi^o, I, I^o, \lambda, \lambda^o)$ at different rates in conditions (iii), and (v) to (ix). Consistent with Proposition 1, optimal EHI coverage rates (π, π^o) and optimal public health subsidies (ξ, ξ^o) are substitutable as reflected in conditions (iii) and (v).

In the absence of the EHI in the economy, optimal universal public health financed by optimal taxes is a special case of Proposition 2 with $\pi = \pi^o = I = I^o = \lambda = \lambda^o = 0$ as follows. We define the following expressions for optimal public policies:

$$\Lambda_4 \equiv \alpha \left[\frac{P^o}{n} + \frac{f_m(k,\Omega(h,m)l)}{T_m(h,m)}\left(T(h,m) + \frac{\alpha vnhT_h(h,m)}{\alpha(1-vn)-vn}\right) - \frac{vn(hf_h(k,\Omega(h,m)l)+P)}{\alpha(1-vn)-vn}\right],$$

$$\Lambda_5 \equiv -\frac{(n-\alpha)(\alpha-vn)k}{\alpha(1-vn)-vn},$$

$$\Lambda_6 \equiv -\frac{\alpha\left\{(1-vn)n[vf_l(k,\Omega(h,m)l)+k] - \frac{T(h,m)}{n}[vnd+\alpha(1-vn)(m-f_l(k,\Omega(h,m)l)] - vnc\right\}}{\alpha(1-vn)-vn},$$

$$\Lambda_7 \equiv \left(\frac{\alpha T(h,m)}{nT_m(h,m)}\right)\left[T(h,m) + \frac{\alpha vnhT_h(h,m)}{\alpha(1-vn)-vn}\right],$$

$$\Lambda_8 \equiv n[vf_l(k,\Omega(h,m)l)+k] - \alpha\left[c + \frac{T(h,m)\left(d+m-f_l(k,\Omega(h,m)l)\right)}{n}\right].$$

Corollary 3. *Given the social planner's allocation with the specific functions, $h = \bar{h}$ and $m = \bar{m}$ and public policies (P, P^o, ξ^s, τ^c), the government can determine optimal public health subsidies and taxes on capital and labor income $(\xi, \xi^o, \tau^s, \tau, \tau^o)$ in the steady state in the absence of the EHI as follows*

(i) $\tau^s = \frac{\xi^s n}{(n-\alpha)}$,

(ii) $\xi^o = \frac{\Lambda_4 + \Lambda_5\tau^s + \Lambda_6\tau^c}{\Lambda_7}$,

(iii) $\tau^o = \frac{\xi^o\left(m + \frac{T(h,m)}{T_m(h,m)}\right) - \frac{nf_m(k,\Omega(h,m)l)}{T_m(h,m)}}{f_l(k,\Omega(h,m)l)}$,

(iv) $\xi = (1-\alpha)f_h(k,\Omega(h,m)l) + \frac{\alpha T_h(h,m)T(h,m)\xi^o}{T_m(h,m)n}$,

(v) $\tau = \frac{\alpha[h\xi + P + (n-\alpha)k\tau^s] + \Lambda_8\tau^c}{f_l(k,\Omega(h,m)l)[\alpha(1-vn)-vn]}$.

When universal public health is absent in the economy, the optimal EHI and optimal taxes are a special case of Proposition 2 with $\xi = \xi^o = 0$ as follows:

Corollary 4. *Given the socially optimal allocation with the specific functions, $h = \bar{h}$ and $m = \bar{m}$ and public policies (P, P^o, ξ^s, τ^c), the government can determine optimal taxes on capital and labor income (τ^s, τ, τ^o) to support optimal employer-based health insurance $(\pi, \pi^o, I, I^o, \lambda, \lambda^o)$ in the steady state in the absence of universal public health.*

The theoretical results in Sections 5 and 6 illustrate the importance of health subsidies, i.e., public health subsidies or private health subsidies through the EHI, in internalizing the health externalities. The economy can fully mitigate the efficiency loss of the health externalities through appropriate health subsidies and taxes. The next section calibrates the model in Section 6 to provide a quantitative assessment of the effects of health externalities to labor productivity for policy improvements.

7. Quantitative analysis in steady state with specific functions

Public health subsidies are available worldwide. Almost all the OECD countries have universal public healthcare such as Australia where the EHI is not popular. By contrast, the health system in the US largely consists of private providers and private health insurance, especially for the working population. Most workers in the US receive their health care through the EHI, while most seniors (as well as low-income families and children) receive their health care via public health programs.

To compare the quantitative results for policy improvements between a country with universal public health to a country with both the EHI and public health subsidies, we calibrate key parameters of the model in Section 6 to Australian and US data. Specifically, we calibrate key parameters of the model ($\alpha, \beta, \delta/y, D, \rho, P/y, P^o/y, \tau, \tau^o, \tau^c, \tau^s, \xi^s, \xi, \xi^o, \pi, \pi^o$) to match certain targets in each country and assume that both Australia and the US share the same parameter values for $\sigma_1, \sigma_2, v, \theta, A, \mu, \epsilon, \psi$ and ϕ in preferences and technologies.[10] One period in our model is 30 years. We assume that individuals in this model are born when they are 5 years old and live to be at most 94 years old.[11]

7.1. Calibration, data moments and parameter values

This subsection describes the calibration procedure, the targeted data moments used in the calibration and the parameter values obtained from the literature or from the calibration. The targeted moments and parameter values are reported in Tables 1 and 2, respectively.

[Tables 1 and 2 go here]

7.1.1. Parameter values for both countries

To express the optimal and equilibrium conditions for c, d, s, k, h, m in Section 6 as a fraction of y for calibration,[12] we assume log utility for consumption ($\sigma_1 = 1$). Since a lower

[10] This assumption is reasonable as Australia and the US share similar levels of economic development.
[11] Hence, agents in our model enter old age at 65 years old, the earliest age where old agents are eligible for the public health program, Medicare, in the US.
[12] We normalize all the quantity variables by output per young worker, y, to detrend the model.

intertemporal elasticity of substitution for fertility than for consumption can account for the secular decline in fertility when income rises (e.g., Greenwood et al., 2005), we set $1/\sigma_2 = 1/4.5$. The fixed time rearing a child at $v = 0.1$ is reasonable for the parental time cost in the OECD countries.[13] Capital's income share takes a standard value $\theta = 0.33$. We normalize the total factor productivity parameter in the final good production technology A to unity. The degree of the health externalities at $\mu = 9\%$ follows the estimate of Bloom et al. (2022) that marginally better health of the labor force raises labor productivity by 6% to 12% in 133 countries when $\theta = 0.33$. We set the coefficient of the health function ϵ at unity, the return factor on health spending ψ at 0.8 and the share of young-age health spending in the health technology ϕ at 0.5 for both Australia and the US.

7.1.2. Country-specific parameter values

We can rewrite the longevity function as follows:

$$T = D\left[\frac{\left(\frac{h/y}{m/y}\right)^{\phi}\frac{m}{y}}{\frac{\delta}{y}+\epsilon\left(\frac{h/y}{m/y}\right)^{\phi}\frac{m}{y}}\right]^{\psi}.$$

For ϵ at unity, ψ at 0.8 and ϕ at 0.5, we calibrate country-specific coefficients δ/y and D in the longevity function to match country-specific health spending (% of GDP) and old-age life T in Australian and US data (see Table 1) using the first-order conditions with respect to young- and old-age health spending.[14] This results in $\delta/y = 0.81\%$ and $D = 0.6832$ in Australia, and $\delta/y = 6.05\%$ and $D = 0.7836$ in the US, given that old-age longevity is lower but health spending is higher in the US than in Australia.

By using the first-order condition for savings, the country-specific intergenerational discount factor α follows the country-specific investment to GDP ratio in Table 1. The country-specific taste for the old parent's consumption β is half of α because old-age life is shorter than the young age. From the first-order condition for fertility, the country-specific taste for the number of children ρ matches the country-specific fertility rate per young parent and other observations in Table 1. Doing so gives $\alpha = 0.7103, \beta = 0.3552$ and $\rho = 0.3069$ in Australia, whereas $\alpha = 0.6317, \beta = 0.3159$ and $\rho = 0.3205$ in the US, given that the investment to GDP ratio is lower and fertility is higher in the US than in Australia.

