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Juan Carlos Conesa
Timothy J. Kehoe
Vegard M. Nygaard
Gajendran Raveendranathan

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Implications of Increasing College Attainment for Aging in General Equilibrium
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ABSTRACT

We develop and calibrate an overlapping generations general equilibrium model of the U.S. economy with heterogeneous consumers who face idiosyncratic earnings and health risk to study the implications of exogenous trends in increasing college attainment, decreasing fertility, and increasing longevity between 2005 and 2100. While all three trends contribute to a higher old age dependency ratio, increasing college attainment has different macroeconomic implications because it increases labor productivity. Decreasing fertility and increasing longevity require the government to increase the average labor tax rate from 32.0 to 44.4 percent. Increasing college attainment lowers the required tax increase by 10.1 percentage points. The required tax increase is higher under general equilibrium than in a small open economy with a constant interest rate because the reduction in the interest rate lowers capital income tax revenues.

Juan Carlos Conesa
Department of Economics
Stony Brook University
Stony Brook, NY 11794-4384
juan.conesa@stonybrook.edu

Timothy J. Kehoe
University of Minnesota
Department of Economics
1925 Fourth Street South
Minneapolis, MN 55455-0462
and Federal Reserve Bank of Minneapolis
and also NBER
tkehoe@umn.edu

Vegard M. Nygaard
Department of Economics
University of Minnesota
1925 Fourth Street South
Minneapolis, MN 55455
United States
nygar028@umn.edu

Gajendran Raveendranathan
Department of Economics
MacMaster University
1280 Main Street West
Hamilton Ontario L8S 4M4
Canada
raveeg1@mcmaster.ca

1 Introduction

The ratio of the population 65 and older to the population that is 20–64 (that is, the *old age dependency ratio*) in the United States is projected to increase from about 20 percent in 2005 to more than 50 percent by 2100 according to estimates by the United Nations. The literature has used overlapping generations models with heterogeneous consumers to analyze the implications of the projected increase in the old age dependency ratio due to decreasing fertility rates and increasing longevity. Attanasio et al. (2010), for example, have argued that the U.S. government will have to increase the labor tax rate by 12.7 percentage points by 2080 to finance the increase in Medicare, Medicaid, and Social Security spending. Our paper extends this literature by introducing increasing college attainment into the model. We argue that increasing college attainment—which accounts for some of the increase in the old age dependency ratio because college-educated individuals have higher life expectancy—has different macroeconomic implications than decreasing fertility and increasing longevity because higher college attainment leads to a more productive labor force.

Following Conesa et al. (2018), we develop an overlapping generations general equilibrium model with heterogeneous consumers who face idiosyncratic earnings and health risk. Consumers are *ex ante* heterogeneous in education. In particular, some are college-educated and some are not. Consistent with the data, college-educated consumers in the model have both higher life expectancy and higher labor productivity. Consumers in our model can save in non-state-contingent bonds and partially insure against health risk through employer-provided insurance or by purchasing private insurance. Furthermore, the model economy incorporates the key social insurance programs in the United States through Medicare, Medicaid, Social Security, and a welfare program that combines institutional features of food stamps, disability insurance, and medical relief for the poor (for brevity, referred to as *Emergency Relief*). The government finances its spending on consumption, interest payments on debt, Medicare, Medicaid, Emergency Relief, and Social Security by levying consumption taxes, capital income taxes, and labor income taxes. We assume that the consumption and capital income tax rates are fixed and that the government balances its budget each period by adjusting the labor tax rate.

After calibrating the model to match key features of the U.S. economy in 2005, we use the model to study the macroeconomic implications of the three channels that contribute to an increase in the old age dependency ratio mentioned above: increasing college attainment, decreasing fertility, and increasing longevity (for brevity, we refer to the three channels that lead to an increase in the old age dependency ratio as the three channels of *aging*). In particular, we change the mass of 20-year-olds entering the economy with a college degree, the growth rate of the 20-year-old population, and the age-specific survival probabilities to match relevant projections for 2100. Increasing college attainment increases the old age dependency

ratio because college graduates have higher life expectancy than non-college graduates. Decreasing fertility increases the old age dependency ratio because it leads to relatively fewer young consumers. Lastly, increasing longevity increases the old age dependency ratio because it leads to relatively more old consumers.

We start by studying the individual fiscal implications of the three channels of aging. Our results show that decreasing fertility and increasing longevity require the government to increase the labor tax rate, whereas increasing college attainment allows the government to reduce the labor tax rate. There are a number of reasons for this result. First, and most importantly, an increase in college attainment leads to an economy with more productive workers and therefore higher labor earnings, which in turn leads to higher labor tax revenues. Second, college graduates are less likely to enroll in Medicaid and Emergency Relief. Higher college attainment thus reduces government spending on these programs. Third, higher college attainment leads to higher consumption tax revenues and higher capital income tax revenues. This follows because college graduates both consume and save more than non-college graduates. College graduates save more since they have higher labor earnings, higher life expectancy, and a stronger precautionary savings motive because they are less likely to enroll in Medicaid and Emergency Relief. Lastly, there are general equilibrium effects. Higher college attainment leads to higher capital accumulation, which in turn leads to lower interest rates and higher wages. Lower interest rates reduce interest payments on government debt, thereby lowering government spending. Higher wages lead to a further increase in labor tax revenues, not only because of the direct effect of higher wages on earnings but also because higher wages induce consumers to work more.

The forces that we have mentioned so far contribute to lower labor taxes, but there are forces that move in the opposite direction. In particular, an increase in college attainment leads to higher spending on Medicare and Social Security. This is because college-educated consumers have higher life expectancy than non-college-educated consumers and because college-educated consumers claim higher Social Security benefits due to higher lifetime labor earnings.

We then study the joint fiscal implications of the three channels of aging. In particular, we study the fiscal implications of introducing increasing college attainment into the model with decreasing fertility and increasing longevity. We find that decreasing fertility and increasing longevity require the government to increase the average labor tax rate from 32.0 to 44.4 percent by 2100. Adding increasing college attainment to this model lowers the required increase in the labor tax rate by 10.1 percentage points. Consequently, we find that all three channels of aging require the government to increase the average labor tax rate from 32.0 to 34.3 percent by 2100.

Finally, to identify the general equilibrium effects in our results, we compare the results from the benchmark closed economy with the results from those of a small open economy in which the real interest rate is

constant and exogenous. By construction, the wage rate in the detrended balanced growth economy is also constant in the small open economy. We find that the capital stock increases in both the general equilibrium model and the small open economy model. In the general equilibrium model, however, the increase in the capital stock also leads to higher wages and lower interest rates. Lower interest rates reduce government revenues from capital income taxation. Consequently, introducing higher college attainment in the model with decreasing fertility and increasing longevity leads to a larger increase in capital income tax revenues per capita in the small open economy model relative to the general equilibrium model. Our results show that this additional increase in government revenues from capital income taxation results in a larger reduction in the labor tax rate in the small open economy model. In particular, adding higher college attainment in the model with decreasing fertility and increasing longevity lowers the required increase in the labor tax rate by 10.1 percentage points in the general equilibrium model but by 13.1 percentage points in the small open economy model.

Our paper is related to the literature that develops general equilibrium overlapping generations models to study the implications of decreasing fertility and increasing longevity. These demographic trends will lead to a large increase in government spending on Medicare, Medicaid, and Social Security over the next century. De Nardi et al. (1999), Kotlikoff et al. (2007), and Attanasio et al. (2010) study the macroeconomic and welfare implications of various fiscal policy reforms that have been proposed to finance government spending on social insurance programs in the future, such as increasing payroll taxes, increasing the eligibility age for benefits, or reducing the generosity of benefits. In a recent paper, Jung et al. (2017) develop a general equilibrium overlapping generations model with endogenous health to study the implications of aging for health care spending and health insurance coverage. They use the model to study how the implications of aging are affected by the introduction of the Patient Protection and Affordable Care Act (ACA). Unlike our paper, these papers do not focus on increasing college attainment. While increasing college attainment, decreasing fertility, and increasing longevity all contribute to an increase in the old age dependency ratio, we show that increasing college attainment has different macroeconomic implications than decreasing fertility and increasing longevity.

Our paper also contributes to the literature that develops overlapping generations models to study the implications of earnings, health, medical expenditure, and mortality risk. Auerbach and Kotlikoff (1987), Conesa and Krueger (1999), Kotlikoff et al. (1999), Altig et al. (2001), Nishiyama and Smetters (2007), and İmrohoroglu and Kitao (2012) develop overlapping generations models to study the implications of Social Security and tax reforms. Hubbard et al. (1994), Palumbo (1999), De Nardi et al. (2010), Kopecky and Koreshkova (2014), and Nakajima and Telyukova (2018) develop models to examine how medical expenditure risk affects the savings of the elderly. Pashchenko and Porapakarm (2013) develop a model to examine the

implications of the ACA, and Conesa et al. (2018) develop a model to study the macroeconomic and welfare effects of Medicare. Finally, Ozkan (2014), Jung and Tran (2016), Scholz and Seshadri (2016), and Cole et al. (2019) develop models in which health evolves endogenously over the life cycle to study the macroeconomic effects of health insurance reforms. Our paper extends this literature by developing a general equilibrium overlapping generations model to study the long-run implications of increasing college attainment, decreasing fertility, and increasing longevity.

The rest of the paper is organized as follows. Section 2 presents the benchmark model used in the paper. After calibrating the model in Section 3, we study the macroeconomic implications of increasing college attainment, decreasing fertility, and increasing longevity in Section 4. Lastly, Section 5 concludes and gives directions for future research.

2 Model

The following subsections present the benchmark model used in the analysis. The model is a discrete time, general equilibrium, overlapping generations model with heterogeneous consumers that follows closely that in Conesa et al. (2018).

2.1 Firms

Firms hire labor at wage w_t and rent capital at rate r_t from consumers to produce goods. We assume that the technology at time t can be represented by a constant returns to scale Cobb-Douglas production function:

$$\hat{Y}_t = \hat{K}_t^\alpha (Z_t N_t)^{1-\alpha}, \quad (1)$$

where \hat{K}_t is the aggregate capital stock, Z_t denotes labor-augmenting technological progress, N_t denotes effective labor supply, and α is capital's share of income. Technological progress is given by $Z_t = \theta (1 + g_z)^t$, where g_z denotes the growth rate of technology. Similarly, g_n denotes the growth rate of 20-year-old consumers, which is the age at which consumers enter the economy.

Output is used for total private consumption, \hat{C}_t , government consumption, $\hat{G}_{c,t}$, investment, $\hat{K}_{t+1} - (1 - \delta) \hat{K}_t$, and purchase of health care services, \hat{M}_t , where δ denotes the rate of capital depreciation. Let $x_t \equiv \frac{\hat{x}_t}{(1+g_z)^t}$ denote productivity-detrended variables. The detrended resource constraint can then be written as follows:

$$C_t + G_{c,t} + M_t + (1 + g_z)(1 + g_n) K_{t+1} = K_t^\alpha (\theta N_t)^{1-\alpha} + (1 - \delta) K_t. \quad (2)$$

For the remainder of the paper, we drop time subscripts and use t to denote next-period variables.

2.2 Consumers

The economy is populated by a continuum of *ex ante* and *ex post* heterogeneous consumers. Consumers are indexed by type $s = (j, e, h, \eta, a, i)$, where j is age, e is educational level, h is health status, η is the stochastic component of labor productivity, a is assets, and i is the consumer's health insurance status. We let $\Phi(s)$ denote the measure of consumers of type s .

The consumer's educational level is permanent over her lifetime and can take two values: college or non-college. Health status is stochastic and is a function of the consumer's current age, education, and health. It follows a finite-state Markov process with stationary transitions over time:

$$Q_{j,e}(h, H) = \text{Prob}(h' \in H : (h, j, e)), \quad (3)$$

where $Q_{j,e}(h, H)$ denotes the probability of next period's health conditional on current health, age, and education. The stochastic component of labor productivity is given by a stationary finite-state Markov process:

$$Q(\eta, E) = \text{Prob}(\eta' \in E : \eta), \quad (4)$$

where $Q(\eta, E)$ denotes the probability of next period's stochastic labor productivity conditional on current stochastic labor productivity. Lastly, the consumer's health insurance status, i , specifies whether she is uninsured, i_S , has private health insurance, i_P , or has employer-provided health insurance, i_E .

Consumers are endowed with one unit of time in every period that can be allocated between work and leisure. The period-by-period utility function is given by

$$U(c, \ell) = \frac{[c^\gamma(1 - \ell)^{1-\gamma}]^{1-\sigma}}{1 - \sigma}, \quad (5)$$

where c denotes consumption and ℓ denotes labor supply. We assume that labor supply is indivisible, $\ell \in \{0, \ell_p, \dots, \ell_e\}$, where ℓ_p and ℓ_e refer to part-time and extra time, respectively. The consumer's labor earnings depend on her labor supply, ℓ , stochastic labor productivity, η , health status, ξ_h , and deterministic life cycle labor productivity, ϵ_{je} , the last of which varies with the consumer's age and educational level. Starting at age j_r , all consumers receive health insurance from the government in the form of Medicare. They also receive Social Security benefits, SS_{je} , that depend on their cohort and education. Lastly, consumers face a conditional survival probability, ψ_{jeh} , that depends on their age, education, and health. The maximum

life span of consumers is J . In the event of death, the consumers's assets are uniformly distributed across the population by means of lump-sum transfers, B .

2.3 Health insurance and welfare programs

This section presents the different types of health insurance in the economy. As noted earlier, health insurance is available in the form of private health insurance and employer-provided health insurance. In addition, the government provides health insurance through Medicare and Medicaid. Health insurance is used to cover non-discretionary health care expenses, m_{jh} , which vary with the consumer's age and health status. Throughout, we let χ_P , χ_E , χ_{CARE} , and χ_{CAID} denote the coinsurance rate for private health insurance, employer-provided health insurance, Medicare, and Medicaid, respectively. To illustrate, a value of 0.229 for χ_P means that the consumer covers 22.9 percent of the health care expenses, and that private health insurance covers the remaining 77.1 percent of the health care expenses.

Medicaid Medicaid is a means-tested program that provides health insurance to income/asset poor consumers. Consistent with the U.S. eligibility criteria, we model two ways to qualify for Medicaid. First, consumers qualify under the *categorical* criterion if the sum of their gross income and interest earnings is below a threshold, y^{CAT} . Second, consumers qualify under the *medically needy* criterion if the sum of their gross income and interest earnings net of out-of-pocket medical expenses is below a threshold, y^{MN} , and their assets are less than a threshold, a^{MN} .

Medicare The government also provides health insurance in the form of Medicare. Unlike Medicaid, Medicare is not a means-tested program, but covers a share $1 - \chi_{CARE}$ of health care expenses of all consumers aged j_r and older. Since Medicare has a positive coinsurance rate, $\chi_{CARE} > 0$, old consumers can purchase private health insurance to further lower their out-of-pocket medical expenditure risk.

