Global Demographic Trends and Social Security Reform *

Orazio Attanasio†, Sagiri Kitao‡, and Giovanni L. Violante§

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Abstract

How sustainable are the PAYG social security systems in the developed economies, given the projected demographic trends? The most recent literature has answered this question through dynamic general equilibrium models in a closed economy framework. This paper provides a new quantitative benchmark of analysis for this question represented by a two-region model (South and North) of the world economy where capital flows across regions. The timing and the extent of the demographic transition—and the associated economic forces shaping capital accumulation and equilibrium factor prices—are very different in the two regions. Thus, the projected paths of interest rate and wage rate in the North diverge substantially between closed and open economy. We perform a wide range of policy experiments under closed and open economy. The main conclusion of our exercise is that if one is interested in quantifying the path of the fiscal variables (e.g., the value of the payroll tax) needed to keep the PAYG viable or to finance a transition towards a fully-funded system, then these two benchmarks yield similar results. However, if the focus is on quantifying the path of factor prices, aggregate variables and, ultimately, welfare, then the two approaches can diverge significantly.

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†University College London, CEPR, IFS, and NBER
‡New York University
§New York University, and CEPR
1 Introduction

The developed world will experience dramatic demographic changes throughout the 21st century. The most important projected demographic “events” are three: (i) a significant increase in longevity which will increase life expectancy at 65 by 1.5 years per decade; (ii) a decline in fertility which will induce negative rates of population growth for the next 50 years; (iii) the retirement of the baby-boom generations, born in the 1950s, which will accelerate the rise of the old-dependency ratio (population 60+ as a fraction of the total) after 2010.

These demographic changes raise a number of crucial public policy issues. The one at the forefront of the current debate in the economic and political arena is the “sustainability” of the Pay-As-You-Go (PAYG) pension systems which, since their inception in the 1930s, represent one of the main pillars of social insurance policies in many countries across the developed world.\footnote{The economic consequences of such demographic changes are not limited to pension systems. The changes in the age structure are expected to also deeply affect the health insurance system, as the demand for health services raises steeply with age (see Bohn, 2003) and asset prices, since retired baby-boomers will increase the relative demand of particular financial products that preserve the value of the assets and its liquidity (see Brooks, 2000; Poterba, 2001; Abel, 2003).}

When the PAYG system was created people lived beyond retirement age, on average, for much fewer years than now. As a consequence of the changes in longevity (and parallel trends in fertility) since then, the ratio of retirees to active workers has constantly increased. The three trends highlighted above will accelerate further the ageing of the population structure in the north of the planet and will put the PAYG system under severe strain. For example, in the case of the United States (where the trends are not as daunting as in Japan or Europe), the social security administration, which is currently running a large surplus cumulated thanks to the contributions of the large generations of individuals born immediately after WWII (the so-called baby boomers), is projected to experience a deficit by 2016 and to exhaust the trust fund entirely, barring reforms, by 2042.\footnote{The current legislation, which corresponds to one of the scenarios we study, would require a substantial drop in pension benefits in order to balance the system on a pure flow basis, i.e. only through the tax revenues paid by households of working age.}

The absence of a structural adjustment in the medium-run is an unlikely scenario. The relevant question is, rather, how big should the changes in the current tax/benefits parameters be to ensure the PAYG system will be in equilibrium in the long-run? A vast literature has attacked this question using general equilibrium overlapping-generations (OLG) models, in the
tradition of Auerbach and Kotlikoff (1987). For example, one can quantify the necessary long-run increase in the payroll tax, in absence of any change in the current level of benefits. De Nardi, Imrohoroglu and Sargent (1999) and Kotlikoff, Smetters and Walliser (2002) predict an increase of around 15% in the next 100 years to keep the U.S. system solvent.

Clearly, the quantitative results of these experiments are very sensitive to the dynamic path of the rate of return on capital and the wage rate which are predicted for the next century. At least since Diamond (1965), economists have recognized that these factor prices are affected, in general equilibrium, both by the demographic trends and by the particular (pension) policy option in place during and after the demographic transition. Moreover, if the demographic trends around the world are not fully synchronized, the evolution of factor prices depends crucially on whether one assumes a closed or an open economy. The set of issues arising when considering an open economy are very rarely addressed. For instance, the calculations mentioned above are typically performed under the assumption of closed economy.