[13] For example, the fraction of time that a young parent allocated to a child aged 0-17 is about 0.08 in the US (Yew et al., 2024).

[14] As one period corresponds to 30 years in our model, longevity (T) is calculated from life expectancy at age 35 (LE) i.e., $T = LE/30 - 1$.

We set $\pi = \pi^o = 0\%$ in Australia that has no EHI. From total health spending (8.8% of GDP) and public health spending (6% of GDP) in Australia, the flat rate of health subsidies ($\xi = \xi^o$) is 68.18%. From the OECD tax system, the average labor income tax rates at young and old age ($\tau = \tau^o$) are 28%; the tax rate on returns to savings (τ^s) follows the 30% corporate income tax; and the consumption tax rate (τ^c) is 10% in Australia. As compulsory retirement savings (superannuation) are exemptible from labor income taxes, we set the savings subsidy rate (ξ^s) at 2%.[15] Public transfers to the elderly at 4% of output per young worker (P^o/y) follow public pension spending (% of GDP). We then set public transfers per young worker (P/y) at 19.14% to balance the government budget.

For the policy instruments in the US, we follow Zhao (2017) to set the old-age public health subsidy rate (ξ^o), or the Medicare subsidy rate, at 0.5 and the fraction of young-age medical expenses covered by the EHI (π) at 0.65. We set $\xi = 0\%$ in the US as most young workers below age 65 are covered by the EHI rather than public health subsidies. We set $\pi^o = 0\%$ in the US as old workers (aged 65 or above) receive old-age public health subsidy ξ^o rather than the EHI.[16] From the OECD tax system for the US, average labor income tax rates at young and old ages ($\tau = \tau^o$) are 27% and the tax rate on returns to savings (τ^s) follows the 33% corporate income tax. Following Conesa and Dominguez (2020), the consumption tax rate (τ^c) is 6% in the US. We set ξ^s at 0.8% to match the cost of tax subsidies for retirement savings at $146 billion in 2014 (Friedman, 2017) that is about 0.8% of US GDP in 2014. In the same way we compute Australian public transfers, US public transfers to the elderly at 6% of output per young worker (P^o/y) follow public pension spending (% of GDP), and public transfers per young worker (P/y) in the US at 18.09% balance the government budget.

7.2. Quantitative results

To compare different equilibrium outcomes, we use the consumption equivalent variation to measure the welfare change in economy *i* relative to the welfare level in benchmark competitive equilibrium (BCE). Specifically, it is the percentage change in both young-age and old-age consumption in every period Δ^i such that the welfare level in the BCE (U_0^{BCE}) reaches the welfare level in economy i (U_0^i). Using logarithmic preference for consumption in Eq. (1), it is straightforward to show that

[15] The compulsory superannuation contributions are 1.5% of GDP in Australia. From the labor income tax rate at 28%, subsidized savings equal 0.42% of GDP. Then, the roundup savings subsidy is 2% as the national saving rate (or equivalently the national investment rate in our model) is 22% in Australia (World Bank).

[16] Our quantitative analysis abstracts from means-tested health subsidies in the US such as Medicaid that subsidizes healthcare to low-income families and children who may be out of the US labor force.

$$U_0^i = U_0^{BCE} + \frac{(\beta+\alpha)\ln(1+\Delta^i)}{(1-\alpha)},$$

and thus

$$\Delta^i = exp\left[\frac{(U_0^i - U_0^{BCE})(1-\alpha)}{\beta+\alpha}\right] - 1.$$

7.2.1. Comparisons of equilibrium outcomes

Tables 3a and 3b compare the equilibrium outcomes at steady states for Australia and the US in ten cases, respectively. The social optimum (SO) is reported in Case (1), and the laissez faire without the EHI (LF) is reported in Case (2). The benchmark competitive equilibrium (BCE) is given in Case (3). Cases (4) to (10) are counterfactual experiments with a 10% variation in one of the concerned policy instruments from the BCE, holding other policy rates unchanged. These counterfactual experiments provide some insights into the quantitative effects of the variation in a specific policy instrument. Case (4) in Table 3a lowers ξ for Australia and Case (4) in Table 3b lowers π for the US. We also lower ξ^o in Case (5), lower P^o/y in Case (6), and raise τ, τ^o, τ^s and τ^c in Cases (7) to (10), respectively. In each of these counterfactual experiments, we adjust young-age public lump-sum transfers to balance the government budget when a specific tax or subsidy varies from the benchmark rate.

[Tables 3a and 3b go here]

Compared with the SO allocation in Case (1), the LF in Case (2) has lower old-age longevity or old-age labor (T), young-age health spending over output per young worker (h/y), old-age health spending over output per young worker (m/y), capital over output per young worker (k/y), young-age labor ($1 - vn$) and total labor per young worker ($l = 1 - vn + T/n$). However, the LF allocation has higher fertility (n), young-age consumption over output per young worker (c/y) and old-age consumption over output per young worker (d/y) than the SO allocation. These quantitative results for both Australia and the US in Tables 3a and 3b are consistent with the theoretical results established in Subsection 5.1.

For Australia BCE in Case (3) of Table 3a, old-age longevity or old-age labor (T) is substantially higher than the LF level, owing to high young-age and old-age public health subsidies (ξ, ξ^o) in Australia. However, taxes on labor income and consumption cause higher fertility (n), and hence lower young-age and total labor time ($1 - vn$, $l = 1 - vn + T/n$) as well as lower capital over output per young worker (k/y) in the BCE than in the LF. Overall, the LF has a welfare gain equivalent to a 0.21% rise in consumption from the BCE. These results suggest that the welfare loss of distortionary taxes outweighs the welfare gain of public health subsidies. Thus, the current policy rates in Australia reduce efficiency from the LF.

When comparing the Australia BCE with the SO in Table 3a, the BCE has lower old-age longevity or old-age labor (T), young-age health spending over output per young worker (h/y), capital over output per young worker (k/y), young-age labor ($1 - vn$) and total labor per young worker ($l = 1 - vn + T/n$) than the SO. However, the BCE has higher old-age health spending over output per young worker (m/y), fertility (n), young-age consumption over output per young worker (c/y) and old-age consumption over output per young worker (d/y) than the SO. The welfare improvement of the SO over the BCE in Australia is equivalent to a 6.28% rise in consumption due to the health externalities and suboptimal policy rates.

Specifically, high tax rates on consumption, capital income and labor income, especially old-age labor income, in Australia BCE have led to substantially lower capital over output per young worker (k/y), young-age labor ($1 - vn$) and total labor per young worker ($l = 1 - vn + T/n$) than the SO levels but considerably higher fertility (n) than the SO level. Additionally, young-age health spending over output per young worker (h/y) is lower but old-age health spending over output per young worker (m/y) is higher in the BCE than the SO levels, suggesting potential gains of increasing young-age public health subsidy (ξ) and reducing old-age public health subsidy (ξ^o) to correct health spending toward the SO level.

In Cases (4) and (5) of Table 3a, the welfare loss of a 10% reduction in the young-age or old-age health subsidy is equivalent to a 0.72% or 0.53% decline in consumption. Since health subsidies reduce the marginal cost of health spending but increase the marginal cost of childrearing, lower health subsidies lead to lower longevity (T) and higher fertility (n) than the BCE. Young-age labor and total labor also fall when fertility rises. Thus, health subsidies are essential to mitigate the efficiency loss of the health externalities. Subsidizing young-age health spending brings greater welfare improvements than subsidizing old-age health spending because young-age health spending improves labor productivity and labor supply at both young and old ages.

In Case (6) of Table 3a, a 10% reduction in old-age public transfers leads to a moderate welfare loss equivalent to a 0.25% decline in consumption. Lower old-age public transfers reduce the transfer cost of childrearing, causing fertility to rise and labor to fall from the BCE. In Case (7) of Table 3a, a 10% rise in the young-age labor income tax yields a relatively small welfare loss equivalent to a 0.09% decline in consumption.