Emergency relief The government runs a welfare program that combines institutional features of food stamps, disability insurance, and medical relief for the poor (for brevity, referred to as *Emergency Relief*). To qualify for this program in the model, consumers have to forfeit all assets and work zero hours. In return, the government covers all health care costs and guarantees a minimum consumption level, \underline{c} .

Private health insurance Consumers can purchase private health insurance for the following period. We assume that the premium for private health insurance is actuarially fair for each insurance pool, where the insurance pool is given by consumers with the same age, education, and health (j, e, h) . This gives the

following expression for the detrended private health insurance premium:

$$\pi_{jeh} = \begin{cases} \frac{\psi_{jeh}(1-\chi_P)(1+g_z) \int m_{j'h'} Q_{j,e}(h, dh')}{1+r} & \text{if } j < j_r - 1 \\ \frac{\psi_{jeh}(1-\chi_P)\chi_{CARE}(1+g_z) \int m_{j'h'} Q_{j,e}(h, dh')}{1+r} & \text{if } j \geq j_r - 1, \end{cases} \quad (6)$$

where π_{jeh} is the expected medical expense for the insurance company, discounted by the interest rate.

Employer-provided health insurance We assume that a fraction of consumers that are younger than age j_r work for an employer that provides health insurance. In that case, $i = i_E$. The employer pools the health care expenses of all their employees that do not choose to go on Emergency Relief. These costs are then split evenly across the employees. That is, we model employer-provided health insurance as a pay-as-you-go system where current contributors pay for the health care expenses of current receivers. This gives the following expression for the detrended employer-provided health insurance premium:

$$\pi_E = \frac{(1 - \chi_E) \int \mathbf{1}_{F=0} m_{jh} \Phi(\{1, \dots, j_r - 1\} \times de \times dh \times d\eta \times da \times \{i_E\})}{\int \mathbf{1}_{\ell > 0} \Phi(\{1, \dots, j_r - 1\} \times de \times dh \times d\eta \times da \times \{i_E\})}, \quad (7)$$

where the indicator function $\mathbf{1}_{F=0}$ in the numerator equals one for all consumers that do not choose to go on Emergency Relief. We assume that consumers are not allowed to have both employer-provided and private health insurance. Moreover, to alleviate the adverse selection problem associated with group insurance plans, we assume that consumers that work for an employer that provides health insurance are not allowed to opt out of employer-provided insurance. Lastly, motivated by the low take-up rate of employer-provided health insurance among individuals that are older than 65 in the United States, we assume that consumers aged j_r and older do not receive employer-provided insurance in the model.

2.4 Government

The government engages in five activities in the model. First, as already noted, it provides public health insurance in the form of Medicare and Medicaid. Second, it runs a welfare program that covers all health care costs and guarantees a minimum consumption level. Third, it consumes goods. We assume that government consumption per capita, \hat{g}_c , grows at the rate of technological progress. Hence, total government consumption is given by $\hat{G}_c = \hat{g}_c \int \Phi(ds)$. We include government consumption in the model to equalize the size of the government sector in the model and the data, thereby ensuring that the tax burden in the model is consistent with the data. Fourth, it supplies one-period risk-free debt, \hat{D} , which by no arbitrage carries

the same return as physical capital in equilibrium. We assume that government debt grows at the rate of technological progress. Lastly, it runs a Social Security program. In the United States, Social Security payments are tied to an individual's earnings history. To reduce computational costs, we abstract from this in the model and assume that benefits only depend on the consumer's education and cohort. In particular, we assume that a cohort's Social Security benefits depend on the wage rates that existed in the economy during the last 35 years before that cohort reached retirement age. Let b_e denote the education-specific Social Security replacement rate. Detrended Social Security benefits are given by

$$SS_{ej} = \frac{b_e}{35} \sum_{k=j_r-35}^{j_r-1} \frac{w_{k-j}}{(1+g_z)^{j-k}}. \quad (8)$$

This functional form implies that younger cohorts will receive higher Social Security benefits than older cohorts because of productivity-induced wage growth.

The government finances its expenditures on consumption, interest payments on debt, Medicare, Medicaid, Emergency Relief, and Social Security by means of three taxes: a consumption tax, τ_c , a capital income tax on the net return on wealth, τ_k , and a proportional labor tax, τ_ℓ . Let G_M denote total productivity-detrended government spending on Medicare, Medicaid, and Emergency Relief. We assume that consumers on Emergency Relief do not pay taxes on their consumption. Moreover, we assume that the consumption and capital income tax rates stay fixed, and that the government balances its budget period-by-period by means of the labor tax. The labor tax rate then has to satisfy

$$\begin{aligned} \tau_\ell wN + \tau_c \int \mathbf{1}_{F=0} c(s) \Phi(ds) + \tau_k r \int (a(s) + B) \Phi(ds) + (1+g_z)(1+g_n) D' \\ = G_M + g_c \int \Phi(ds) + (1+r) D + SS_{ej} \int \Phi(ds|j \geq j_r), \end{aligned} \quad (9)$$

where the indicator function $\mathbf{1}_{F=0}$ equals one for all consumers that do not choose to go on Emergency Relief, and where by $\Phi(ds|j \geq j_r) = \Phi(\{j_r, \dots, J\} \times de \times dh \times d\eta \times da \times di)$ it is understood that the integral is over all types s but restricted to agents of age $j \geq j_r$.

2.5 Consumer problem

The consumer's choice set depends on her current age and health insurance status. Throughout, we use the word *young* to denote consumers less than age j_r and *old* to denote consumers that are at least j_r years old. We start by presenting the problem of young consumers without employer-provided health insurance. This subsection also defines the value of going on Emergency Relief. Next, we set up the problem faced by young consumers with employer-provided health insurance. Lastly, we discuss the problem of old consumers.

2.5.1 Young consumers without employer-provided health insurance

Recall that a consumer's type is given by $s = (j, e, h, \eta, a, i)$, where j is age, e is educational level, h is health status, η is the stochastic component of labor productivity, a is assets, and i is the consumer's health insurance status. Let $V^I(s)$ denote the value of young consumers without employer-provided health insurance. Similarly, let $V^F(s)$ denote the value of going on Emergency Relief. Young consumers without employer insurance then solve the following problem:

$$V(s) = \max \{V^I(s), V^F(s)\}, \quad (10)$$

where $V^I(s)$ is given by

$$\begin{aligned} V^I(s) &= \max_{c, a', \ell, i'} U(c, \ell) + \beta \psi_{jeh} \mathbb{E}_{\eta'|\eta} \mathbb{E}_{h'|jeh} V(s') \\ \text{s.t. } & (1 + \tau_c) c + (1 + g_z) a' + m_{op} + \mathbf{1}_{i'=i_P} \pi_{jeh} = w(1 - \tau_\ell) \eta \xi_h \epsilon_{je} \ell + (1 + r(1 - \tau_k))(a + B) \\ & m_{op} = \begin{cases} \mathbf{1}_{i=i_P} \chi_P m_{jh} + (1 - \mathbf{1}_{i=i_P}) m_{jh} & \text{if } \mathbf{1}_{CAID}(s, \ell) = 0 \\ \mathbf{1}_{i=i_P} \chi_P \chi_{CAID} m_{jh} + (1 - \mathbf{1}_{i=i_P}) \chi_{CAID} m_{jh} & \text{if } \mathbf{1}_{CAID}(s, \ell) = 1 \end{cases} \\ & \ell \in \{0, \ell_p, \dots, \ell_e\} \\ & c, a' \geq 0 \\ & i' \in \{i_P, i_S\}. \end{aligned} \quad (11)$$

Consumers without employer insurance choose how much to consume, c , how much to save, a' , how many hours to work, ℓ , and whether to purchase private health insurance for the following period, i' . In the event that a consumer qualifies for Medicaid, $\mathbf{1}_{CAID}(s, \ell) = 1$, Medicaid will cover a share $1 - \chi_{CAID}$ of the consumer's out-of-pocket medical expenses, m_{op} , which are given by m_{jh} for self-insured consumers and $\chi_P m_{jh}$ for consumers that purchased private health insurance in the preceding period.

Consumers that choose to go on Emergency Relief have to forfeit all assets and work zero hours. In return, the government covers all out-of-pocket health care expenses and provides the consumer with a minimum

consumption level, \underline{c} . The value of going on Emergency Relief is then given by

$$\begin{aligned}
V^F(s) &= U(\underline{c}, 0) + \beta \psi_{jeh} \mathbb{E}_{\eta'|\eta} \mathbb{E}_{h'|jeh} V(s') \\
\text{s.t.} \quad a' &= 0 \\
i' &= i_S.
\end{aligned} \tag{12}$$

2.5.2 Young consumers with employer-provided health insurance

Let $V^E(s)$ denote the value of being on employer-provided health insurance. Young consumers with employer insurance solve the same problem as young consumers without employer insurance, with the exception that the former group is not allowed to purchase private health insurance. Young consumers with employer insurance solve the following problem:

$$V(s) = \max \{V^E(s), V^F(s)\}, \tag{13}$$

where $V^E(s)$ is given by

$$\begin{aligned}
V^E(s) &= \max_{c, a', \ell} U(c, \ell) + \beta \psi_{jeh} \mathbb{E}_{\eta'|\eta} \mathbb{E}_{h'|jeh} V(s') \\
\text{s.t.} \quad (1 + \tau_c) c + (1 + g_z) a' + m_{op} + \mathbf{1}_{\ell > 0} \pi_E &= w(1 - \tau_\ell) \eta \xi_h \epsilon_{je} \ell + (1 + r(1 - \tau_k))(a + B) \\
m_{op} &= \begin{cases} \chi_{EM} m_{jh} & \text{if } \mathbf{1}_{CAID}(s, \ell) = 0 \\ \chi_{EX} \chi_{CAID} m_{jh} & \text{if } \mathbf{1}_{CAID}(s, \ell) = 1 \end{cases} \\
\ell \in \begin{cases} 0, \ell_p, \dots, \ell_e & \text{if sick} \\ \ell_p, \dots, \ell_e & \text{if healthy} \end{cases} \\
c, a' &\geq 0 \\
i' &= i_E.
\end{aligned} \tag{14}$$

Out-of-pocket health care expenses are given by $\chi_{EM} m_{jh}$ for consumers on employer insurance. All consumers on employer insurance that work must pay a premium π_E . We assume that healthy consumers on employer insurance have to supply a minimum of $\ell_p > 0$ hours. Sick consumers, on the other hand, are free to

choose zero hours. In the model, consumers are considered sick if they have a catastrophic health state (see Subsection 3.1.7 for details). Finally, the value of going on Emergency Relief is the same as above, with the exception that consumers continue to be eligible for employer-provided insurance in the following period, $i' = i_E$.

2.5.3 Old consumers

Let $V^R(s)$ denote the value of an old consumer of type s . Old consumers solve the same problem as young consumers without employer-provided health insurance:

$$V(s) = \max \{V^R(s), V^F(s)\}, \quad (15)$$

where $V^R(s)$ is given by

$$\begin{aligned} V^R(s) &= \max_{c, a', \ell, i'} U(c, \ell) + \beta \psi_{jeh} \mathbb{E}_{\eta' | \eta} \mathbb{E}_{h' | jeh} V(s') \\ \text{s.t. } & (1 + \tau_c)c + a' + m_{op} + \mathbf{1}_{i'=i_P} \pi_{jeh} = SS_{ej} + w(1 - \tau_\ell) \eta \xi_h \epsilon_{je} \ell + (1 + r(1 - \tau_k))(a + B) \\ m_{op} &= \begin{cases} \mathbf{1}_{i=i_P} \chi_P \chi_{CARE} m_{jh} + (1 - \mathbf{1}_{i=i_P}) \chi_{CARE} m_{jh} & \text{if } \mathbf{1}_{CAID}(s, \ell) = 0 \\ \mathbf{1}_{i=i_P} \chi_P \chi_{CARE} \chi_{CAID} m_{jh} + (1 - \mathbf{1}_{i=i_P}) \chi_{CARE} \chi_{CAID} m_{jh} & \text{if } \mathbf{1}_{CAID}(s, \ell) = 1 \end{cases} \\ \ell &\in \{0, \ell_p, \dots, \ell_e\} \\ c, a' &\geq 0 \\ i' &\in \{i_P, i_S\}. \end{aligned} \quad (16)$$

Note that old consumers are allowed to work in the model. This is motivated by the observation that nearly 20 percent of individuals aged 65 and older still participate in the workforce. Old consumers receive transfers from the government in the form of Medicare and Social Security, SS_{ej} , the last of which varies with their educational level and cohort. Neither program is tied to retirement, and hence consumers continue to receive both Medicare and Social Security even if they choose to work in old age. Out-of-pocket health care expenses are given by $\chi_{CARE} m_{jh}$ for self-insured consumers and $\chi_{CARE} \chi_P m_{jh}$ for consumers that purchased private health insurance in the preceding period.

2.6 Definition of equilibrium

Given a consumption tax rate, τ_c , capital income tax rate, τ_k , government consumption, G_c , government debt, D , coinsurance rates χ_P , χ_E , χ_{CARE} , and χ_{CAID} , and initial conditions for capital K_1 and the measure of types Φ_1 , an *equilibrium* in our model is a sequence of model variables such that:

1. Given prices, insurance premia, government policies, and accidental bequests, consumers maximize utility subject to their constraints.
2. Factor prices satisfy marginal product pricing conditions:

$$r = \theta \alpha \left(\frac{N}{K} \right)^{1-\alpha} - \delta$$

$$w = \theta (1 - \alpha) \left(\frac{K}{N} \right)^\alpha.$$

3. Goods, capital, and labor market clearing conditions are met:

$$C + G_c + M + (1 + g_z) (1 + g_n) K' = \theta K^\alpha N^{1-\alpha} + (1 - \delta) K$$

$$K' + D' = \frac{\int a'(s) \Phi(ds)}{(1 + g_n)} + \frac{\int \mathbb{I}_{i'(s)=i_P} \pi_{jeh} \Phi(ds)}{(1 + g_z) (1 + g_n)}$$

$$N = \int \eta \epsilon_{je} \xi_h \ell(s) \Phi(ds).$$

4. Accidental bequests are given by

$$B' = \frac{\int (1 - \psi_{jeh}) a'(s) \Phi(ds)}{(1 + g_n) \int \Phi(ds)}.$$

5. Insurance market clearing conditions are met.
6. Government policies satisfy the government budget constraint.
7. The aggregate law of motion for Φ is induced by the policy functions and the exogenous stochastic processes for idiosyncratic risk.

3 Calibration

We calibrate the model in two steps. In the first step, we calibrate a set of parameters outside the model equilibrium. In the second step, we assume that the initial balanced growth economy is 2005 and jointly

calibrate the remaining parameters to match moments in the U.S. economy in that year.

3.1 Parameters determined outside the model equilibrium

The following subsections discuss the parameters that are determined outside the model equilibrium. These parameters are presented in Table 1.