In this paper, we argue that an equally interesting –but surprisingly overlooked in the literature– benchmark of analysis for social security reform is a two-region (South and North) open economy model, where unobstructed capital flows across regions equalize the rate of return on capital. Every country in the developed world (the North) faces quantitatively similar demographic trends and the same thorny issue of how to reform an obsolete PAYG pension system. In contrast, in the developing world (the South), large-scale social security systems are absent and the demographic trends are markedly different from those of the North. In particular, old-age dependency ratios are less than half than in the North: 8% compared to 18% in 2000, and are projected to converge to 35% only after 2100. Roughly speaking, the South tracks the demographic transition in the North by seven or eight decades.

This lack of synchronization in the demographic trends between North and South generates, in a two-region open economy model, major economic forces that have not been fully explored in this literature.

The objective of the paper is to study whether the quantitative implications of various social security reforms for the key policy variables, factor prices, macroeconomic aggregates of interest, and welfare of different cohorts are sensitive to the benchmark adopted, i.e. closed economy vs. the two-region model. The two-region economy approach seems to be a relevant alternative framework especially in light of the ever-increasing magnitude of global linkages in the world.
We perform two types of policy experiments. First, we assume that the North will retain the current PAYG scheme and we examine several options to finance the system through the demographic transition. In particular, we look, in turn, at the effects of financing the imbalance of the current system by increasing payroll taxes, consumption taxes, capital taxes, issuing debt, reducing benefits and increasing retirement age. Second, we assume the PAYG will be transformed into a fully-funded system, and we study alternative ways of financing this privatization. We perform all these experiments both under open and closed economy.

In the first set of experiment, somewhat surprisingly, we find that the evolution of the policy variables used to finance the PAYG system (i.e., rise in payroll tax, consumption tax, debt, fall in benefits) is remarkably similar in closed and open economy. However, this similarity hides important discrepancies in the dynamics of the aggregate capital stock, aggregate output and prices. In the two-region model, the North accumulates capital faster in the long-run than in closed economy, thanks to the inflow of resources from the South. Interest first decrease less in the open than in the closed economy experiment, but then, in the long run, they turn out to be lower. For wages the opposite is true. However, from the point of view of the government budget constraint, in the open economy equilibrium the gains in the labor income tax revenues due to the higher wage offset almost exactly the losses in the capital income tax revenues due to the lower interest rates. As a result, the equilibrium path of the fiscal variables is almost identical in the two benchmarks.

In the second set of privatization experiments, we find that households in the North massively accumulate capital for retirement, as the PAYG system is phased out. Interestingly, most of the demographics-driven divergence in the speed of decline of the interest rate between closed and open economy are offset by the extent of capital deepening in the North. What is due to the demographic transition in the South occurs in the North because of the social security transition towards a fully-funded system. The path of prices in closed and open economy turns out to be quite similar. As in the first set of experiments, but for very different reasons, the policy variables end up changing similarly in the two benchmarks.

With respect to welfare, the main result that holds across experiments is that in open economy the welfare effects of the reforms across generations are significantly smaller in absolute value than in closed economy. The key reason is that, in open economy, social security reforms have
a lighter impact on wage rates and interest rates in the North. Capital can flow into the North when domestic savings are low, keeping wages of the future generations high, independently of the reform, whereas in closed-economy the nature of the reform greatly affects capital accumulation and the future path of wages and interest rates.

The main conclusion of our exercise is, perhaps, that if one is interested in quantifying the path of the fiscal variables (e.g. the value of the payroll tax) needed to keep the PAYG viable or needed to finance a transition towards a fully-funded system, then it does not matter too much whether the closed or open economy view is taken. However, if the focus is on quantifying the evolution of factor prices and aggregate variables, then the two approaches can lead to diverging results. In terms of welfare, in virtually every policy experiment, the welfare effects of the reform in closed economy are larger in absolute values than those in open economy.\(^3\)

There are several branches of the literature related to our paper. First, there is a vast literature on equilibrium OLG models that evaluates quantitatively different scenarios for social security reform in closed economy. A far from exhaustive list includes Huang, Imrohoroglu and Sargent (1997), Geanakoplos, Mitchell and Zeldes (1998), De Nardi, Imrohoroglu and Sargent (1999), Huggett and Ventura (1999), Kotlikoff, Smetters and Walliser (1999), Abel (2001a,b, 2003), Bohn (2003), Diamond and Geanakoplos (2003), Krueger and Kubler (2005). Third, some authors have argued, within structural models, that the unsynchronized demographic trends across more and less developed countries can shape the dynamics of current accounts. See, among others, Brooks (2003), Domeij and Floden (2004). Attanasio, Kitao and Violante (2006).\(^4\)