However, in Case (8) or (9) in Table 3a, a 10% increase in the old-age labor income tax or capital income tax causes a large welfare loss equivalent to a 0.66% or 0.62% decline in consumption from the BCE level. In this regard, the negative effects of old-age labor income taxes on the transfer cost of childrearing and on the marginal benefits of health spending are substantial. Hence, the old-age labor income tax imposes larger distortions on individual decisions on fertility, young-age and total labor and old-age longevity or labor than the young-age labor income tax. The negative effect of the capital income tax on the marginal benefit of savings is also substantial, causing capital over output per young worker to fall substantially. A 10% rise in the consumption tax in Case (10) results in a moderate welfare loss equivalent to a 0.3% decline in consumption.

For the US in Table 3b, the BCE in Case (3) has higher young-old and old-age health spending, and hence higher old-age longevity or labor, than their counterparts in the LF owing to a high old-age public health subsidy (ξ^o) and high young-age EHI coverage (π) in the BCE. However, high distortionary taxes, especially high capital income taxes, cause much higher fertility and much lower capital over output per young worker than their counterparts in the LF. The welfare cost of the distortionary taxes on fertility outweighs the welfare gain of health subsidies in the BCE. Thus, the elimination of the taxes and subsidies in the BCE leads to a welfare gain equivalent to a 0.97% rise in consumption in the LF over the BCE. In other words, the current policies in the US reduce efficiency from the LF. Hence, there is a large welfare gain of the SO over the US BCE equivalent to a 7.37% rise in consumption.

Specifically, the US BCE has lower old-age longevity or labor, young-age and old-age health spending over output per young worker, capital over output per young worker, young-age labor and total labor per young worker than the SO levels. The BCE also has much higher fertility, young-age consumption over output per young worker and old-age consumption over output per young worker than those in the SO. Moreover, the welfare loss of policies is greater in the US BCE than in the Australia BCE.

In Cases (4) and (5) of Table 3b, the welfare loss of a 10% reduction in the young-age EHI coverage π is equivalent to a 1.01% fall in consumption, whereas the welfare loss of a 10% reduction in the old-age health subsidy ξ^o is equivalent to a 0.5% fall in consumption, much smaller than that from reducing the young-age EHI coverage. As in Australia, a 10% reduction in US old-age public transfers in Case (6) of Table 3b yields a moderate welfare loss equivalent to a 0.36% decline in consumption.

In Case (7) of Table 3b, a 10% rise in the young-age labor income tax in the US leads to a relatively small welfare loss equivalent to a 0.11% fall in consumption. In Case (8) or (9) of Table 3b, a 10% rise in the old-age labor income tax or capital income tax in the US engenders a large welfare loss equivalent to a 0.72% or 1.21% decline in consumption. In Case (10) of

Table 3b, a 10% rise in the consumption tax in the US yields a small welfare loss equivalent to a 0.18% fall in consumption.

Notice that the higher capital income tax in Case (9) of Table 3b leads to the largest welfare loss relative to other counterfactual experiments for the US BCE. These quantitative results are consistent with the conventional wisdom that the capital income tax is harmful for savings (e.g., Judd, 1985; Chamley, 1986). However, the efficiency loss of the capital income tax in the previous models is smaller than that in this model that treats fertility, labor supply and longevity as endogenous variables. For instance, a higher capital income tax in the US not only substantially decreases capital over output per young worker, young-age labor and total labor but also considerably increases fertility from their BCE levels.

In general, the quantitative effects of the counterfactual experiments for the US BCE in Table 3b are consistent with those for Australia BCE in Table 3a.[17] The main difference is that the welfare loss of a reduction in the young-age health subsidy or a rise in the tax on labor income or capital income is much higher in the US than in Australia. This is mainly because the US has lower longevity and a lower investment rate but higher fertility than Australia.

Moreover, a rise in the young-age labor income tax in both countries in Case (7) has the smallest welfare loss compared with an equivalent rise in any other taxes. This is in contrast with the conventional view that regards the consumption tax as the least distortionary taxes. Intuitively, the consumption tax has negative effects on the time cost, bequest cost and transfer cost of childrearing, while the young-age labor income tax has a negative effect only on the time cost of childrearing. Thus, the consumption tax yields higher fertility but lower capital over output per young worker, young-age labor and total labor per young worker than the young-age labor income tax. This result is different from those that ignore intergenerational transfers and assume fixed fertility and old-age labor.

7.2.2. Optimal health subsidies and optimal taxes

This subsection derives optimal health subsidies at steady states quantitatively for Australia and the US using benchmark parameterization in Table 2. Since the income tax is the largest source of government revenue and the most important source of funding public health subsidies in Australia and the US,[18] this subsection explores optimal public health subsidies financed by

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[17] Fertility is responsive to changes in tax rates quantitatively in our model, in line with the empirical evidence that finds statistically significant effects of taxes on fertility (Whittington, 1992; Whittington et al., 1990).

[18] To cover the cost of public health subsidies in Australia and the US, taxpayers pay Medicare taxes. High-income earners may need to pay additional Medicare taxes.

taxes on labor income and capital income. In doing so, we take the benchmark savings subsidy as given and set all other government instruments to zero.

Given the AUS BCE savings subsidy $\xi^s = 2\%$, Panel (1) of Table 4 shows that the optimal young-age public health subsidy (ξ) at 73.49% is much higher than the benchmark rate at 68.18%, while the optimal old-age public health subsidy (ξ^o) at 66.18% is slightly lower than the benchmark rate at 68.18%. The results suggest that age-specific health subsidies rates are essential to achieve the SO. Particularly, young-age workers should have higher health subsidies than old-age workers. To fund public health subsidies optimally, we need tax rates on young-age and old-age labor income and capital income at $\tau = 10.61\%$, $\tau^o = 6.01\%$ and $\tau^s = 15.82\%$, respectively. Thus, to achieve the SO, young workers receiving higher optimal health subsidies should also pay higher labor income taxes than old workers. The current Medicare levy in Australia is 2% of taxable income,[19] which is uniform across ages and far below the optimal labor income taxes computed here.

Given the US BCE savings subsidy $\xi^s = 0.8\%$, Panel (2) of Table 4 shows that for the US, the optimal young-age EHI coverage is $\pi = 57.98\%$ and the optimal old-age public health subsidy is $\xi^o = 46.41\%$, lower than their benchmark rates 65% and 50%, respectively. The corresponding optimal private health subsidy to a young worker is λ =58.62%, which is also lower than the benchmark rate 80% in the US (Jeske and Kitao, 2009). Therefore, our quantitative results suggest that the benchmark health subsidy rates in the US are too high compared with the optimal rates. Hence, to achieve the SO, young workers should receive higher health subsidies than old workers, as in the current health policy in the US.

Funding the old-age public health subsidy (Medicare) optimally in the US requires optimal tax rates on young-age and old-age labor income and capital income at $\tau = 0.47\%$, $\tau^o = 10.48\%$ and $\tau^s = 2.84\%$, respectively. In the US, the Medicare tax rate is 1.45% for the employer and 1.45% for the employee. Thus, the overall contribution rate 2.9% is higher than the aforementioned optimal young-age labor income tax rate but lower than the aforementioned optimal old-age labor income tax rate. To achieve the SO, old workers covered by the Medicare should pay more taxes than young workers in contrast to the result for Australia that requires young workers receiving more health subsidies to pay more taxes than old workers to achieve the SO. Hence, even if the young-age labor income tax is the least distortionary tax relative to other taxes to fund public health subsidies, the optimal rate of the young-age labor income tax depends positively on how much young workers benefit from public health subsidies.

[19] The Medicare Levy surcharge, an additional Medicare tax, is 1% to 1.5% depending on the income level.

Additionally, the optimal capital income tax rate should be low given the low benchmark savings subsidy rate in the US.

[Table 4 goes here]

When using the benchmark consumption tax to finance health subsidies as well, optimal public and private health subsidies (ξ, ξ^o, π) and optimal labor income taxes (τ, τ^o) are lower in both countries, as shown by Panels (1) and (2) of Table 5, than those in Table 4. In this case, reductions in labor income taxes are substantial for old workers who will now receive labor income subsidies.[20] This is because the consumption tax reduces the time cost, bequest cost and transfer cost of childrearing, thereby requiring the optimal old-age labor income tax to fall substantially such that the transfer cost of childrearing can be high enough to counteract the effects of the consumption tax. Taking the benchmark savings subsidy ξ^s as given, the optimal capital tax τ^s is unaffected by the benchmark consumption tax, as shown in Proposition 2.