3.1.1 Life cycle

We assume that a model period is 5 years because the population estimates that we use from the United Nations are given for 5-year age bins (20–24, 25–29, ...). In our model, consumers enter the economy at age 20. We set the retirement age, j_r , to 10, which implies that consumers start receiving Medicare and Social Security benefits at age 65. The maximum life span, J , is set to 17 such that consumers live at most 100 years.

3.1.2 Risk aversion and indivisible labor

We set the risk aversion parameter, σ , to 4.195, which implies an intertemporal elasticity of substitution of 0.5. The discrete grid for labor supply is $\ell \in \{0, \ell_p, \dots, \ell_f, \dots, \ell_e\}$, where ℓ_p , ℓ_f , and ℓ_e refer to part-time, full-time, and extra time, respectively. We set ℓ_f to 0.333, ℓ_p to 75 percent of full-time, and ℓ_e to 125 percent of full-time. We use 11 equally spaced grid points between ℓ_p and ℓ_e .

3.1.3 Technology

We set the growth rate of labor-augmenting technological progress, g_z , to 0.104, which implies an annual growth rate of 2 percent. The capital share, α , is set to 0.360. Lastly, we set the depreciation rate, δ , to 0.262, which implies an annual rate of 0.059, as in Castañeda et al. (2003).

3.1.4 Idiosyncratic labor productivity

The idiosyncratic labor productivity in the model comprises the stochastic component, η , the health-specific stochastic component, ξ_h , and the age-education-specific deterministic component, ϵ_{je} . The parameters of the idiosyncratic stochastic process are calibrated jointly in equilibrium, as will be discussed in Subsection 3.2. For the health-specific stochastic component, we set ξ_h to 1 for consumers with low and high health care expenses, and to 0 for consumers with catastrophic expenses (see Subsection 3.1.7 for details about the health care expenditure states). For the age-education-specific deterministic component, we convert

the annual estimates from Conesa et al. (2018) to 5-year estimates by computing the averages for each age-education bin. Further details are given in the online appendix.

3.1.5 Taxes

We compute effective tax rates for consumption and capital income using OECD data on national accounts and tax revenues, following the methodology pioneered by Mendoza et al. (1994). We use the average value between 2005 and 2009, which results in a consumption tax rate, τ_c , of 4.7 percent, and a capital income tax rate, τ_k , of 32.1 percent. As noted in Section 2.4, the labor tax rate, τ_ℓ , is set to balance the government budget period-by-period and hence is determined endogenously in equilibrium.

3.1.6 Health insurance

We use the following approach to compute the coinsurance rates for private insurance, employer-provided insurance, and Medicaid. Using data from the Medical Expenditure Panel Survey (MEPS), we first derive each individual's primary insurance provider, defined as the insurer that pays for the largest share of the individual's health care expenses. To illustrate, if Medicaid and private health insurance both cover a share of the individual's health care expenses, but Medicaid covers the largest share, then we let Medicaid be defined as this individual's primary insurance provider. Next, we pool all the individuals in the MEPS with the same primary insurance provider and compute the average share of expenses paid by this insurance provider. Let these values be denoted by $\tilde{\chi}_P$, $\tilde{\chi}_E$, and $\tilde{\chi}_{CAID}$ for individuals with private health insurance, employer-provided health insurance, and Medicaid as their primary insurance provider, respectively. We then let the coinsurance rate for private insurance, employer-provided insurance, and Medicaid be given by $\chi_P = 1 - \tilde{\chi}_P$, $\chi_E = 1 - \tilde{\chi}_E$, and $\chi_{CAID} = 1 - \tilde{\chi}_{CAID}$. Finally, we set the coinsurance rate on Medicare, χ_{CARE} , to match the observation that about 50 percent of the elderly's total health care expenses are covered by Medicare in the United States.

We use the following approach to compute the Medicaid eligibility criteria. We first get data on state-specific Medicaid eligibility criteria from the Kaiser Family Foundation. We then set the categorical income limit, y^{CAT} , the medically needy income limit, y^{MN} , and the medically needy asset limit, a^{MN} , to match the corresponding weighted average limits in the data, with weights given by each state's share of total health care expenses. To ensure a balanced growth path, we assume that the Medicaid income and asset thresholds grow at the rate of technological progress, g_z .

3.1.7 Health care expenses and transition probabilities

We split health care expenses into three categories: low, high, and catastrophic. To identify these expenses in the MEPS, we first pool all health care expenses for each age and educational group (college and non-college), and compute the 60th and 99.9th percentile. We then identify age-education-specific low, high, and catastrophic health care expenses as the average value between the 0–60th percentile, the 60–99.9th percentile, and the 99.9–100th percentile, respectively. Since the MEPS top-codes age at age 85, we extrapolate health care expenses for consumers aged 85 to 100 using a log-linear trend. Finally, for each age group, we use the average value of health care expenses between college and non-college-educated individuals.

The health transition matrix must guarantee that, for each age and educational group, 60.0, 39.9, and 0.1 percent of consumers have low, high, and catastrophic health care expenses, respectively. The following discussion explains how we adjust the health transition probabilities. Using our MEPS sample, we first estimate age-health-education-specific health transition probabilities by running an ordered probit regression of next period’s health on current age, age squared, education, health, and interaction terms. Next, we iterate on the transition matrix until the probabilities guarantee that, for each age and educational group, the correct percentage of consumers transition to each health state. That is, we iterate on the transition matrix, $Q_{j,e}(h, H)$, until $x^T Q_{j,e}(h, H) = x^T$, where $x^T = [0.600, 0.399, 0.001]$ denotes the probability distribution of consumers across health states. Note that this is an augmented version of the RAS method, which is a method used to generate matrices that satisfy pre-specified row and column sum constraints. Further details are given in the online appendix.

3.1.8 Survival probabilities

In the model, survival probabilities vary with age, education, and health, ψ_{jeh} . These probabilities cannot be derived directly from the MEPS since the MEPS does not sample institutionalized individuals. Survival probabilities estimated from the MEPS will therefore be upwardly biased. Moreover, the estimates are not guaranteed to match the education survival premium, defined as the difference in age-specific survival probabilities between college and non-college-educated individuals. Building on Attanasio et al. (2010), we therefore adjust the estimated survival probabilities to match both the age-specific survival probabilities in the data and the education survival premium. The following discussion explains how we adjust the survival probabilities.

We obtain age-specific survival probabilities from the Social Security Administration, $surv_j$. Next, we derive age-education-specific survival probabilities for college and non-college-educated individuals, where college-educated individuals are defined as individuals with at least a bachelor’s degree or a minimum of

4 years of college. To do this, we first obtain mortality statistics from the 2010 National Vital Statistics System (NVSS). The NVSS provides data on the total number of deaths by age and educational attainment. We then use data from the 2010 census and the 2010 Current Population Survey (CPS) to obtain estimates of the total number of college and non-college educated individuals by age. Since the CPS top-codes age at age 85, we assume that 85- to 100-year-olds have the same college attainment as 80- to 84-year-olds. Lastly, we combine the NVSS, census, and CPS data, and compute the age-education-specific survival probabilities by dividing the total number of deaths by the total number of people in each age and educational group. These estimates are then used to compute the education survival premium by age, $educprem_j$, defined as the difference in age-specific survival probabilities between college and non-college-educated individuals.

Using the MEPS sample, we then estimate age-education-health-specific survival probabilities, $\tilde{\psi}_{jeh}$. Lastly, to ensure that the model matches both the age-specific survival probabilities and the education survival premium in the data, we solve the following system of equations:

$$\begin{aligned} surv_j &= \sum_h \sum_e \Lambda_{jeh} a_{ej} \tilde{\psi}_{jeh} \\ educprem_j &= a_{2j} \tilde{\psi}_{j2h} - a_{1j} \tilde{\psi}_{j1h}, \end{aligned} \tag{17}$$

where $\Lambda_{je}(h)$ denotes the mass of individuals by age, education, and health in the MEPS. That is, we derive the scaling terms, a_{ej} , that solve Equation (17). The age-education-health-specific survival probabilities in the model are then given by $\psi_{jeh} = a_{ej} \tilde{\psi}_{jeh}$.

3.1.9 College attainment and 20-year-old population growth rate

For college attainment, we use data from the U.S. Census Bureau. For the initial balanced growth economy estimate, we use the average value of the percentage of college graduates in the population aged 20+ from 1980 to 2005. To compute the 20-year-old population growth rate, we use population estimates from the World Population Prospects: The 2012 Revision, United Nations. This data set provides population estimates for 5-year age groups (20–24, 25–29, ...). We compute $g_{n,t}$ as the number of individuals aged 20–24 in period t divided by the number of individuals aged 20–24 in period $t - 1$. For the initial balanced growth economy estimate, we use the average $g_{n,t}$ from 1980 to 2005.

3.2 Parameters determined jointly in equilibrium

Table 2 reports the parameters that are determined jointly in equilibrium. As mentioned above, we assume that the initial balanced growth economy is 2005. The parameters are calibrated jointly to match key moments of the U.S. economy during the period 2005–2009 (for simplicity, we refer to the period 2005–2009

as 2005 below).

We normalize θ such that GDP per capita is equal to 1 in 2005. The discount factor is set to match a capital-to-output ratio of 0.6, which corresponds to an annual value of 3. We calibrate the consumption share in the utility function, γ , such that average hours worked per employee is equal to full-time, 0.333. We calibrate the Social Security replacement rates, b_e , to match average Social Security benefits across individuals with and without a college degree. We calibrate the percentage of 20-year-olds that qualify for employer-provided insurance to match the percentage of the working-age population with employer-provided insurance in the data. We calibrate government consumption, G_c , and government debt, D , to match government consumption to output and government debt to output, respectively. We scale health care expenditures to match a health care expenditure-to-GDP ratio of 15.2 percent. The consumption floor, c , is calibrated to match the average annual Supplemental Nutrition Assistance Program benefits reported by the United States Department of Agriculture. To ensure a balanced growth path, we assume that the minimum consumption level grows at the rate of technological progress.

Finally, we follow Castañeda et al. (2003) and calibrate the parameters of the stochastic labor productivity process to match the empirical earnings distribution in the United States. We choose a right-skewed productivity shock process to match the top decile of the earnings distribution, and calibrate the variance of the process to match the dispersion observed in the data.

3.3 Comparing the Frisch elasticity in the model and the data

The extent to which the government has to increase the labor tax rate to finance the costs of an aging population depends critically on the Frisch elasticity of labor supply. This follows because a higher labor tax rate reduces incentives to work. The Frisch elasticity determines the responsiveness of hours worked to changes in the post-tax wage rate—holding constant the marginal utility of wealth—and hence determines how much consumers will reduce their labor supply in the event of a tax increase. We end this section by comparing the Frisch elasticity of labor supply in the model and the data.

We estimate the *micro* Frisch elasticity of labor supply for each consumer in the initial balanced growth economy by computing the responsiveness of hours worked to a 5 percent transitory increase and to a 5 percent transitory decrease in hourly earnings. We focus on responses to transitory shocks to minimize the wealth effects of the shocks. Moreover, we focus solely on changes along the *intensive* margin by excluding consumers that do not work with or without the transitory shocks. The average Frisch elasticity for 20- to 64-year-old consumers in the model is 0.285 for the positive shock and 0.279 for the negative shock. Both values are within the range of 0 to 0.5 commonly used in the literature (see, for example, Blundell and

MaCurdy 1999, Chetty et al. 2011, and Keane 2011 for reviews of this literature).

Figure 1 plots the estimated micro Frisch elasticities across all 20- to 64-year-old consumers in the model. The solid black line plots the estimated elasticities for the positive earnings shock and the dotted red line plots the estimated elasticities for the negative shock. As illustrated in the graph, 69.8 percent of the consumers do not adjust their hours worked in response to a 5 percent transitory increase in hourly earnings because labor supply is indivisible in the model. For 24.3 percent of the consumers, the elasticity is greater than zero but less than two. This is due to the substitution effect given our assumption about preferences (see Equation 5) combined with the indivisibility of labor supply. Note that 4.1 percent of consumers respond to the positive earnings shock by reducing hours worked, thereby leading to negative Frisch elasticities for these consumers. This follows because some consumers reduce their hours worked in response to the positive earnings shock to maintain eligibility for Medicaid. The positive earnings shock can also make consumers ineligible for Medicaid even if they choose to work the minimum number of hours (part-time). These consumers may respond to the positive earnings shock by significantly increasing their hours worked, thereby leading to high positive Frisch elasticities. Accordingly, for 1.8 percent of the consumers, the elasticity is greater than two.

4 Comparative statics: College attainment, fertility, and longevity

In this section, we perform comparative statics exercises with balanced growth paths for three channels that contribute to an increase in the old age dependency ratio: increasing college attainment, decreasing fertility, and increasing longevity. As we have explained, we assume that the initial balanced growth economy is 2005. For the comparative statics, we use projections for the year 2100, discussed in the next subsection.

4.1 Projections of college attainment, fertility, and longevity for 2100

Table 3 presents the 1980–2005 averages and the 2100 projections for measures of college attainment and fertility. As noted in Subsection 3.1.9, the parameters used for the 2005 balanced growth economy are the averages for 1980–2005. For the 2100 college attainment projection, we start by estimating a linear trend for the percentage of the population aged 20+ with a college degree from 1960 to 2010. We then extrapolate this trend to 2100 and assume that it stays fixed in the balanced growth path after that. If the increasing trend in college attainment continues, then the percentage of the population with a college degree will increase from an average of 23 percent during 1980–2005 to 67 percent in 2100. We view the 2100 projection for college attainment as an upper bound and perform comparative statics for different levels of college attainment.

In our model, changes in fertility rates are captured through changes in the population growth rate of 20-year-olds. To obtain estimates for the population growth rate of 20-year-olds in 2100, we use population

forecasts for the years 2095 and 2100 from the World Population Prospects: The 2012 Revision, United Nations, the same data set used for the 2005 estimate. The U.N. forecasts are given for alternative simulations based on different assumptions about fertility, mortality, and migration. We use the median forecasts for fertility and mortality. Furthermore, because our model does not feature migration, we use the forecasts that are based on the assumption of zero migration. Table 3 shows that the population growth rate of 20-year-olds is projected to decrease from 1.50 percent per 5 years (an annual rate of 0.29 percent) to -0.26 percent per 5 years (an annual rate of -0.05 percent).

Increased longevity in our model is captured through increasing age-specific survival probabilities. For 2005, we use the age-education-health-specific estimates discussed in Subsection 3.1.8. For the 2100 projection, we first compute age-specific survival probabilities for the years 2005 and 2100 using the U.N. data. We then calculate the factor by which we need to increase the age-specific survival probabilities in 2005 to match the corresponding estimates in 2100. This scaling factor is depicted in Figure 2. Finally, we scale the age-education-health-specific 2005 survival probabilities by our scaling factor. Note that our approach relies on the assumption that, for each age group, the health and education survival premia discussed in Subsection 3.1.8 are the same in 2100 as in 2005.