Finally, some authors have explicitly recognized that the closed economy benchmark may not be the right one to study the implications of reforming the PAYG system. Huang, Imrohoroglu and Sargent (1997) analyze reforms in the U.S. under the “small open economy” assumption, with fixed interest rates. Borsch-Supan, Ludwig and Winter (2003) and Fehr, Jokisch and Kotlikoff (2004b) proposed multi-region models of the developed world (i.e., a subset of OECD countries), where the focus is on the effects of pension reform in U.S. and Germany, respectively, in open economy. Fehr, Jokisch and Kotlikoff (2005) extend their multi-country model to analyze the

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\(^3\)The observed demographic trends induce huge fluctuations in factor prices. An equally interesting question is calculating the welfare effects of the demographic transition (and how they differ in an open versus closed economy) for various cohorts. We make these calculations, from the perspective of households living in developing economies, in a companion paper (see Attanasio, Kitao and Violante, 2006).

\(^4\)Higgins (1998), Helliwell (2004) and Luhrmann (2005) have documented an empirical association in the data between capital flows and age-structure of the population, via reduced-form regressions.
role of China and conclude that capital flowing from China to the more developed world will significantly contribute to the rise in labor productivity and after-tax wages, counteracting the payroll tax hike needed to sustain the PAYG systems.

Our paper lies right at the center of these contributions, since it combines all these various approaches by studying quantitatively social security reform in the developed world through a North-South equilibrium OLG model with demographics-induced capital flows. Inevitably, we make a number of assumptions that leave on the side some important issues addressed in the literature. For instance, our model does not contain individual uncertainty and, as such, it is silent on the within-cohort insurance role of social security discussed for example by Conesa and Krueger (1998). Our model does not display aggregate uncertainty, thus we do not speak to the issue of diversification and risk of retirement savings, as addressed, for instance, by Abel (2001b), Diamond and Geanakoplos (2003), Geanakoplos, Mitchell and Zeldes (1998). In our economy labor is immobile, hence we do not consider the potential of labor migration for mitigating the pressures on the PAYG system, as emphasized by Storesletten (2000) and Fehr, Jokisch and Kotlikoff (2004a).

The rest of the paper is organized as follows. Section 2 provides a description of the data on demographic trends in the North and the South. Section 3 outlines the economic environment of our two-region open economy model and defines the equilibrium. Section 4 describes the calibration of the model. Section 5 contains our results. In Section 5.1 we discuss the baseline results we obtain from our simulations that will be used as a benchmark. We then move on, in section 5.2 to discuss the first set of experiments, on the sustainability of the current PAYG system in the North. In Section 5.3 we perform a second set of experiments where the social security system of the North transits towards a full privatization. Section 6 discusses how robust our results are to the relaxation of various assumptions. Section 7 concludes. The Appendixes contain (i) a detailed description of the data sources and the methodology chosen to model the demographic transition in the two regions, and (ii) an outline of the computational algorithm.

2 Global Demographic Trends

We begin by documenting empirically one of the building blocks of our analysis, i.e. the fact that the demographic trends across regions in the world are unsynchronized.
Our main source of demographic data is the *United Nations World Population Prospects: The 2002 Revision Population Database United Nations (2003).* The database provides historical and projected demographic data across countries for the period 1950-2050. The projections include four variants differing with respect to the assumptions made about the future course of fertility. We always use the so-called “medium scenario”.

In preparation for our two-region model, we divide the world into two regions which we call the North and the South. The North corresponds to the set of “More Developed Regions” according to the United Nations’ (UN) classification (i.e., North America, Europe, Japan, plus Australia and New Zealand). The South corresponds to the UN group of “Less Developed Regions”, which includes Africa, Asia (except for Japan), Latin America and the Caribbeans, plus Melanesia, Micronesia and Polynesia.