[Table 5 goes here]

7.2.3. Quantitative implications of health externalities to labor productivity

This subsection examines the sensitivity of the optimal allocation and optimal policy at the steady state when the health externalities become stronger (i.e., a rise in μ from the benchmark 0.09 to 0.15), holding other policy instruments at their benchmark levels.[21]

Figures 1a and 1b illustrate the quantitative sensitivity of optimal fertility, optimal time allocations and optimal proportional allocations to variations in μ for Australia and the US, respectively. Internalizing the stronger health externality increases the optimal young-age and old-age health spending over output per young worker, old-age longevity or labor, capital over output per young worker, young-age labor and total labor per young worker. Doing so increases the costs of childrearing and the relative price of consumption, thereby reducing the optimal fertility and consumption over output per young worker at young and old ages.

[Figures 1a and 1b go here]

When only using income taxes to finance health subsidies in Figures 2a and 2b at the benchmark savings subsidy, the internalization of the stronger health externality increases optimal health subsidies and income taxes. The results are consistent with Proposition 1 that stronger health externalities require higher public health subsidies or higher private health

[20] As noted in Brewer et al. (2021), income-tax deductions for the elderly exist in the US and many OECD countries.

[21] Variations in the degree of health externalities do not affect fertility, time allocations and proportional allocations in the competitive equilibrium as agents ignore the external effects of their health spending.

subsidies through the EHI to internalize the marginal products of average health spending at young and old ages.

[Figures 2a and 2b go here]

Hence, the sensitivity analysis also suggests that universal public health becomes more expensive to internalize stronger health externalities by increasing workers' tax burden. This may motivate a health reform that expands the EHI to replace public health subsidies. We conduct a sensitivity analysis in Figures 3a and 3b to consider only the universal EHI in Australia and the US to fully replace public health. The quantitative results for the health reform are consistent with Proposition 1 that the EHI must be accompanied by appropriate taxes, such as income taxes in this exercise, to correct the marginal cost of childrearing to achieve the SO.

Specifically, internalizing the stronger health externality increases the optimal young-age and old-age EHI coverage (π, π^o), optimal old-age labor income tax (τ^o) and optimal capital income tax (τ^s). However, doing so decreases the young-age labor income tax (τ) or increases the young-age labor income subsidy for $\tau < 0$. The difference in labor income taxes between the young and old workers increases with the degree of the health externalities. The optimal capital income tax increases in Figures 2a, 2b, 3a and 3b because the stronger health externalities reduce optimal fertility in Figures 1a and 1b. The optimal young-age EHI coverage should be higher than the optimal old-age EHI coverage as the former benefits workers' health lifetime. Moreover, comparing Figures 2a and 2b with Figures 3a and 3b reveals a lower tax burden on young and old workers when replacing public health by the EHI as the young-age and old-age labor income tax rates are lower at each degree of health externalities.[22]

[Figures 3a and 3b go here]

The health reform that replaces public health with the universal EHI may be an extreme health reform. In fact, the theoretical results in Propositions 1 and 2 as well as the quantitative analysis in Subsections 7.2.2 and 7.2.3 suggest that public health subsidies and the EHI, which co-exist in the US, can support each other by covering different age groups of workers to achieve the SO outcome. Consequently, the findings of this paper may provide new insights for future health reforms in countries without universal public health or the EHI.

8. Conclusion

This paper developed a lifecycle-dynastic model with the choices of health spending, savings, labor supply, longevity and fertility to explore the effects of health externalities to labor

[22] For Australia, replacing public health with the EHI reduces the tax burden of old workers if the degree of health externalities is not sufficiently high.

productivity for efficiency concerns and policy implications. This paper makes the following theoretical contributions. First, the health externalities cause low health spending, longevity, labor productivity, labor supply, savings and output but high fertility because perceived private returns to health spending are below the social return.

Second, appropriate public or private health subsidies or both, accompanied by appropriate taxes, can attain the socially optimal outcome through age-specific rates of health subsidies and labor income taxes. In other words, the key policy tool to internalize health externalities to labor productivity is to find the respective optimal policy rates in each health system. Intuitively, health subsidies, particularly to young workers, either through universal public health insurance or employer-based group health insurance, increase the cost of childrearing and decrease the cost of health spending, thus increasing longevity, young-age and old-age labor and labor productivity and lowering fertility. Conversely, taxes on young-age and old-age labor income and consumption reduce the costs of childrearing. Taxes on young-age and old-age labor income also increase the cost of health spending. Subsidies on savings have negative effects on the cost of childrearing and the cost of savings which counteract the wedge of capital income taxes. Old-age public transfers induce altruistic parents to increase transfers to children, thus increasing the cost of childrearing. Appropriate subsidies and taxes with these opposing effects can give rise to the socially optimal outcome.

Third, private health subsidies through the EHI can ease the financial burden of funding public healthcare but the EHI for profit maximization alone cannot fully internalize health externalities to labor productivity when individuals choose the number of children. This is because the EHI increases the cost of childrearing excessively, causing fertility to fall below the socially optimal level. The EHI and appropriate taxes together can achieve the socially optimal outcome when their opposite effects on the cost of childrearing just correct the excessive fertility that arises from the health externalities.

Our quantitative analyses provide several results that may shed light on optimal health and tax policies. From calibration results based on Australian and the US data, fertility in both benchmark economies is above their laissez-faire and socially optimal levels, while young-age labor supply and capital per young worker in both benchmark economies are below the laissez-faire and socially optimal levels. Lower capital per young worker also implies lower output per young worker. Owing to high public and private health subsidies to young workers, young-age health spending and old-age labor supply or longevity in both benchmark economies are above the laissez-faire levels but below the socially optimal levels. Due to high public health subsidies to the elderly in Australia, old-age health spending is higher but total labor supply per young worker is lower in the Australia benchmark than the laissez-faire and socially optimal levels. In contrast, public health subsidies to workers are lower in the US than in Australia, thus old-age health spending and total labor supply per young worker in the US benchmark are above the laissez-faire levels but below the socially optimal levels. These quantitative results suggest policy improvements on the tax and health policies.

Specifically, when financing public health subsidies only by income taxes, the optimal policies to internalize health externalities to labor productivity depend on whether an economy has universal public health or not. For Australia with only universal public health, optimal public health subsidies and labor income taxes should be higher for young workers than for old workers because optimal young-age public health subsidies are higher than optimal old-age public health subsidies. On the contrary, for the US with public health for the elderly including old workers and private health subsidies for young workers, the optimal old-age labor income tax should be higher than the optimal young-age labor income tax. The optimal taxes here depart from those in models with fixed fertility and without health externalities to labor productivity. It allows for age-dependent health subsidies and labor income taxes in relation to the age-dependent marginal products of health spending at young and old age.

Furthermore, the internalization of the stronger health externality increases optimal health subsidies and income taxes to attain optimal allocations, suggesting that public health is expensive for non-negligible degrees of the health externalities. Replacing public health with the universal EHI lowers the optimal labor-income tax for all workers. However, replacing public health with the universal EHI requires old workers to pay higher labor income taxes than young workers to achieve the social optimum, and this intergenerational tax gap increases with the degree of the health externalities. Thus, this health reform may be extreme compared to a health system that allows for the co-existence of both public health subsidies and the EHI, such as by targeting each type of health subsidies at different age groups of workers.

In practice, public health subsidies have the advantage of providing healthcare services for those outside the labor force including young children and future workers, while the universal EHI has the advantage of reducing public health expenditure especially for countries facing rapid population ageing and high public debt. We leave these for future research.

References

Acton, R.K., Cao, W., Cook, E.E., Imberman, S.A., Lovenheim, M.F., 2022. The effect of vaccine mandates on disease spread: evidence from college COVID-19 mandates. NBER Working Paper Series w30303.

Aisa, R., Pueyo, F., 2006. Government health spending and growth in a model of endogenous longevity. Economics Letters 90(2), 249-253.