4.2 Individual implications of college attainment, fertility, and longevity

We perform comparative statics exercises for different levels of the 2100 projections for college attainment, fertility, and longevity. In the figures, the three cases are referred to as college attainment, fertility, and longevity. The horizontal axes in the figures refer to the fraction of the 2100 projection. To illustrate, a value of 0.6 for fertility refers to the case of $g_n = 0.6g_{n,2100} + 0.4g_{n,2005}$.

Figure 3 plots the old age dependency ratio in the model. All three channels lead to a higher old age dependency ratio. Increasing college attainment increases the old age dependency ratio because college graduates have higher life expectancy than non-college graduates. Decreasing fertility increases the old age dependency ratio because it leads to relatively fewer young consumers. Lastly, increasing longevity increases the old age dependency ratio because it leads to relatively more old consumers.

Although all three channels contribute to a higher old age dependency ratio, they have different fiscal implications. In particular, we find that increasing college attainment allows the government to reduce the labor tax rate, whereas decreasing fertility and increasing longevity require the government to increase the labor tax rate. This can be seen in Figure 4. Increasing college attainment allows the government to reduce the labor tax rate for several reasons. First, and most importantly, since college-educated consumers have higher labor productivity than non-college-educated consumers, an increase in college attainment leads

to an economy with more productive workers. Second, hours worked per capita is higher in the economy with higher college attainment. Both effects contribute to an increase in effective labor per capita. This is illustrated in Figure 5b. Higher effective labor per capita, in turn, leads to higher government revenues from labor taxation, thereby allowing the government to reduce the labor tax rate.

Third, college graduates are less likely to enroll in Medicaid and Emergency Relief. Increasing college attainment thus lowers government spending on these programs, thereby contributing to a lower labor tax rate. This mechanism is illustrated in Figures 6a, 6b, and 6c, which show how the health care expenditure distribution by insurance provider changes as we increase college attainment, decrease fertility, and increase longevity, respectively. In particular, Figure 6a shows that increasing college attainment lowers the share of health care expenses covered by both Medicaid and Emergency Relief. This is because college graduates, on average, have both higher earnings and wealth. Hence, in the model, enrolling in Medicaid and Emergency Relief is more costly for them. The reduction in government spending on Medicaid and Emergency Relief following the increase in college attainment contributes to a small reduction in public health care spending. This is illustrated in Figure 7a. In contrast, we find that decreasing fertility and increasing longevity lead to higher public health care spending per capita.

Fourth, as illustrated in Figures 8a and 8b, higher college attainment leads to both higher consumption tax revenues per capita and higher capital income tax revenues per capita. This follows because college graduates both consume and save more than non-college graduates. In contrast, decreasing fertility and increasing longevity lead to lower government revenues from consumption and capital income taxation.

A fifth reason why higher college attainment allows the government to reduce the labor tax rate is that higher college attainment leads to higher wages, thereby further increasing government revenues from labor taxation. This is illustrated in Figure 9. The wage rate goes up because the increase in college attainment leads to more capital per capita relative to effective labor per capita. This is driven by the fact that college-educated consumers save more than non-college-educated consumers. College graduates save more because they have higher labor earnings, higher life expectancy, and a stronger precautionary savings motive since enrolling in Medicaid and Emergency Relief is more costly for them.

Finally, the increase in capital accumulation due to higher college attainment leads to a lower interest rate. This is illustrated in Figure 10, which shows that increasing college attainment and increasing longevity both contribute to reduced interest rates. Lower interest rates reduce interest payments on government debt, which accounts for 7.9 percent of total government spending in the initial balanced growth economy. As illustrated in Figure 7c, we find that higher college attainment reduces interest payments on government debt per capita by 34.3 percent.

The forces that we have mentioned so far contribute to lower labor taxes, but there are forces that move

in the opposite direction. In particular, higher college attainment leads to higher spending on Medicare and Social Security, the latter of which is illustrated in Figure 7b. This follows because college-educated consumers have higher life expectancy than non-college-educated consumers and because college graduates claim higher Social Security benefits due to higher lifetime labor earnings. These effects partially offset the reduction in the labor tax rate brought about by higher college attainment.

Thus far, we have studied how increasing college attainment affects labor taxes. Next, we study the implications for welfare. We use *consumption equivalent variation* to measure the welfare effects of increased college attainment. In particular, we measure welfare as the percentage change in consumption in all periods and all states of the world in the economy without increased college attainment that would make a consumer indifferent between entering that economy and entering the economy with increased college attainment. We focus on a 20-year-old consumer who has zero assets, and for whom the education type (college or non-college), but not the stochastic components of productivity and health, has been revealed. Note that all consumers entering a balanced growth economy in the future are better off because of economic growth. In particular, by 2150, in a balanced growth path without any of the three channels of aging, real GDP per capita will be about 18 times higher than in 2005 because of the 2 percent annual productivity growth. In this paper, we only report the welfare results from the detrended models. We find that both 20-year-old consumers with a college degree and 20-year-old consumers without a college degree that enter an economy with increased college attainment experience higher welfare. In particular, we find that increased college attainment increases the welfare of a 20-year-old consumer with a college degree by 17.4 percent. Similarly, increased college attainment increases the welfare of a 20-year-old consumer without a college degree by 18.4 percent.

4.3 Joint implications of college attainment, fertility, and longevity

We now study the joint implications of increasing college attainment, decreasing fertility, and increasing longevity. We focus on the following scenarios: increasing college attainment only (college), decreasing fertility and increasing longevity (fertility + longevity), and introducing all three channels (all). We start by studying the joint implications of the three channels for the old age dependency ratio. Recall from Figure 3 that all three channels contribute to an increase in the old age dependency ratio. Figure 11a shows that the joint effect of college attainment, fertility, and longevity is larger than the individual effects of college attainment and fertility + longevity ($26.3 > 3.3 + 20.0 = 23.3$). Hence, higher college attainment not only increases the old age dependency ratio but also amplifies the increase in the old age dependency ratio brought about by decreasing fertility and increasing longevity.

Figures 11b and 11c compare the changes in the interest rate and the wage rate in the different models. We find that higher college attainment not only reduces the interest rate but also amplifies the reduction in the interest rate due to decreasing fertility and increasing longevity. Analogously, higher college attainment amplifies the increase in the wage rate brought about by the other channels. These interaction effects have implications for government spending. In particular, Figure 12a shows that the interaction effects between the three channels of aging lead to an additional 13.6 percentage point increase in Social Security spending per capita ($13.6 = 73.4 - 59.8$). This is partially due to the amplified increase in the wage rate. Similarly, the amplified reduction in the interest rate leads to a further reduction in interest payments on government debt. As illustrated in Figure 12b, we find that the three channels of aging lead to a 58.3 percent reduction in interest payments on government debt.

Next, we study the implications for government revenues. Recall that the government derives revenues from consumption taxes, capital income taxes, and labor income taxes. Figure 13a shows that consumption tax revenues per capita are higher in the model with all three channels of aging. This shows that the increase in consumption tax revenues due to higher college attainment more than offsets the reduction in consumption tax revenues caused by decreasing fertility and increasing longevity. Capital income tax revenues, on the other hand, decline when we introduce all three channels of aging in the model. This is illustrated in Figure 13b, which shows that the increase in capital income tax revenues due to increased college attainment only partially mitigates the drop in capital income tax revenues caused by decreasing fertility and increasing longevity. This is partially because higher college attainment amplifies the reduction in the interest rate caused by decreasing fertility and increasing longevity, which in turn lowers government revenues from capital income taxation.

The increase in the wage rate, on the other hand, leads to higher labor tax revenues, not only because of the direct effect of higher wages on earnings but also because higher wages lead to an increase in effective labor per capita. This is illustrated in Figure 14a. The increase in effective labor per capita is partially due to higher labor force participation rates among 20- to 64-year-old consumers and among 65+ year-old consumers. This is illustrated in Figures 14b and 14c, which report the percentage point changes in the labor force participation rates for 20–64 and 65+ year-old consumers in the model.

We find that decreasing fertility and increasing longevity require the government to increase the average labor tax rate from 32.0 to 44.4 percent. Adding increasing college attainment to this model lowers the required increase in the labor tax rate by 10.1 percentage points. This is illustrated in Figure 13c. Consequently, we find that all three channels of aging require the government to increase the average labor tax rate from 32.0 to 34.3 percent by 2100.

4.4 General equilibrium effects of college attainment, fertility, and longevity

Lastly, we compare the results from the benchmark closed economy with the corresponding results from a small open economy with a constant and exogenous interest rate. By construction, the detrended wage rate is also constant in the small open economy. All other variables such as the labor tax rate and the employer-provided insurance premium are determined endogenously in equilibrium. We do this not because we think the United States is well modeled as a small open economy but because it enables us to quantify the general equilibrium effects of higher wages and lower interest rates brought about by higher capital accumulation.

We study the tax implications of introducing higher college attainment into two different versions of the model with decreasing fertility and increasing longevity: one, our benchmark general equilibrium model (GE), and the other, the small open economy model (SOE). We compare the change in tax revenues and the resulting change in the labor tax rate needed to balance the government budget. These results are illustrated in Figures 15a, 15b, and 16b. In the figures, $all - f+l$ refers to the difference between the model with all three channels of aging and the model with only decreasing fertility and increasing longevity.

We find that the capital stock increases in both the general equilibrium model and the small open economy model. In the general equilibrium model, however, the increase in the capital stock also leads to higher wages and lower interest rates. Higher wages lead to higher earnings, not only because of the direct effect of higher wages but also because higher wages induce consumers to work more. This can be seen in Figure 16a, which shows that the increase in hours worked per capita due to increased college attainment is higher in the general equilibrium model than in the small open economy model for the 2100 projection.

Higher wages, however, also lead to higher Social Security benefits. More importantly, the reduction in the interest rate in the general equilibrium model lowers government revenues from capital income taxation. Introducing higher college attainment in the model with decreasing fertility and increasing longevity therefore results in a larger increase in capital income tax revenues per capita in the small open economy model than under general equilibrium. We find that this additional increase in government revenues from capital income taxation in the small open economy model results in a larger reduction in the labor tax rate in the small open economy model. In particular, as illustrated in Figure 16b, introducing higher college attainment in the model with decreasing fertility and increasing longevity lowers the required increase in the labor tax rate by 10.1 percentage points in the general equilibrium model but by 13.1 percentage points in the small open economy model.

4.5 Sensitivity analysis

We have conducted a wide range of sensitivity analyses, and we find that our main results are robust. That is, the findings that higher college attainment lowers the required increase in the labor tax rate due to decreasing fertility and increasing longevity, and that the fiscal implications of higher college attainment depend critically on general equilibrium effects, are robust to alternative parameterizations of the model. We limit our discussion here to two robustness checks. First, we study the effects of adding a labor force participation cost to better match the observed labor force participation rate in the data. Then we study the effects of removing government debt in the model. In both cases, we recalibrate the model to match the same targets as described in Section 3. Table 4 summarizes the implications of introducing decreasing fertility and increasing longevity (f+l) and of introducing all three channels of aging (all) under different parameterizations of the model.

Labor force participation cost The benchmark model presented in Section 3 overestimates the age-specific labor force participation rates in the data. Data from the Current Population Survey show that 79 percent of 20- to 64-year-olds and 16 percent of 65+ year-olds participated in the labor force between 2005 and 2009. The corresponding labor force participation rates in the benchmark model are 88 and 25 percent. This is partially because the model abstracts from the fixed time costs of working and the time loss due to sickness, both of which have been shown to affect labor force participation decisions. By overestimating the number of workers that contribute by paying labor taxes, the model underestimates the labor tax burden in the economy. To address this, we add a utility cost of working in the model. All consumers that choose to participate in the labor force suffer a utility cost. We calibrate this cost to match average labor force participation rates for 20+ year-olds between 2005 and 2009. To ensure a balanced growth path, we assume that the utility cost grows at the rate of technological progress. A comparison of the labor force participation rate in the model and the data is given in Figure 17. As illustrated in the graph, the model closely matches the observed labor force participation rates of 40+ year-olds but continues to overestimate the labor force participation rates of 20- to 40-year-olds. This is partially because of the assumption that consumers enter the economy with zero assets.

Table 4 shows that the three channels of aging lead to similar changes in Social Security spending per capita, public health care spending per capita, and interest payments on government debt per capita in the model with and without labor force participation costs. Moreover, the increase in both effective labor per capita and capital per capita are comparable in the two models. As a result, the increase in the wage rate and the reduction in the interest rate are also similar in the model with and without labor force participation costs. Furthermore, we find that the tax implications are similar in the two models. In particular, the

increase in consumption tax revenues per capita and the reduction in capital income tax revenues per capita are comparable in the model with and without labor force participation costs. Consequently, the three channels of aging have similar implications for the labor tax rate in the two models. In particular, increasing college attainment lowers the required increase in the labor tax rate due to decreasing fertility and increasing longevity from 12.4 to 2.3 percentage points in the benchmark model, and from 11.6 to 2.8 percentage points in the model with labor force participation costs.

No government debt Recall that interest payments on government debt account for 7.9 percent of total government spending in the initial balanced growth economy of the benchmark model, and that the reduction in the interest rate due to the three channels of aging leads to a 58.3 percent reduction in interest payments on government debt. Lower interest payments on government debt thus partially mitigate the negative fiscal implications of aging. To better understand how government debt affects the fiscal implications of aging, we end this section by studying an alternative parameterization of the model with no government debt.

The reduction in government spending caused by lower interest payments on government debt lowers the required increase in the labor tax rate due to decreasing fertility and increasing longevity. Table 4 shows that the government has to increase the labor tax rate by 12.4 percentage points in the benchmark model with decreasing fertility and increasing longevity but by 15.1 percentage points in the model with no government debt. Moreover, the reduction in the labor tax rate due to increasing college attainment is larger in the benchmark model. We find that increasing college attainment lowers the required increase in the labor tax rate due to decreasing fertility and increasing longevity by 10.1 percentage points in the benchmark model and by 9.0 percentage points in the model with no government debt. The higher increase in the labor tax rate in the model with no government debt reduces incentives to work. Consequently, we find that the three channels of aging lead to an additional 2.6 percentage point increase in effective labor per capita and an additional 21.8 percentage point increase in capital per capita in the benchmark model compared to the model with no government debt. The relatively higher increase in capital per capita compared to effective labor per capita leads to an additional 5.2 percentage point increase in the wage rate and to an additional 0.7 percentage point reduction in the interest rate in the benchmark model compared to the model with no government debt. These price effects have implications for government tax revenues. On the one hand, the higher increase in the wage rate in the benchmark model leads to a larger increase in consumption and therefore a higher increase in consumption tax revenues per capita. On the other hand, the higher increase in the wage rate in the benchmark model leads to a higher increase in government spending on Social Security. More importantly, the larger reduction in the interest rate in the benchmark model has negative implications for capital income tax revenues, which decline by 9.2 percent in the benchmark model when we introduce

all three channels of aging but increase by 0.2 percent in the model with no government debt.