Demographics in these two regions display three key differences. First, whereas the North is currently rebounding from a secular decline in fertility rates, the South is still undergoing a rapid fall in fertility. For example, in the North the total fertility rate (children per woman) was 1.6 in 2000 and is projected to rise to 2.05 in 2200. In contrast, in the South the fertility rate was close to 3.0 in 2000 and is projected to converge to the same value for the North over the next two centuries. Second, both regions are experiencing a rise in surviving rates, but the increase in the South is significantly more rapid: male life-expectancy at birth is projected to grow from 71 in 2000 to 94 in 2200 in the North and from 61 to 92 in the South. Finally, female participation rates are expected to settle at roughly 72% in the next two decades in the North, while in the South they are currently at 40% and are projected to reach the North’s levels only in 100 years or so.

These three trends will represent a key input in our simulated policy experiments. We now present the data more in detail and describe how we will model these demographic changes in our simulations.

**Fertility Transition:** Age-specific fertility rates are only available from UN data for 1995-2050. For the years before 1995, only the total fertility rates for each region are available, hence we extrapolate the available age-specific fertility rates backward and compute age-specific rates for 1950-1995 to match the data on total fertility rates. For the periods beyond 2050, we use the projected total fertility rates based on the study in United Nations (2004) and extrapolate
forward the age-specific fertility rates using the projected total fertility rates of United Nations (2004) for the years 2100 and 2200 as targets. See Appendix B for details.

Figure 1 reports the age-specific fertility rates and the top panel of Figure 2 reports the data on total fertility rates and the model’s fit. The most interesting facts in Figure 1 are two: first, in the North the rebound in fertility rates occurs for the age classes 25-39, but fertility before age 25 keeps declining; second, in the South, it is projected that after 2050, the women in the age-group 25-34 will overcome women in the age group 20-24 as those more likely to have children, exactly like what happened in the North since 2000. In terms of total fertility rates, Figure 2 shows that fertility dropped from 3.0 to 1.6 in the North in the past 40 years and is now rising back towards the “replacement value” of 2.0. In the same period, the number of children per woman in the South dropped from 6.0 to 3.0 and is forecasted to converge to 2.0 by 2100.\textsuperscript{5} Note that in both regions fertility remained high for a decade or so in the 1950s, marking the so-called baby-boom.

**Life-Expectancy Transition:** Age-specific surviving probabilities in the two regions for the period 1950-2050 are computed based on the actual and projected data on population shares by age-group in the UN database. We compute the surviving rates of the two regions beyond 2050 to match the UN projections (see United Nations, 2004) for three key population moments: median age in 2100 and 2200, old-dependency ratio (proportion of persons aged 60+) in 2100 and 2200, and the average population growth rate for 2100-2150 and 2150-2200. We make an adjustment in the surviving rates for the South so that they converge smoothly to the same demographic steady-state as the North by the year 2200. See Appendix B for details.

The second, third and fourth panels of Figure 2 plot the evolution of median age, old-dependency ratio, and population growth in the data and that implied by the estimated age-specific surviving rates which fit the data quite well. Note that until 2050, an individual in the North is, on average, 10 year older than one in the South, then the age structure converges quickly in the following 50 years. The old-dependency ratio, a rough index of the (un-) sustainability of the PAYG system grows from 10% in 1950 to over 30% in 2050 in the North. Population growth in the North fluctuates around zero since 2000, and in the South it declines steadily from 1.5% in 2000 towards 0.05% in the long-run.

\textsuperscript{5}The sharp decline in fertility in the South is caused by a combination of three forces: 1) health improvements that reduced infant mortality, 2) the diffusion of family planning services, and 3) new labor market opportunities for women. See Schultz (1997).
Female Participation Transition: Another important demographic trend is the rise in female labor-force participation. The top panel of Figure 3 plots historical data on women's participation rates for the U.S. (representing the North) and the average of four countries in the South (Brazil, India, Korea and Mexico), obtained from The International Data Base of the U.S. Census Bureau (2004). Female participation rates in 2000 were roughly 42% in the South and 67% in the North, so the South is expected to substantially increase its stock of human capital over the next few decades. Based on the projections in the U.S. Census Bureau (2003), the female participation rate will reach 72% in the North in the next twenty years and settle at that level for the long-run. We assume that the level of women's participation to the labor market in the South converges to the North's level by 2200, like every other demographic variable.

Increased women's participation is at least partially associated to the fertility decline. How can we capture this link? We use Consumers Expenditures Survey (CEX) data (sample of married household headed by males, aged 17-69, for 1982-1999) on female hours worked and number of children of different age groups (0-4, 5-9, 10-14) and estimate, through a Probit regression, the marginal effect of having dependent children of a particular age on hours worked measured as a fraction of the time endowment. As expected, we find that the newborn child has the strongest negative impact on participation and, as the child ages, the effect is smaller.