Altonji, J.G., Hayashi, F., Kotlikoff, L.J., 1997. Parental altruism and inter vivos transfers: Theory and evidence. Journal of Political Economy 105(6), 1121–66.

Australia Treasury. https://treasury.gov.au/speech/compulsory-superannuation-and-national-saving

Australian Government Actuary. https://aga.gov.au/

Becker, G., 1964. Human Capital. Chicago: University of Chicago Press.

Bhattacharya, J., Qiao, X., 2007. Public and private expenditures on health in a growth model. Journal of Economic Dynamics and Control 31(8), 2519-2535.

Bloom, D.E., Canning, D., 2003. Health as human capital and its impact on economic performance. The Geneva Papers on Risk and Insurance 28(2), 304–315.

Bloom, D.E., Canning, D., Kotschy, R., Prettner, K., Schünemann, J.J., 2022a. Health and economic growth: Reconciling the micro and macro evidence. NBER Working Paper 26003.

Bloom, D.E., Kuhn, M., Prettner, K., 2022b. Modern infectious diseases: Macroeconomic impacts and policy responses. Journal of Economic Literature 60(1), 85-131.

Brewer, B., Conway, K.S., Rork, J., 2021. Do income tax breaks for the elderly affect economic growth? Contemporary Economic Policy DOI: 10.1111/coep.12549.

Chakraborty, S., 2004. Endogenous lifetime and economic growth. Journal of Economic Theory 116(1), 119–37.

Chen, C., Feng, Z., Gu, J., 2022. Health, health Insurance, and inequality. Working Papers tecipa-730, University of Toronto, Department of Economics.

Conesa, J.C., Domínguez, B., 2020. Capital taxes and redistribution: the role of management time and tax deductible investment. Review of Economic Dynamics 37, 156-172.

Cremieux, P., Ouellette, P., Pilon, C., 1999. Health care spending as determinants of health outcomes. Health Economics 8, 627–39.

de Courville, C., Cadarette, S.M., Wissinger, E., Alvarez, F.P., 2022. The economic burden of influenza among adults aged 18 to 64: A systematic literature review. Influenza Other Respi Viruses 16(3), 376–385.

Davies, J.B., Kuhn, P., 1992. Social security, longevity, and moral hazard. Journal of Public Economics 49(1), 91-106.

Fang, H., Gavazza, A., 2011. Dynamic inefficiencies in an employment-based health insurance system: theory and evidence. American Economic Review 101, 3047-3077.

Feng, Z., Zhao, K., 2018. Employment-based health insurance and aggregate labor supply. Journal of Economic Behavior and Organization 154, 156–174.

Feng, Z., Villamil, A., 2022. Funding employer-based insurance: regressive taxation and premium exclusions. Economic Theory 73, 509–540.

Frankovic, I., Kuhn, M., 2023. Health insurance, endogenous medical progress, health expenditure growth, and welfare. Journal of Health Economics 87, 102717.

Friedman, J.N., 2017. Tax Policy and Retirement Savings. In Auerbach, A.J., Smetters, K. (eds), The Economics of Tax Policy (New York), online edn, Oxford Academic. https://doi.org/10.1093/acprof:oso/9780190619725.003.0018.

Greenwood, J., Seshadri, A., Vandenbroucke, G., 2005. The baby boom and baby bust. American Economic Review 95, 183–207.

Hitiris, T., Posnett, J., 1992. The determinants and effects of health expenditure in developed countries. Journal of Health Economics 6, 173–81.
Jeske, K., Kitao, S., 2009. US tax policy and health insurance demand: can a regressive policy improve welfare? Journal of Monetary Economics 56(2), 210–221.
Jung, J., Tran, C., 2022. Social health insurance: A quantitative exploration. Journal of Economic Dynamics and Control 139, 104374.
Kelly, M., 2020. Medicare for all or Medicare for none? A macroeconomic analysis of healthcare reform. Journal of Macroeconomics 63, 103170.
Kim, T.K., Lane, S.R., 2013. Government health expenditure and public health outcomes. American International Journal of Contemporary Research 3, 1–13.
Kuhn, M., Prettner, K., 2016. Growth and welfare effects of healthcare in knowledge-based economies. Journal of Health Economics 46, 100–19.
Laitner, J., Juster, F.T., 1996. New evidence on altruism: A study of TIAA-CREF retirees. American Economic Review 86(4), 893–908.
Martin, S., Rice. N., Smith, P.C., 2008. Does health care spending improve health outcomes? Evidence from English programme budgeting data.
Journal of Health Economics 27(4), 826-842.
Centers for Disease Control and Prevention. National Center for Health Statistics. https://www.cdc.gov/nchs/index.htm
OECD., 2016. Universal health coverage and health outcomes.
OECD., 2022. Consumption Tax Trends 2022. https://www.oecd.org/tax/consumption-tax-trends-19990979.htm
OECD data. https://data.oecd.org/
Or, Z., 2000. Determinants of health outcomes in industrialized countries: a pooled, cross-country, time-series analysis, 53–77. Paris: OECD.
Pestieau, P., Ponthière, G., Sato, M., 2008. Longevity, health spending, and pay-as-you-go pensions. Finanzarchiv 64 (1), 1–18.
Philipson, T.J., Becker, G.S., 1998. Old-age longevity and mortality-contingent claims. Journal of Political Economy 106, 551–73
Prettner, K., Bloom, D.E., Strulik, H., 2013. Declining fertility and economic well-being: Do education and health ride to the rescue? Labour Economics 22, 70-79.
Pruckner G.J., Schober, T., Zocher, K., 2020. The company you keep: health behavior among work peers. The European Journal of Health Economics 21, 251–259.
Rivera, B., Currais, L., 2004. Public Health Capital and Productivity in the Spanish Regions: A Dynamic Panel Data Model. World Development
32(5), 871-885.
Sauermann, J., 2016. Performance measures and worker productivity. IZA World of Labor.
Suhrcke, M., Urban, D. 2010. Are cardiovascular diseases bad for economic growth? Health Economics 19(12), 1478-1496.
Tang, K.K., Zhang, J., 2007. Health, education, and life cycle savings in the development process. Economic Inquiry 45(3), 615-630.
Tompa, Emile. 2002. The impact of health on productivity: Empirical evidence and policy implications. In The Review of Economic Performance and Social Progress 2002: Towards a Social Understanding of Productivity, ed. Andrew Sharpe, France St-Hilaire, and Keith Banting, 181–202.
Montreal: Institute for Research on Public Policy.
World Bank data. https://data.worldbank.org/
Weinzierl, M., 2011. The surprising power of age-dependent taxes. Review of Economic Studies 78, 1490–518.

White, C., 2021. Measuring social and externality benefits of influenza vaccination. Journal of Human Resources 56(3), 749–85.
Whittington, L. A., 1992. Taxes and the family: the impact of the tax exemption for dependents on marital fertility. Demography 29(2), 215-226.
Whittington, L. A., Alm, J., Peters, E., 1990. Fertility and the personal exemption: Implicit pronatalist policy in the United States. American Economic Review 80(3), 545-556.
Wolfe, B.L., Gabay, M., 1987. Health status and medical expenditures: More evidence of a link. Social Science & Medicine 25, 883–88.
Yew, S.L., Zhang, J., 2018. Health spending, savings and fertility in a lifecycle-dynastic model with longevity externalities. Canadian Journal of Economics 51(1), 186–215.
Yew, S.L., Li, S.M., Moslehi, S. 2024. Optimal parental leave subsidization with endogenous fertility and growth. Economic Inquiry 62(1), 97-125.
Zhang, J., 1995. Social security and endogenous growth. Journal of Public Economics 58, 185–213.
Zhang, J., Zhang, J., Leung, M., 2006. Health spending, saving, and public policy. Canadian Journal of Economics 39, 68–93.
Zhao, K., 2017. Social insurance, private health insurance and individual welfare. Journal of Economic Dynamics and Control 78, 102-117.