5 Conclusion

It is well known that the old age dependency ratio will increase over the course of the 21st century due to decreasing fertility rates and increasing longevity. We have shown that increasing college attainment is another important driver of the increase in the old age dependency ratio because college graduates have higher life expectancy than non-college graduates. Using a general equilibrium overlapping generations model with heterogeneous consumers, we have shown that the macroeconomic implications of increasing college attainment are different from those of decreasing fertility and increasing longevity. Most importantly, decreasing fertility and increasing longevity require the government to increase labor taxes, whereas increasing college attainment allows the government to reduce labor taxes. This follows because increasing college attainment leads to a more productive labor force, lower government spending on Medicaid and Emergency Relief, higher revenues from consumption taxation, capital income taxation, and labor income taxation, and lower interest payments on government debt.

We have also studied the joint fiscal implications of the three channels of aging. In particular, we studied the fiscal implications of introducing increasing college attainment into the model with decreasing fertility and increasing longevity. We showed that decreasing fertility and increasing longevity require the government to increase the average labor tax rate from 32.0 to 44.4 percent by 2100. Adding increasing college attainment to this model lowers the required increase in the labor tax rate by 10.1 percentage points. Consequently, we found that all three channels of aging require the government to increase the average labor tax rate from 32.0 to 34.3 percent.

Finally, we have shown that the fiscal implications of aging depend critically on general equilibrium effects. We showed that increasing college attainment leads to an increase in capital income tax revenues in both the benchmark general equilibrium model and the small open economy model with a constant interest rate. The reduction in the interest rate under general equilibrium, however, dampens the increase in capital income tax revenues brought about by higher college attainment. Consequently, adding higher college attainment to the model with decreasing fertility and increasing longevity lowers the required increase in the labor tax rate by 10.1 percentage points under general equilibrium but by 13.1 percentage points in the small open economy.

In this paper, we performed comparative statics exercises in a model with balanced growth paths where the three channels of aging were exogenous. Focusing on balanced growth paths is restrictive. In particular, our results do not indicate how the U.S. economy will be affected by our three channels of aging between

2005 and 2100. We also do not take into account the effects of aging on generations already born in 2005 or the effects of aging on generations born during the transition. We leave it for future research to compute transition paths to perform such an analysis. Another worthwhile extension of our analysis would be to endogenize the three channels of aging.

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Table 1: **Parameters determined outside the model equilibrium**

Parameter	Description		Value
Life cycle			
J	Maximum life span	100 years	17
j_r	Retirement age	65 years	10
Preferences and indivisible labor			
σ	Risk aversion parameter	IES = 0.5	4.195
$\ell_p, \dots, \ell_f, \dots, \ell_e$	Indivisible labor supply grid	Hours (fraction of time endow.)	0.250, ..., 0.333, ..., 0.417
Technology			
g_z	Productivity growth rate	Annual rate = 0.02	0.104
α	Capital income share		0.360
δ	Capital depreciation rate	Annual rate = 0.059	0.262
Idiosyncratic labor productivity			
ξ_1, ξ_2, ξ_3	Health-specific productivity	Conesa et al. (2018)	1,1,0
ϵ_{je}	Age-education-specific productivity	Conesa et al. (2018)	Online Appendix
Health insurance			
χ_P	Private insurance coinsurance rate	MEPS	0.229
χ_E	Employer insurance coinsurance rate	MEPS	0.229
χ^{CARE}	Medicare coinsurance rate	MEPS	0.500
χ^{CAID}	Medicaid coinsurance rate	MEPS	0.138
y^{CAT}	Categorical income limit	Kaiser Family Foundation	0.196
y^{MN}	Medically needy income limit	Kaiser Family Foundation	0.091
a^{MN}	Medically needy asset limit	Kaiser Family Foundation	0.041
Health care expenses and health transition probabilities			
m_{je}	Health care expenses	MEPS	Online Appendix
$Q_{j,e}(h, h')$	Health transition probabilities	MEPS	Online Appendix
Survival probabilities			
ψ_{jeh}	Age-education-health-specific surv. prob.	MEPS	Online Appendix
College attainment and 20-year-old population growth rate			
	Perc. of population with college degree	Census (average 1980–2005)	0.2276
$g_{n,2005}$	Population growth rate of 20-year-olds	U.N. (average 1980–2005)	0.0150
Taxes			
τ_c	Consumption tax rate	OECD (average 2005–2009)	0.047
τ_k	Capital income tax rate	OECD (average 2005–2009)	0.321

Table 2: Parameters determined jointly in equilibrium

Parameter	Description	Target (year = 2005–2009)	Value
θ	Choice of units for output	GDP pc = 1	1.659
β	Discount factor	Capital to annual output = 3	1.168
γ	Consumption share in utility	Average hours worked per employee = 0.333	0.313
b_c	SS college replacement rate	Average SS benefits to GDP pc college = 0.293	0.481
b_{nc}	SS non-college replacement rate	Average SS benefits to GDP pc non-college = 0.244	0.394
\underline{c}	Consumption floor	Average food stamps = \$1,227	0.026
g_c	Government consumption per capita	Government consumption to output = 0.156	0.156
D	Government debt	Government debt to annual output = 0.545	1.181
	Eligible for employer insurance	Working age share with employer = 0.480	0.480
	Scale for health care costs	Health care expenditure to GDP = 0.152	0.737
σ_η	Variance	Labor earnings Gini = 0.630	2.210
η_{top}	Productivity at the top	Labor earnings top 1 percent = 0.148	14.354
π_{top}	Probability at the top	Labor earnings top 10 percent = 0.435	0.013
ρ_n	Persistence	2-year persistence: Bottom 80 percent = 0.941	0.488
ρ_{top}	Persistence at the top	2-year persistence: Top 1 percent = 0.580	0.332

Figure 1: Micro Frisch elasticity

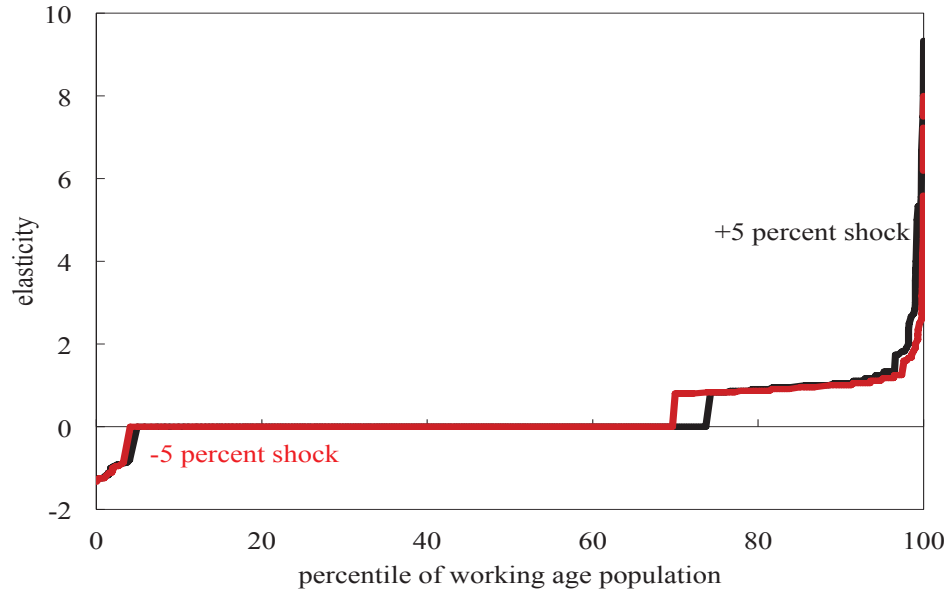


Table 3: 1980–2005 averages and 2100 projections for college attainment and fertility

Parameter	1980–2005 (average)	2100 (projection)
Fraction of college graduates 25+	0.2276	0.6742
5-year population growth rate of 20-year-olds: g_n	0.0150	-0.0026

Figure 2: 2100 projection for age-specific probabilities (longevity)

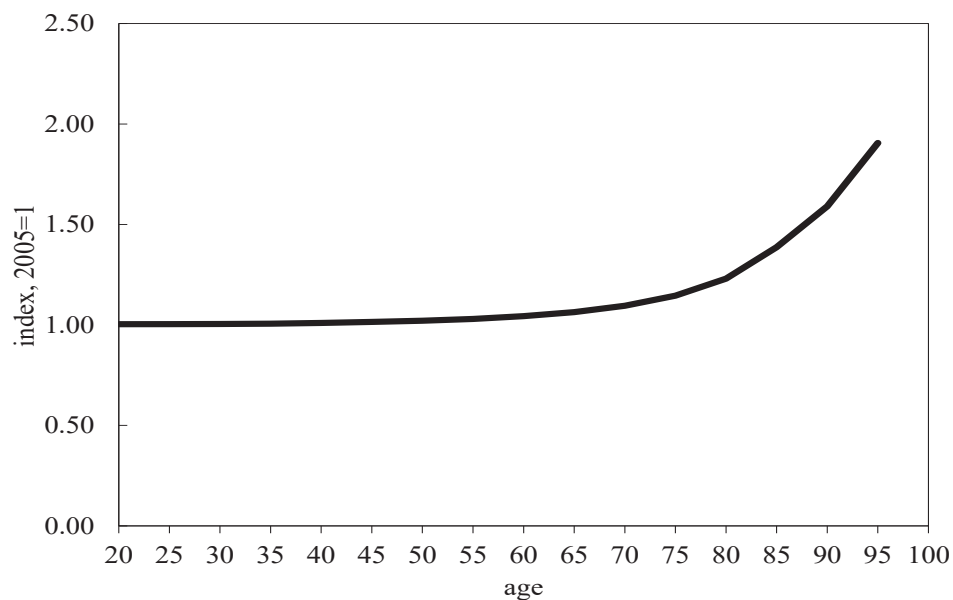


Figure 3: Old age dependency ratio

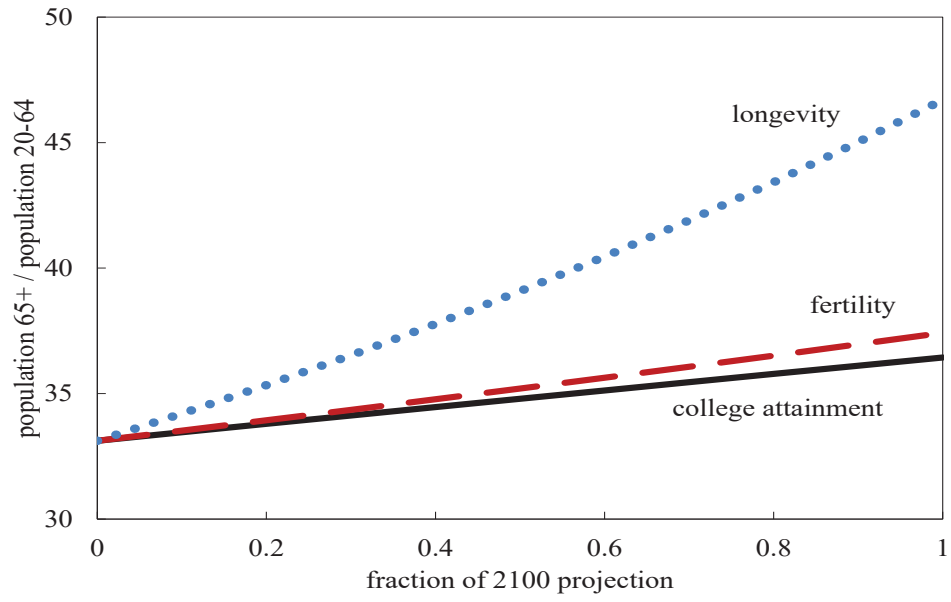


Figure 4: Labor tax rate

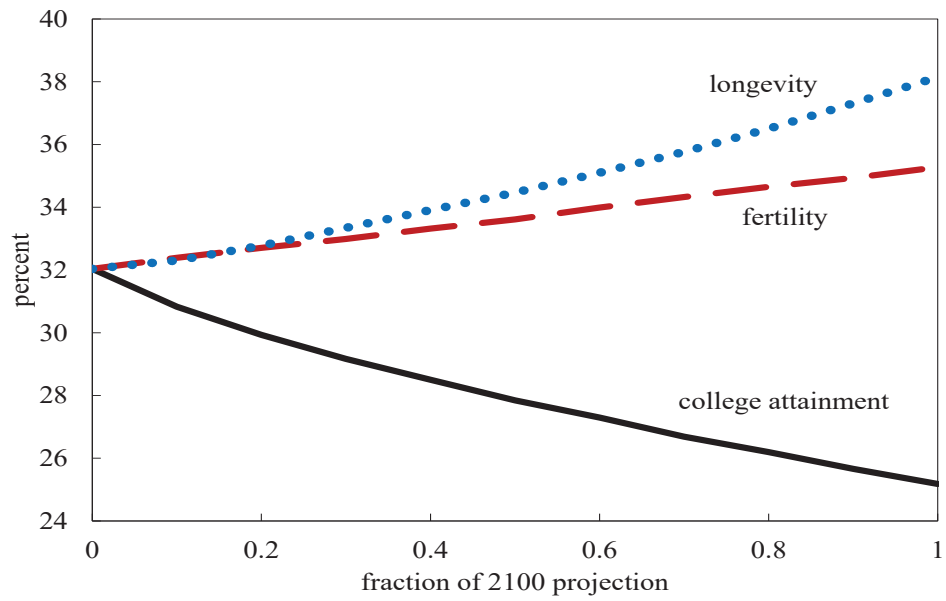


Figure 5: Capital per capita, effective labor per capita, and hours worked per capita