Given our estimated fertility trends in both regions, we then use the estimated coefficients to calculate how much the decline in fertility contributes to the observed rise in participation. The bottom panels of Figure 3 show that only a small fraction -roughly 1/10th- of the observed post-war increase in female participation in the North and in the South can be explained by the decline in fertility.

This finding, consistent with some of the evidence on female labor supply (see, for instance, Attanasio, Low and Sanchez, 2004), makes a second step necessary to fit the data: we introduce a region-specific polynomial time trend that accounts for the residual increase documented above.\footnote{We remain agnostic on the economic forces underlying the trend. Attanasio, Low and Sanchez (2004) have focused on the role of the reduction in child-care cost; Jones, Manuelli and McGrattan (2003) on the reduction of the gender gap; Olivetti (2001) on the rise in the return to experience; Greenwood, Seshandri and Yorukoglu (2005) on technological progress in the household sector.}

The top panel of Figure 3 shows the fit of the model. See the Appendix B for more details.

To conclude, while the North is in the last phase of a long demographic transition, the South is right in the midst of it: the entire world population growth between now and 2050 is projected...
to occur in the South. The presence of economic linkages among the two economies, due to factor mobility, means that the demographic changes in one region will be transmitted to the other region and, though this interaction, an equilibrium path for factor prices will arise that is likely to be very different from the closed-economy equilibrium path. In the next section, we outline a model where this idea is properly formalized.

3 The Model

3.1 Economic Environment

Preliminaries: The world economy is composed by two regions, the North and the South. The two regions differ by demographic structure, total factor productivity level, and fiscal institutions. In what follows these differences are spelled out more in detail. There is no aggregate or region-specific uncertainty, but since we will model a deterministic transition across two steady states, equilibrium factor prices will be time-varying in a deterministic way. The only source of individual risk is related to the uncertain lifespan. We let \( t \) denote time, \( i \) individual's age, and \( r \) the two regions (North and South), with \( r = n, s \).

Technology: In each region \( r \), a constant returns to scale, aggregate production function \( F(Z_t^r, K_t^r, H_t^r) \) produces output of a final good \( Y_t^r \) which can be used interchangeably for consumption \( C_t^r \) and investment \( X_t^r \). Among the arguments of the production function, \( Z_t^r \) denotes the total factor productivity level in region \( r \) at time \( t \), \( H_t^r \) is the stock of human capital (i.e., the aggregate efficiency units of labor), and \( K_t^r \) is the aggregate stock of physical capital used in production in region \( r \). Physical capital depreciates geometrically at rate \( \delta \) each period. The level of technology in region \( r \) grows exogenously at rate \( \lambda_t^r \) between \( t \) and \( t + 1 \), but in the long-run both regions grow at the same constant rate \( \lambda \).

Demographics: Each region in the economy is populated by overlapping generations of

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7For tractability, we have assumed homogeneity of demographics within the two regions. Even though the between-region divergence is an order of magnitude larger, there are some notable within-region differences. Within the North, the most important one is the distinction between the recent trends in population growth in the U.S. and the rest of the developed world. Fertility is, for example, hovering at replacement value in the U.S., while it is much lower in Europe and Japan. Within the South, Africa is at the early stages of the demographic transition compared, say, to Latin America. At the other end of the spectrum, China witnessed a dramatic decline in fertility rate in the past two decades, mostly due to family planning government policies, such as the “one-child” policy implemented in the late 1970’s.
ex-ante identical “pairs of individuals” who may live for a maximum of \( T \) periods indexed by \( i = 1, 2, ..., \bar{I} \). Pairs of individuals are dependent children for the first \( I^d \) periods of their life and then they turn adult and form a household. For a pair of individuals born in region \( r \), denote by \( s_{i,t}^r \) the probability of surviving until age \( i \) at time \( t \), conditional on being alive at time \( t - 1 \) (with age \( i - 1 \)). Hence, in region \( r \), the unconditional probability of surviving \( i \) periods up to time \( t \) is simply

\[
S_{i,t}^r = \prod_{j=1}^{i} s_{j,t+(j-i)}^r,
\]

where \( S_{1,t}^r = s_{1,t}^r = 1 \) for all \( t \) by definition. In each period \( t \), pairs of age \( i \) in region \( r \) have an exogenously given fertility rate (i.e., a probability of giving birth to another pair of individuals) equal to \( \phi_{i,t}^r \). During childhood – i.e. until age \( I^d \) – fertility is assumed to be zero. For what follows, it is useful to define \( d_{i,t}^r \) as the total number of (pairs of) dependent children living in a (adult) household of age \( i \) at time \( t \), i.e.