TABLE 1. Selected observations in Australia and the US

Descriptions	Notations	Australia	US
Savings subsidy	ξ^s	2%	0.8%
Consumption tax	τ^c	10%	6%
Old- and young-age labor income tax	$\tau^o = \tau$	28%	27%
Capital income tax	τ^s	30%	33%
Old-age public transfers (% of GDP)	P^o/y	4%	6%
Old-age public health subsidy	ξ^o	68.18%	50%
Young-age public health subsidy	ξ	68.18%	0%
Old-age EHI coverage rate	π^o	0%	0%
Young-age EHI coverage rate	π	0%	65%
Total health spending (% of GDP)	$(m+h)/y$	8.8%	15.6%
Longevity at age 35	T	0.5913	0.4815
Investment rate (% of GDP)	kn/y	22%	18%
Fertility per young parent	n	0.91	0.965

SOURCE: Consumption tax (OECD, 2022; Conesa and Dominguez, 2020); taxes on labor and capital income (OECD data, 2000-2020); longevity (Australian Government Actuary, 2000-2017; Centers for Disease Control and Prevention, 2000-2017); total and public health spending % of GDP (OECD data, 2000-2020); fertility (OECD data, 2000-2020); old-age public transfers % of GDP (OECD data, 2000-2017); investment rate (World Bank data, 2000-2020); the fraction of young-age medical expenses covered by EHI and US old-age universal public health subsidy (Zhao, 2017); Australian savings subsidy (Australia Treasury); US savings subsidy (Friedman, 2017).

TABLE 2. Benchmark parameterization

a. Parameter values for both Australia (AUS) and US	
$t = 30$	Number of years per period
$v = 0.1$	Fixed time rearing a child
$\sigma_1 = 1$	Reciprocal of intertemporal elasticity of substitution for consumption
$\sigma_2 = 4.5$	Reciprocal of intertemporal elasticity of substitution for fertility
$\theta = 0.33$	Capital's income share
$A = 1$	Total factor productivity
$\epsilon = 1$	Coefficient reducing the marginal effectiveness of health spending
$\psi = 0.8$	Return factor on health spending
$\phi = 0.5$	Share of young-age health spending in the technology of health status
$\mu = 0.09$	Elasticity of output with respect to average health in final goods production
b. Country-specific parameter values	
AUS: $\alpha = 0.7103$	Intergenerational discounting factor
US: $\alpha = 0.6317$	
AUS: $\beta = 0.3552$	Taste for parental old-age consumption
US: $\beta = 0.3159$	
AUS: $\rho = 0.3069$	Taste for the number of children
US: $\rho = 0.3205$	
AUS: $\frac{\delta}{y} = 0.81\%$	Coefficient reducing the effectiveness of health spending
US: $\frac{\delta}{y} = 6.05\%$	
AUS: $D = 0.6832$	Autonomous factor of longevity
US: $D = 0.7836$	

TABLE 3a. Comparisons of equilibrium outcomes at steady states: AUS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variable	SO	LF	BCE	$\xi = 0.6136$	$\xi^o = 0.6136$	$P^o/y = 0.036$	$\tau = 0.308$	$\tau^o = 0.308$	$\tau^s = 0.33$	$\tau^c = 0.11$
T	0.6048	0.5481	0.5913	0.5870	0.5870	0.5913	0.5913	0.5896	0.5913	0.5913
h/y	0.0404	0.0175	0.0278	0.0238	0.0288	0.0277	0.0278	0.0270	0.0277	0.0277
m/y	0.0599	0.0374	0.0603	0.0632	0.0521	0.0604	0.0603	0.0593	0.0605	0.0605
k/y	0.2883	0.2812	0.2418	0.2405	0.2399	0.2401	0.2412	0.2383	0.2366	0.2398
n	0.8131	0.8336	0.9100	0.9135	0.9153	0.9148	0.9117	0.9200	0.9164	0.9157
$1 - vn$	0.9187	0.9166	0.9090	0.9087	0.9085	0.9085	0.9088	0.9080	0.9084	0.9084
l	1.6625	1.5741	1.5588	1.5512	1.5497	1.5549	1.5575	1.5488	1.5537	1.5542
c/y	0.4537	0.4824	0.4753	0.4772	0.4788	0.4757	0.4755	0.4771	0.4776	0.4758
d/y	0.3051	0.3669	0.3658	0.3714	0.3734	0.3680	0.3666	0.3723	0.3701	0.3684
Δ^i	0.0628	0.0021	NA	-0.0072	-0.0053	-0.0025	-0.0009	-0.0066	-0.0062	-0.0030

Note: Young-age public lump-sum transfers are used to balance government budget for cases (4) to (10).

TABLE 3b. Comparisons of equilibrium outcomes at steady states: US

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variable	SO	LF	BCE	$\pi = 0.585$	$\xi^o = 0.45$	$P^o/y = 0.054$	$\tau = 0.297$	$\tau^o = 0.297$	$\tau^s = 0.363$	$\tau^c = 0.066$
T	0.4919	0.4078	0.4815	0.4707	0.4755	0.4814	0.4815	0.4767	0.4814	0.4815
h/y	0.0514	0.0255	0.0484	0.0412	0.0486	0.0482	0.0484	0.0466	0.0481	0.0483
m/y	0.1141	0.0901	0.1076	0.1119	0.1000	0.1080	0.1077	0.1058	0.1082	0.1078
k/y	0.2371	0.2288	0.1865	0.1843	0.1852	0.1846	0.1859	0.1838	0.1795	0.1856
n	0.8793	0.9111	0.9650	0.9739	0.9705	0.9727	0.9674	0.9760	0.9767	0.9687
$1 - vn$	0.9121	0.9089	0.9035	0.9026	0.9029	0.9027	0.9033	0.9024	0.9023	0.9031
l	1.4715	1.3565	1.4025	1.3859	1.3929	1.3977	1.4010	1.3908	1.3952	1.4001
c/y	0.4508	0.4838	0.4786	0.4834	0.4817	0.4791	0.4787	0.4815	0.4821	0.4788
d/y	0.4030	0.5405	0.4796	0.5003	0.4917	0.4841	0.4810	0.4930	0.4891	0.4818
Δ^i	0.0737	0.0097	NA	-0.0101	-0.0050	-0.0036	-0.0011	-0.0072	-0.0121	-0.0018

Note: Young-age public lump-sum transfers are used to balance government budget for cases (4) to (10).

TABLE 4. Optimal health subsidies and income taxes (%) at steady states

	(1)	(2)
Policy variables	Optimal rates at AUS BCE $\xi^s = 0.02$	Optimal rates at US BCE $\xi^s = 0.008$
ξ	0.7349	NA
π	NA	0.5798
ξ^o	0.6618	0.4641
τ^s	0.1582	0.0284
τ	0.1061	0.0047
τ^o	0.0601	0.1048

Note: $\tau^c = P/y = P^o/y = 0$.

TABLE 5. Optimal health subsidies and income taxes (%) at steady states

	(1)	(2)
Policy variables	Optimal rates at AUS BCE $\xi^s = 0.02, \tau^c = 0.1$	Optimal rates at US BCE $\xi^s = 0.008, \tau^c = 0.06$
ξ	0.6732	NA
π	NA	0.5060
ξ^o	0.5830	0.3700
τ^s	0.1582	0.0284
τ	0.0832	-0.0109
τ^o	-0.1587	-0.0525

Note: $P/y = P^o/y = 0$.