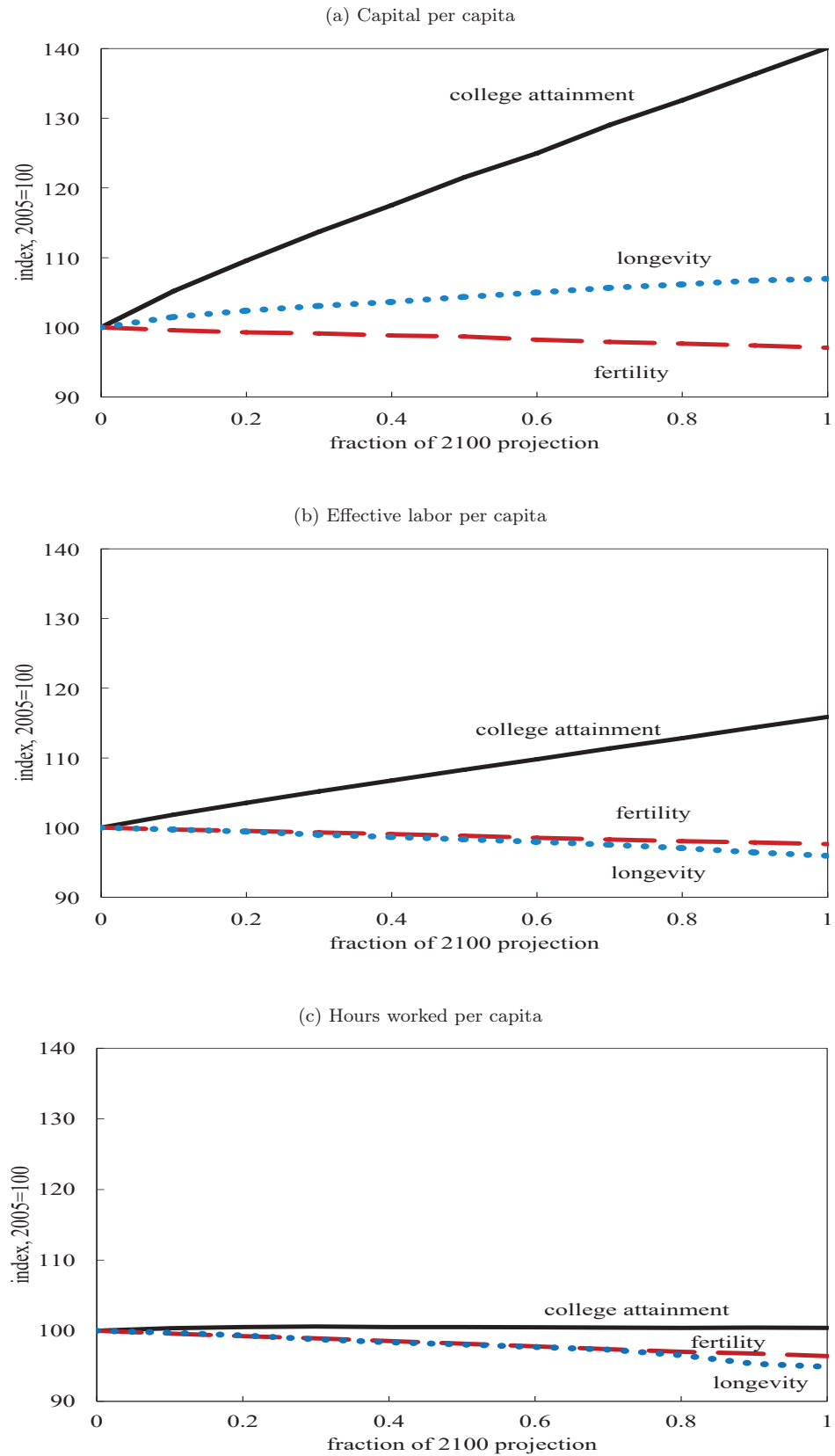


Figure 6: Health care expenditure distribution by provider

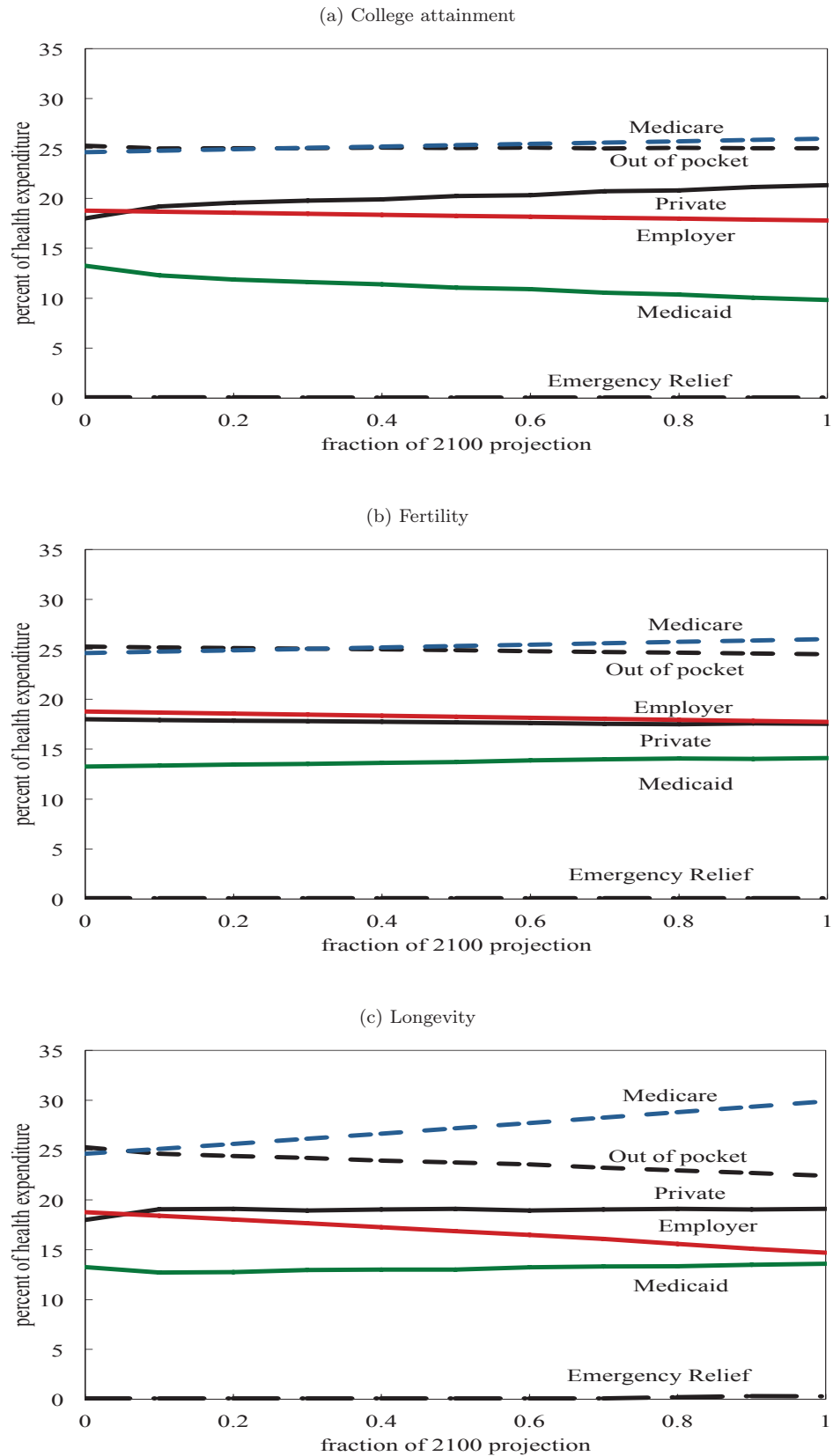
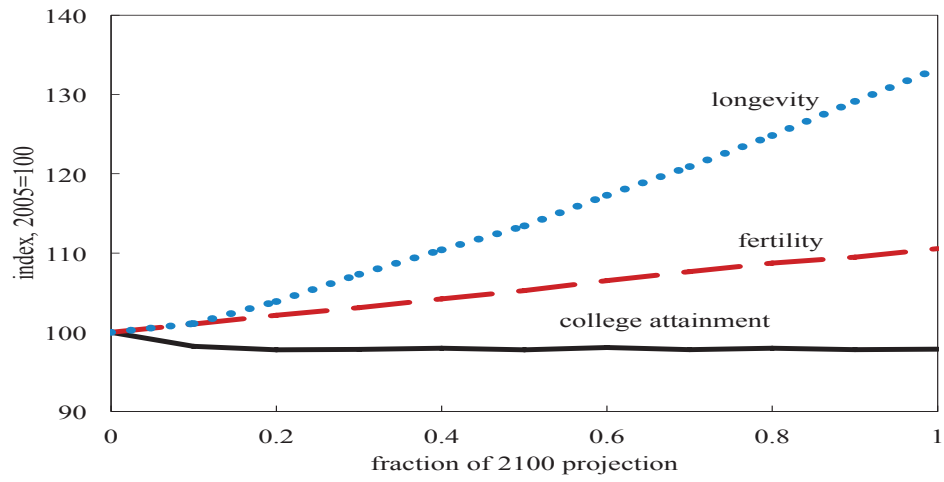
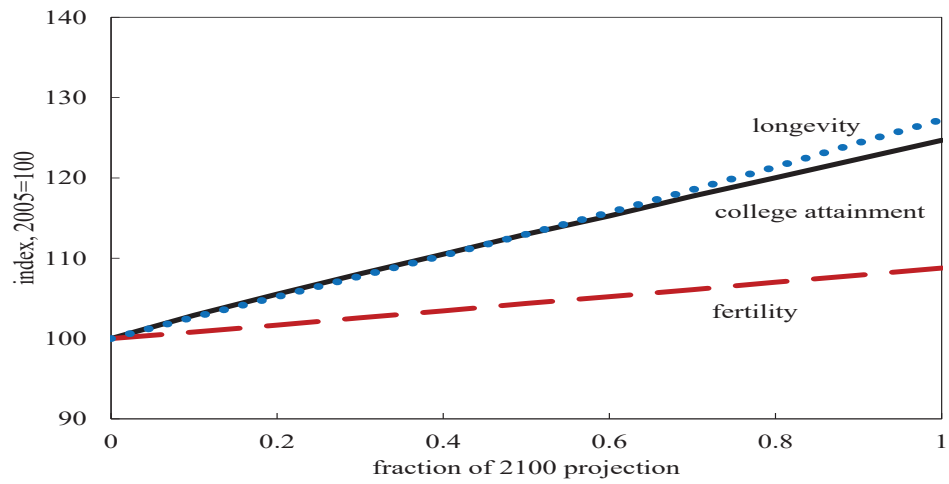


Figure 7: Government spending

(a) Public health care spending per capita



(b) Social Security spending per capita



(c) Interest payments on government debt per capita

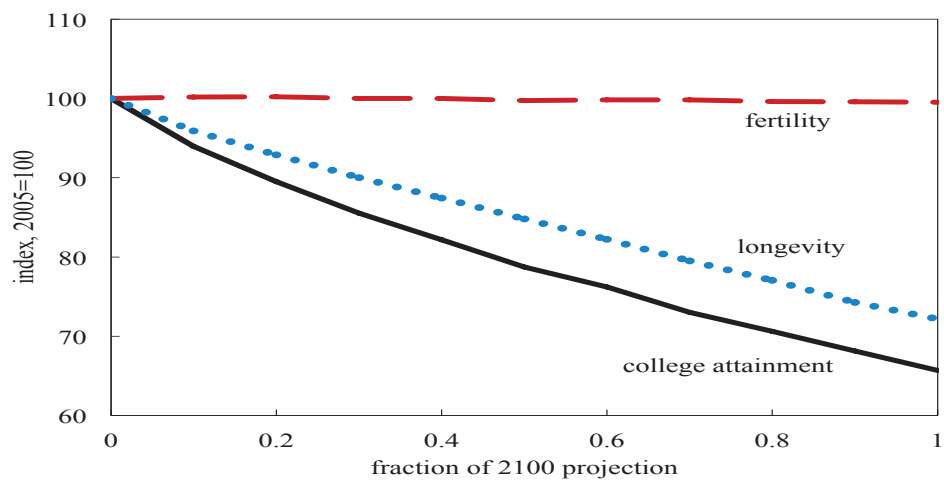
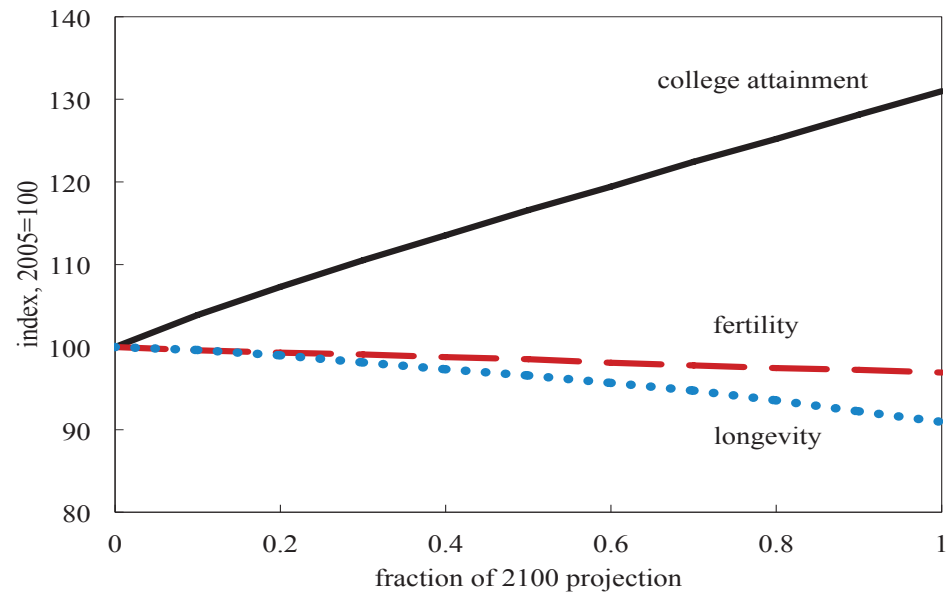