\[
d_{i,t}^r = \begin{cases} 
0 & \text{for } i \leq I^d \\
\sum_{k=i-I^d+1}^{i} \phi_{k,t-(i-k)}^r S_{i-k+1,t}^r & \text{for } i > I^d 
\end{cases}
\]

We denote by \( \mu_{i,t}^r \) the size of the population of age \( i \) at time \( t \) in region \( r \) and by \( \mu_t^r \) the \((\bar{T} \times 1)\) vector of age groups. Thus, in each region the law of motion of the population between time \( t \) and \( t + 1 \) is given by \( \mu_{t+1}^r = \Gamma_t^r \mu_t^r \) where \( \Gamma_t^r \) is a time-varying \((\bar{T} \times \bar{T})\) matrix composed by fertility rates and surviving probabilities for households of region \( r \) described by

\[
\Gamma_t^r = \begin{bmatrix}
\phi_{1,t}^r & \phi_{2,t}^r & \ldots & \ldots & \phi_{I,t}^r \\
s_{2,t+1}^r & 0 & \ldots & \ldots & 0 \\
0 & s_{3,t+1}^r & 0 & \ldots & 0 \\
0 & 0 & \ddots & \ddots & 0 \\
0 & 0 & \ldots & s_{I,t+1}^r & 0
\end{bmatrix}
\]

The first row of this demographic transition matrix contains all the age-specific fertility rates, the elements \((i + 1, i)\) contain the conditional surviving rates, whereas all the other elements are zeros. Lee (1974) shows that the largest eigenvalue of \( \Gamma_t^r \) is the growth rate of the population between time \( t \) and \( t + 1 \), which we denote as \( \gamma_t^r \) (see also Rios-Rull, 2001).

Since we are interested in the economically active population, we reshape the matrix \( \Gamma_t^r \) and the vector \( \mu_t^r \) down to size \( \bar{I} = \bar{T} - I^d \) and we normalize the first period of adulthood (and
economically active) life to be period 1 of life for households. We also restrict the parameters of the two matrices $\Gamma_r^t$ to converge across regions as $t$ becomes large, in order to generate a common long-run growth rate of the population $\gamma$.

**Household Preferences:** Households of age $i$ at time $t$ in region $r$ are composed by a pair of adults and a number $d_{ir}^t$ of pairs of dependent children living with their parents. The adults in the household jointly make consumption allocation decisions for themselves and their dependent children based on the intra-period utility function

$$u^r(c_{i,t}^a, c_{i,t}^d) = \frac{(c_{i,t}^a)^{1-\theta}}{1-\theta} + d_{i,t}^r \omega(d_{i,t}^r) \frac{(c_{i,t}^d)^{1-\theta}}{1-\theta},$$

(1)

where $c_{i,t}^a$ denotes consumption for the adults, $c_{i,t}^d$ consumption per dependent child, and $\omega(d_{i,t}^r) \geq 0$ is a function that weighs consumption of children in households’ utility. The intertemporal elasticity of substitution for consumption is $1/\theta$. This preference specification is convenient, because it permits to express utility only as a function of the total consumption of the household $c_{i,t} = c_{i,t}^a + d_{i,t}^r c_{i,t}^d$. From the optimality condition of the household with respect to $c_{i,t}^d$ one obtains

$$c_{i,t}^d = c_{i,t}^a \omega \left(d_{i,t}^r\right)^{\frac{1}{\theta}},$$

(2)

which sets optimally the consumption of children to a fraction of the consumption of parents proportional to their weight in the utility function. Using (2) into (1), together with the definition of the total consumption of the household $c_{i,t}$ one obtains

$$u^r(c_{i,t}) = \Omega_{i,t}^r \frac{c_{i,t}^{1-\theta}}{1-\theta},$$

(3)

where $\Omega_{i,t}^r = \left[1 + \omega \left(d_{i,t}^r\right)^{\frac{1}{\theta}} d_{i,t}^r\right]^\theta$ and acts like an age- and time-dependent preference shifter. To conclude, the intertemporal preference ordering for households born (adult of age $i = 1$) at time $t$ is given by

$$U^r = \sum_{i=1}^t \beta^{i-1} S_{i,t+i-1}^r \Omega_{i,t+i-1}^r \frac{c_{i,t+i-1}^{1-\theta}}{1-\theta},$$

(4)

where $\beta$ is the discount factor. There is no explicit altruistic motive, all bequests are accidental.