FIGURE 1a. Sensitivity of optimal allocations to higher μ at steady state for Australia

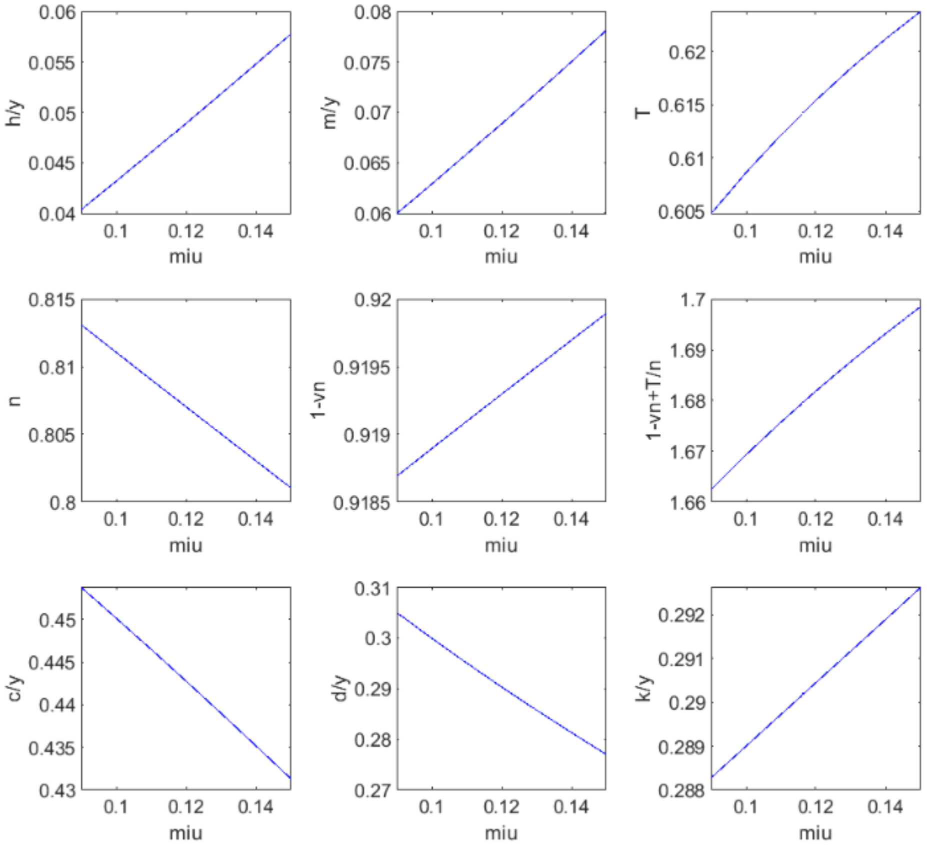
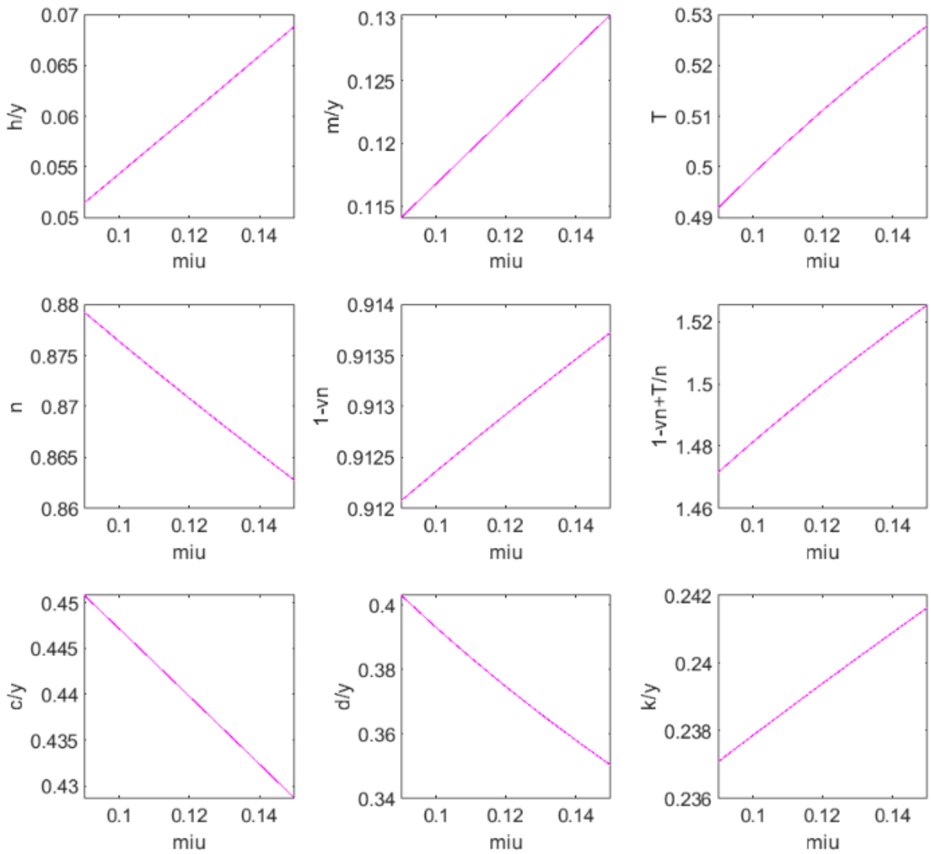


FIGURE 1b. Sensitivity of optimal allocations to higher μ at steady state for the US



NOTE: miu is μ.

FIGURE 2a. Sensitivity of optimal public health subsidies and optimal income taxes to higher μ at AUS benchmark ξ^s at steady state

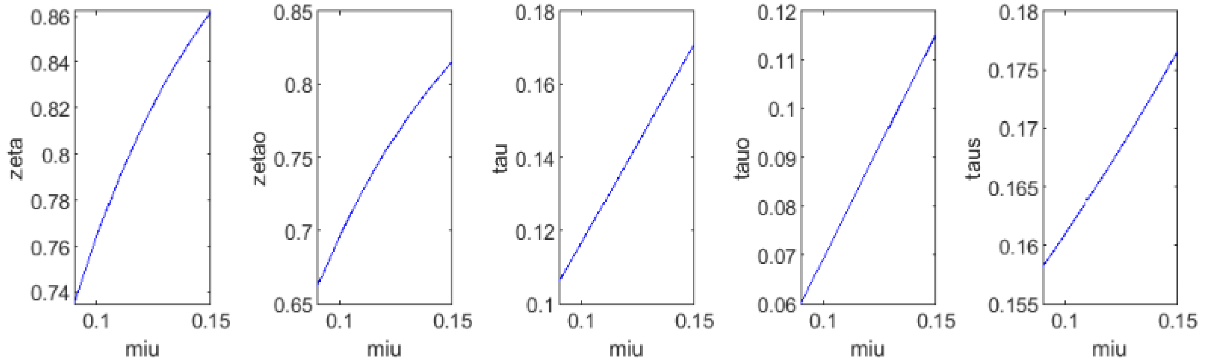
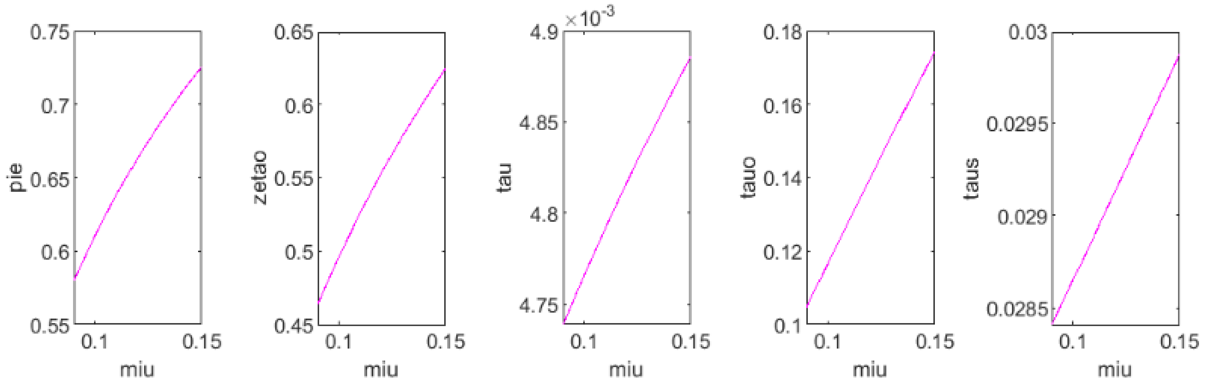


FIGURE 2b. Sensitivity of optimal young-age EHI coverage, optimal old-age health subsidy and optimal income taxes to higher μ at US benchmark ξ^s at steady state



NOTE: $\tau^c = P/y = P^o/y = 0$, miu is μ, zeta is ξ, pie is π, zetao is ξ^o, tau is τ, tauo is τ^o and taus is τ^s.