Figure 8: Government revenues from consumption and capital income taxation

(a) Consumption tax revenue per capita



(b) Capital income tax revenue per capita

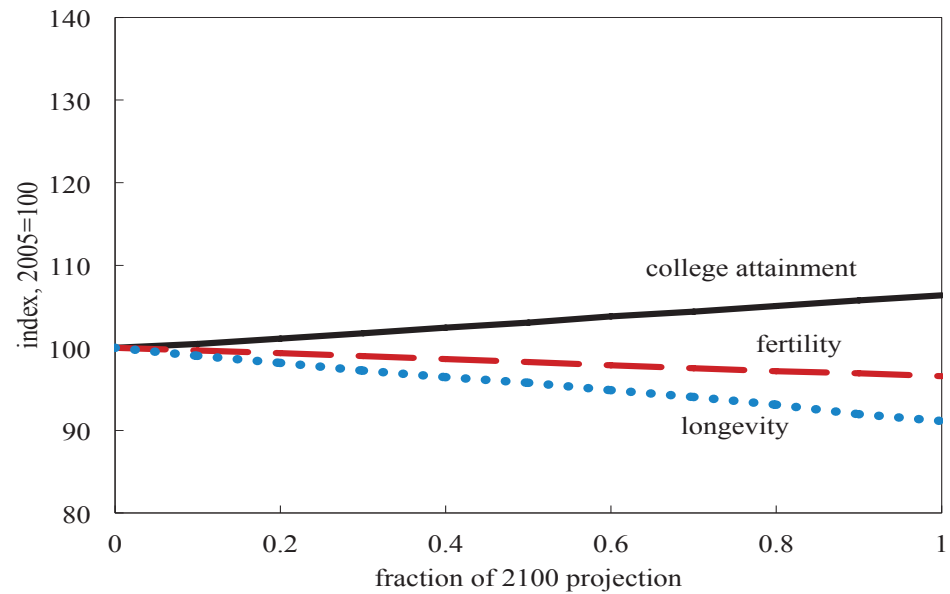


Figure 9: Wage rate

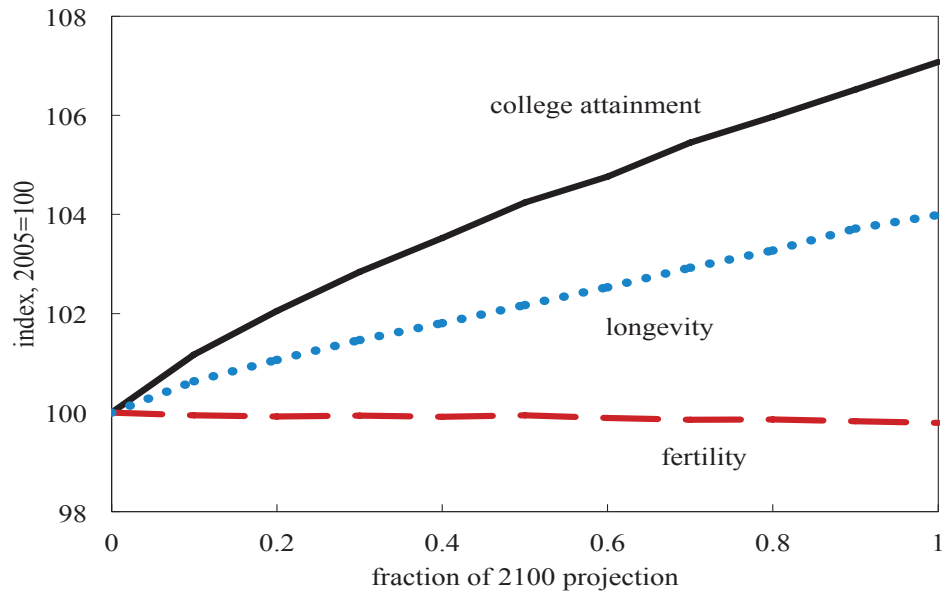


Figure 10: Interest rate

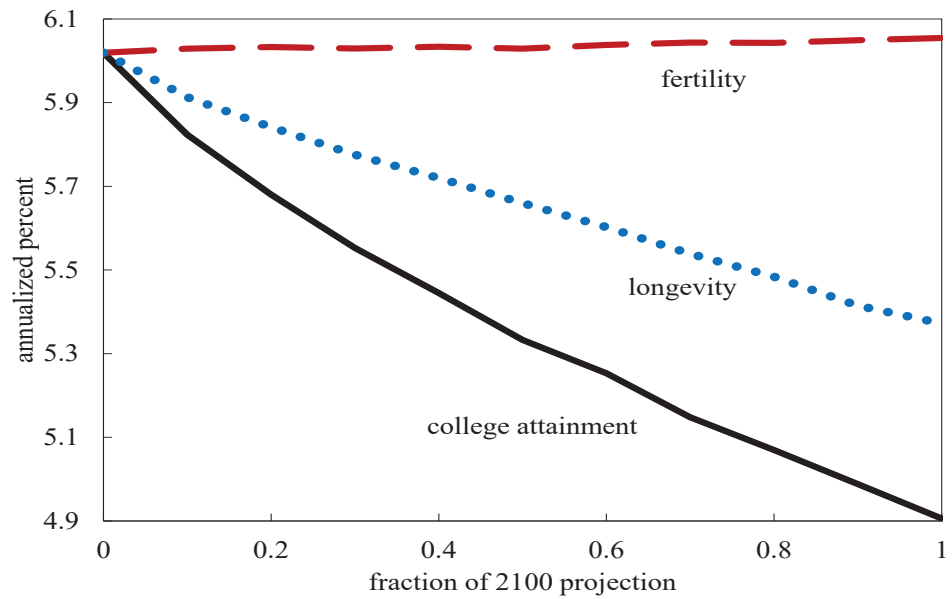


Figure 11: Decomposing interactions between college attainment, fertility, and longevity (part 1)

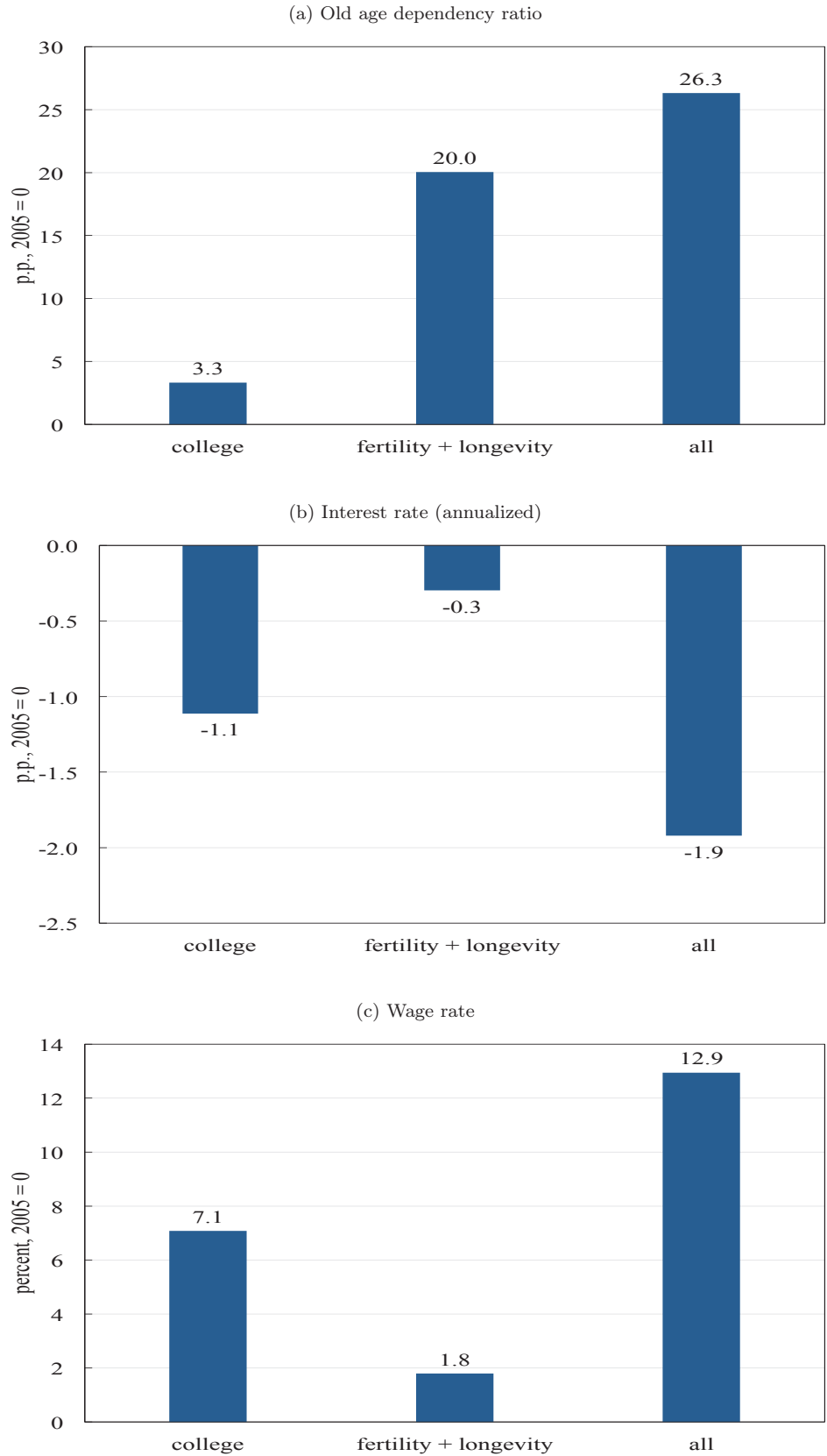


Figure 12: Decomposing interactions between college attainment, fertility, and longevity (part 2)

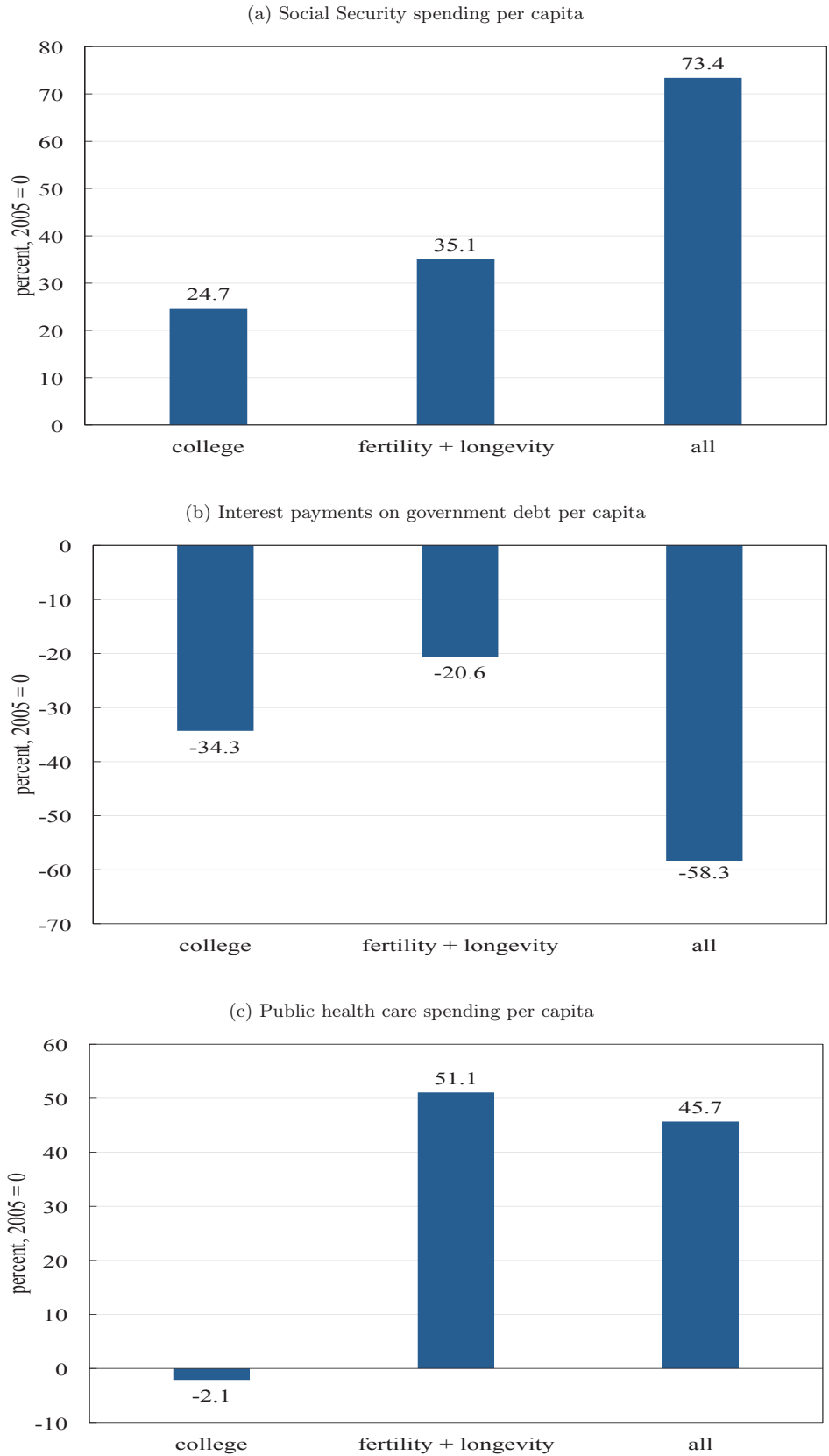


Figure 13: Decomposing interactions between college attainment, fertility, and longevity (part 3)

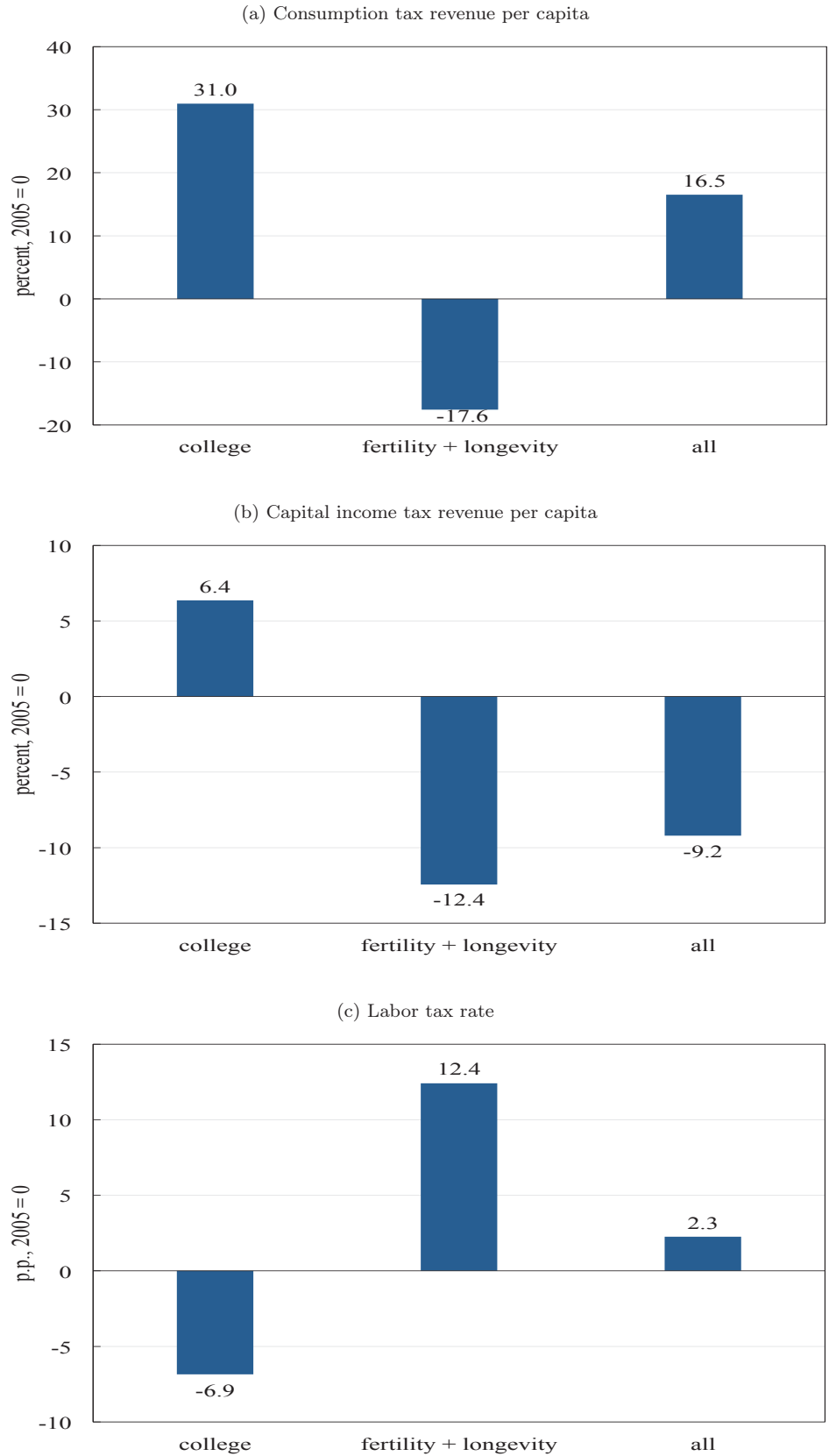


Figure 14: Decomposing interactions between college attainment, fertility, and longevity (part 4)