FIGURE 3a. Sensitivity of optimal EHI coverage and optimal income taxes to higher μ at AUS benchmark ξ^s at steady state

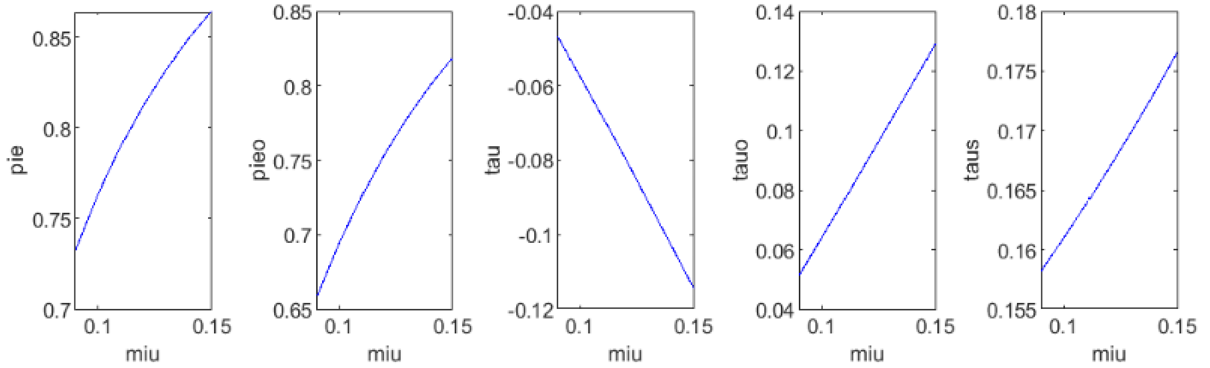
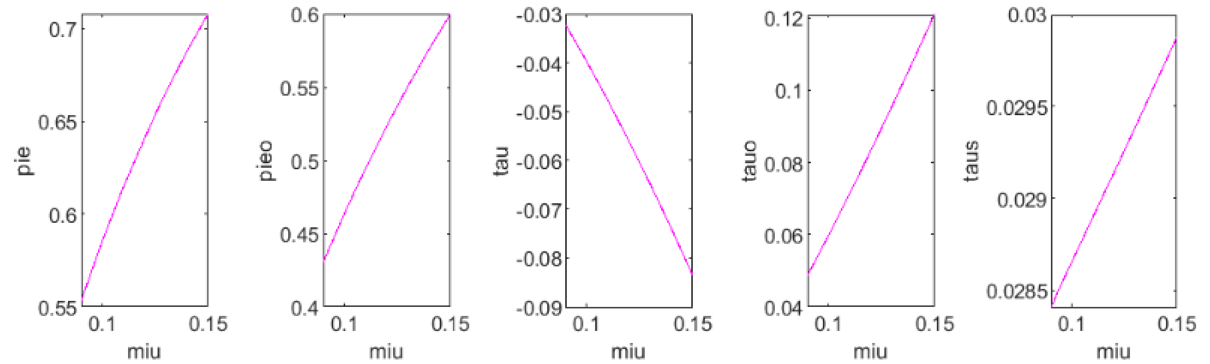


FIGURE 3b. Sensitivity of optimal EHI coverage and optimal income taxes to higher μ at US benchmark ξ^s at steady state



NOTE: $\tau^c = P/y = P^o/y = 0$, miu is μ, pie is π, pieo is π^o, tau is τ, tauo is τ^o and taus is τ^s.

Appendixes

A. ***Proof of Proposition 1.*** The conditions for optimal taxes and subsidies arise from equating the equilibrium conditions with the socially optimal conditions. Substituting market clearing conditions, consistency, zero profit conditions in production and health insurance provision, (5), (6), (v), (vi) and (vii) into the single budget constraint of the dynasty in (24) recovers feasibility in (7). Substituting (iv) into (25) yields (9). Substituting consistency, (ii), (iii), (v) and (5) into (26) yields (10). Substituting consistency, (iii), (v), (5) and (14) into (27) attains (11). Substituting consistency, (i), (iii), (iv), (vii), (ix), (5), (25) and $s_t = k_{t+1}n_t$ into (28) yields (12). Conditions (viii) and (ix) follow (22) and (23). Finally, condition (v) satisfies the government balanced budget constraint.

B. ***Steady-state socially optimal allocation with specific functions.*** Using specific functions, the steady-state socially optimal allocation from conditions (7) to (12) is as follows:

(A1) $c = \frac{y(1-\alpha\theta)-h-mT(h,m)/n}{1+(1/n)(\beta n/\alpha)^{\frac{1}{\sigma_1}}}$,

(A2) $d = (\frac{\beta n}{\alpha})^{\frac{1}{\sigma_1}}\left(\frac{c}{T(h,m)}\right)$,

(A3) $k = \alpha\theta y/n$,

(A4) $f_h(k,\Omega(h,m)l) + \left(\frac{\alpha}{n}\right)T_h(h,m)\left[f_l(k,\Omega(h,m)l) - m\right] - 1 = 0$,

(A5) $f_m(k,\Omega(h,m)l) + \left(\frac{T_m(h,m)}{n}\right)\left[f_l(k,\Omega(h,m)l) - m\right] - \frac{T(h,m)}{n} = 0$,

(A6) $\rho n^{2-\sigma_2}c^{\sigma_1} + \alpha\left[c(\frac{\beta n}{\alpha})^{\frac{1}{\sigma_1}} + mT(h,m)\right] -$

$$f_l(k,\Omega(h,m)l)\left[vn^2 + \alpha T(h,m)\right] + y\alpha\theta n = 0,$$

where $y = \left[A\left(\frac{\alpha\theta}{n}\right)^{\theta}\right]^{\frac{1}{1-\theta}}\left(\mathrm{z}(h,m)\right)^{\mu}l$, $f_l(k,\Omega(h,m)l) = (1-\theta)y/l$,

$$f_k(k,\Omega(h,m)l) = \theta y/k,\ T_h(h,m) = \frac{T(h,m)\psi\delta\phi}{[\delta+\epsilon z(h,m)]h},\ T_m(h,m) = \frac{T(h,m)\psi\delta(1-\phi)}{[\delta+\epsilon z(h,m)]m},$$

$$f_h(k,\Omega(h,m)l) = \mu(1-\theta)y\phi/h,\ f_m(k,\Omega(h,m)l) = \mu(1-\theta)y(1-\phi)/m.$$

From (A3) and the expression for f_k, binding solvency requires $R = f_k = n/\alpha > 1$.

C. ***Proof of Proposition 2.*** At the steady state, the first-order condition with respect to d is similar to (A2). First-order conditions (25) to (28) with specific functions are

(A7) $s = \frac{\alpha\theta yn(1-\tau^s)}{n(1-\xi^s)-\alpha\tau^s}$,

(A8) $\left(\frac{\alpha}{n}\right)T_h(h,m)[(1-\tau^o)f_l(k,\Omega(h,m)l) - (1-\pi^o-\xi^o)m] - (1-\pi-\xi) = 0$, (A9) $T_m(h,m)[(1-\tau^o)f_l(k,\Omega(h,m)l)-(1-\pi^o-\xi^o)m]-$

$$(1-\pi^o-\xi^o)T(h,m)=0,$$

(A10) $\rho n^{2-\sigma_2}c^{\sigma_1}(1+\tau^c)-f_l(k,\Omega(h,m)l)[(1-\tau)vn^2+\alpha(1-\tau^o)T(h,m)]+$

$$\alpha\left[c\left(\frac{\beta n}{\alpha}\right)^{\frac{1}{\sigma_1}}(1+\tau^c)+(1-\xi^o)mT(h,m)-I^o\lambda^o-P^o-\theta yn+\tau^s(\theta yn-s)\right]=0.$$

Substituting (i) and $s=kn$ into (A7) yields (A3). Substituting (ii), (iii) and (v) into (A8) yields (A4). Substituting (ii) and (iii) into (A9) yields (A5). Substituting conditions (i) to (iv), (vii) and (ix), and $s=kn$ into (A10) yields (A6). Substituting market clearing conditions, the zero-profit condition in production, the zero-profit condition for health insurance provision, the government budget constraint, (vi) and (vii) into (24) can recover feasibility in (7) at the steady state or optimal c in (A1). Conditions (viii) and (ix) follow (22) and (23). Finally, conditions (i)-(iv) satisfy the government balanced budget constraint.