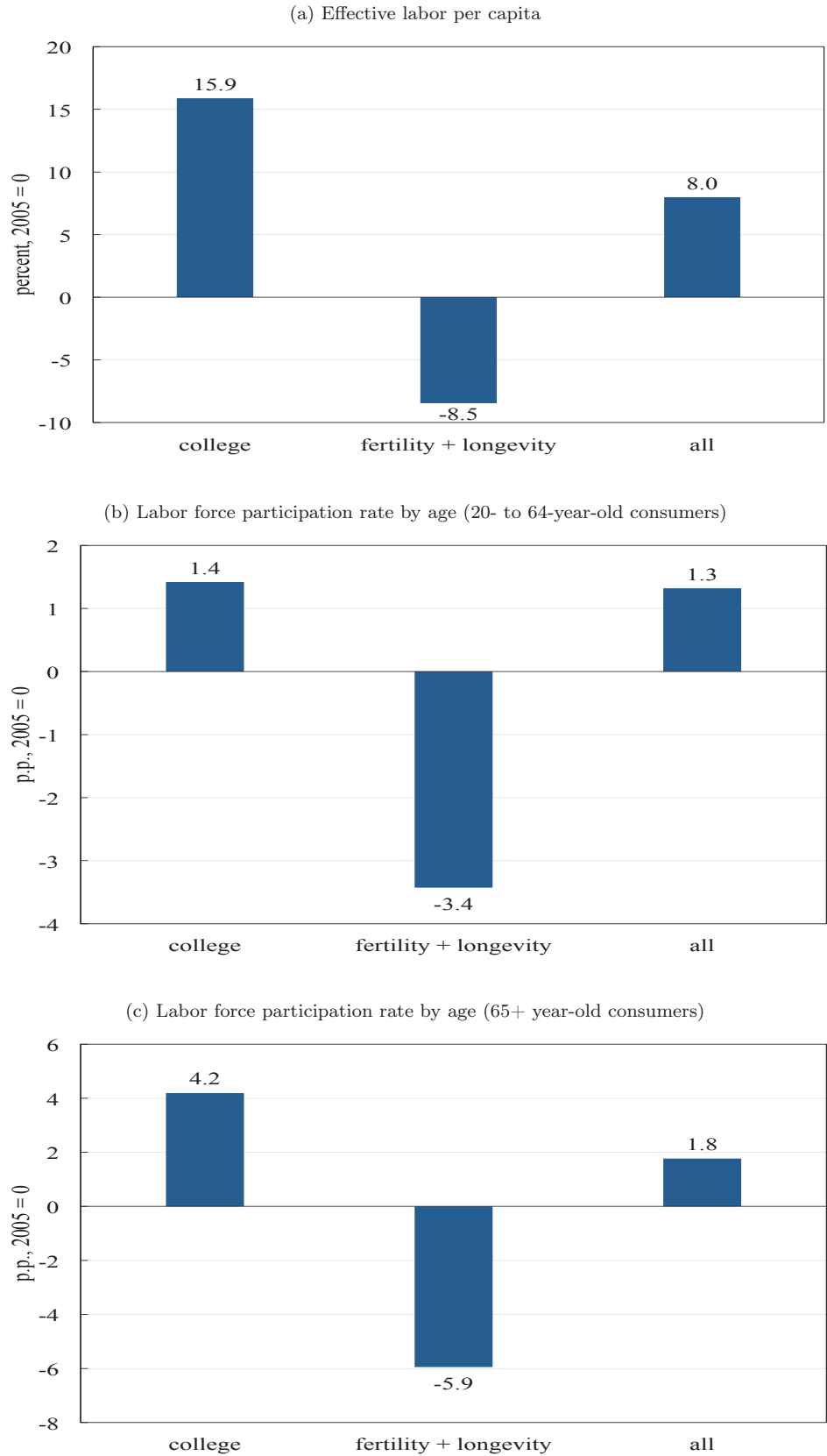
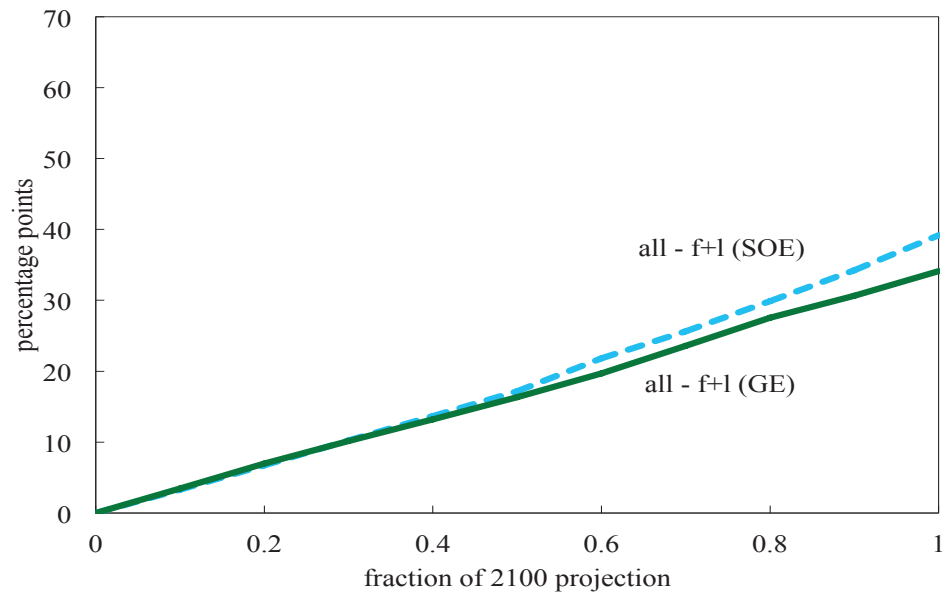


Figure 15: Consumption and capital income tax revenues

(a) Consumption tax revenues per capita



(b) Capital income tax revenues per capita

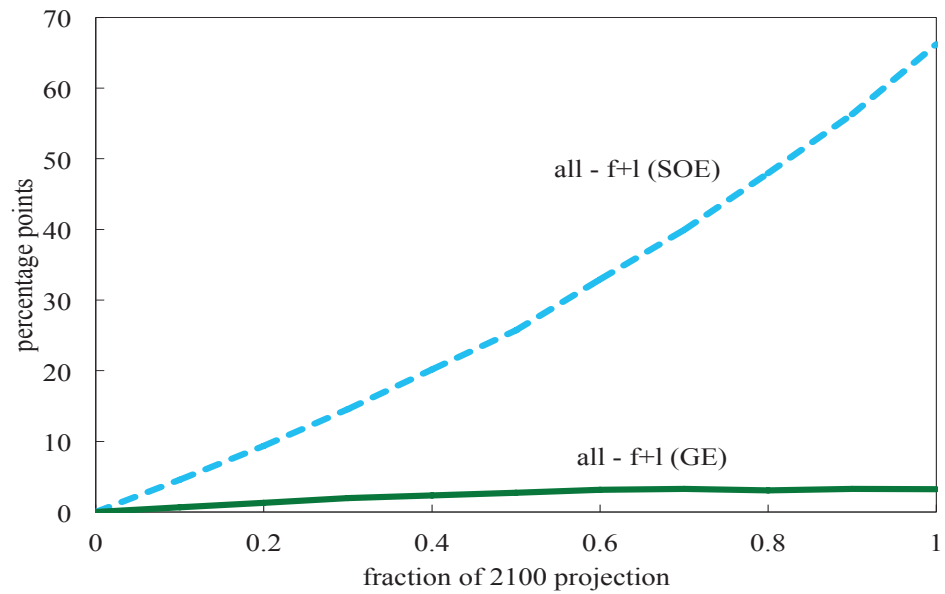


Figure 16: Hours worked per capita and labor tax rate

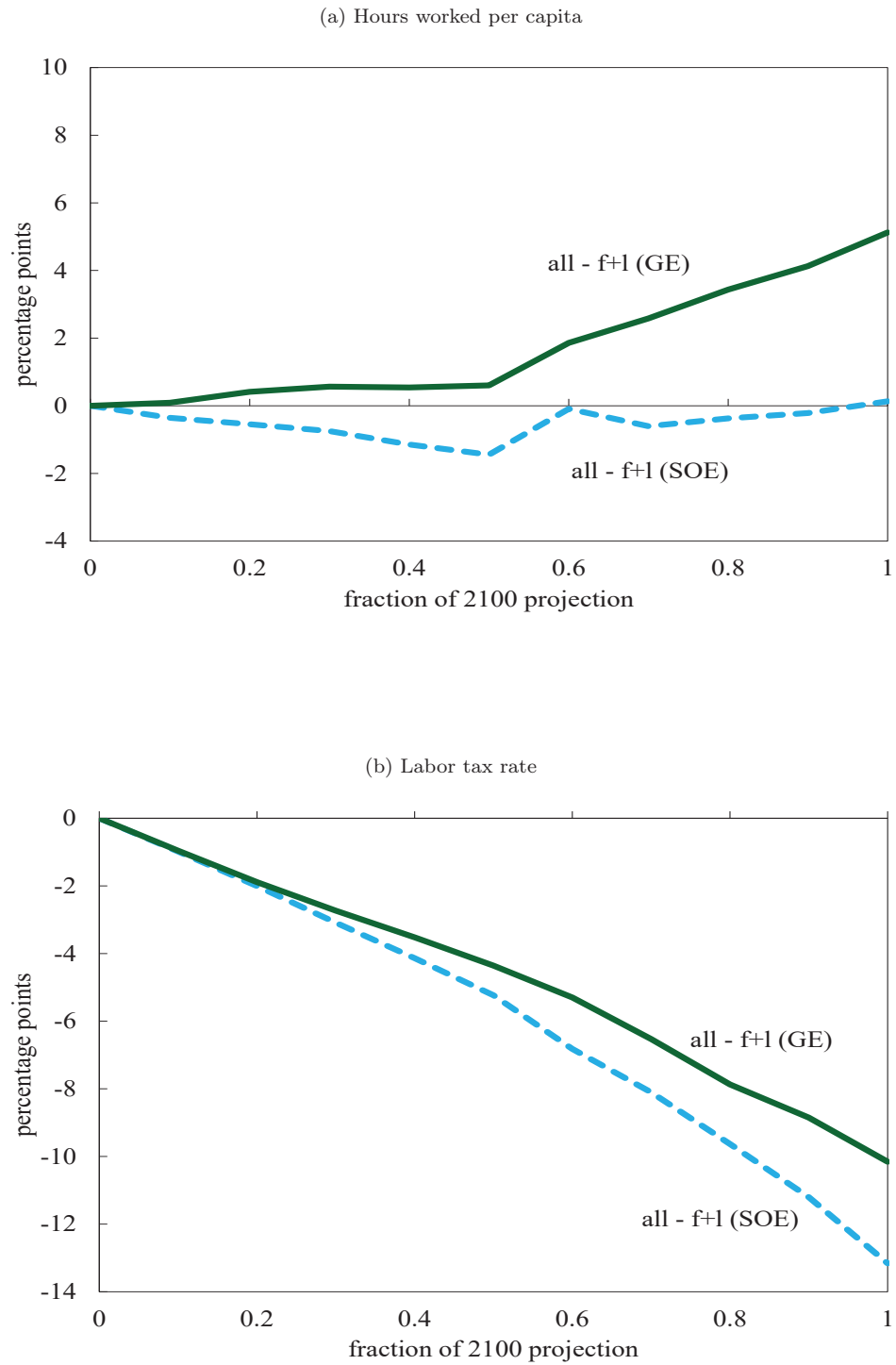


Figure 17: Robustness: model with labor force participation costs

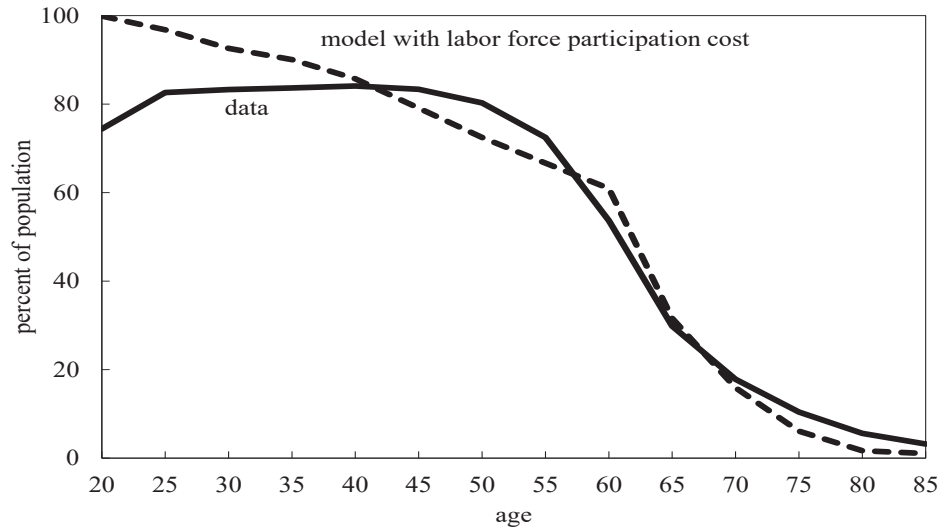


Table 4: Robustness

	Benchmark		Labor part. cost		No gov. debt	
	f+1	all	f+1	all	f+1	all
Variable (percent, 2005 = 0)						
Social Security spending per capita	35.1	73.4	35.3	72.4	31.4	65.4
Public health care spending per capita	51.1	45.7	52.2	49.5	56.2	51.9
Interest payments on gov. debt per capita	-20.6	-58.3	-21.2	-56.7	n/a	n/a
Effective labor per capita	-8.5	8.0	-7.5	7.6	-10.0	5.4
Capital per capita	-3.8	51.4	-2.4	48.5	-12.4	29.6
Wage rate	1.8	12.9	2.0	12.3	-1.0	7.7
Consumption tax revenues per capita	-17.6	16.5	-15.6	15.5	-22.4	8.6
Capital income tax revenues per capita	-12.4	-9.2	-11.6	-8.6	-10.5	0.2
Variable (p.p., 2005 = 0)						
Old age dependency ratio	20.1	26.3	20.1	26.3	20.1	26.3
Interest rate (annualized)	-0.3	-1.9	-0.3	-1.8	0.2	-1.2
Labor tax rate	12.4	2.3	11.6	2.8	15.1	6.1