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8 This restriction, similar to the one we impose for productivity growth, is necessary to achieve a long-run growth path where neither region is negligible in terms of output and population compared to the other one.
Household Endowments: Households derive no utility from leisure. They have a fixed time endowment, normalized to one unit, that they can devote either to productive activities in the labor market or to child care at home. We denote by $d_{i,t}^r$ the $(I^d \times 1)$ vector of number of children’s by age groups for a household of age $i$ at time $t$. Labor supply for households of region $r$ at age $i$ at time $t$ is given by

$$l_{i,t}^r = \begin{cases} \Lambda_i^r(d_{i,t}^r) & \text{if } i < I^R \\ 0 & \text{otherwise,} \end{cases}$$

where $1 - \Lambda_i^r(d_{i,t}^r)$ is an exogenous fraction of time that needs to be devoted to child care. The function $\Lambda_i^r(d_{i,t}^r)$ is decreasing in the number of dependent children and captures the rise in labor force participation of women. At age $I^R$, households are subject to compulsory retirement from any working activity. Households of age $i$ at time $t$ in region $r$ are endowed with $\varepsilon_{i,t}^r$ efficiency units of labor for each unit of time worked in the market. Finally, we assume that the initial asset holdings of each household is zero, i.e. $a_{1,t}^r = 0$ for any $t$ in both regions.

Household Budget Constraint: The budget constraint of the households in region $r$ is

$$(1 + \tau_{c,t}^r) c_{i,t}^r + a_{i+1,t+1}^r = y_{i,t}^r + \left[1 + (1 - \tau_{a,t}^r) r_t \right] a_{i,t}^r + q_{i,t}^r, \quad \text{with } a_{i+1,t}^r \geq 0$$

where $a_{i,t}^r$ is the net asset holding, and $q_{i,t}^r$ is the per-capita accidental bequest received by an individual of age $i$ at time $t$. We assume that there are annuity markets to cover the event of early death. Every household has the right to keep the share of assets of the deceased in the same cohort, i.e. the payment is

$$q_{i,t}^r = \frac{\mu_{i,t}^r (1 - s_{i+1,t+1}^r)}{\mu_{i,t}^r} a_{i+1,t+1}^r = (1 - s_{i+1,t+1}^r) a_{i+1,t+1}^r.$$  

(7)

Using (7), we can rewrite the budget constraint (6) as:

$$(1 + \tau_{c,t}^r) c_{i,t}^r + s_{i+1,t+1}^r a_{i+1,t+1}^r = y_{i,t}^r + \left[1 + (1 - \tau_{a,t}^r) r_t \right] a_{i,t}^r.$$  

(8)

We require households to die with non-negative wealth once they reach age $I$, but otherwise we impose no borrowing constraint during their life. Net income $y_{i,t}^r$ accruing to households of age $i$ in region $r$ at time $t$ is defined as

$$y_{i,t}^r = \begin{cases} (1 - \tau_{w,t}^r) w_{i,t}^r \varepsilon_{i,t}^r l_{i,t}^r & \text{if } i < I^R, \\ p_{i,t}^r & \text{if } i \geq I^R, \end{cases}$$

(9)
where \( w_r^i \) is the wage rate, \( \varepsilon_r^i,t \) is the efficiency units of labor of an individual of age \( i \), and \( p_r^i,t \) is pension income. Households pay taxes \( \tau_{c,t}^r \) on consumption, \( \tau_{a,t}^r \) on capital income, and \( \tau_{w,t}^r \) on labor income. Social security benefits are given by the formula

\[
p_r^i,t = \kappa^r_t \frac{W_r^i,t}{I_R - 1},
\]

where \( \kappa^r_t \) is the replacement ratio of average past earnings. Cumulated past earnings \( W_r^i,t \) are defined recursively as

\[
W_r^i,t = \begin{cases} 
  y_r^1,t & \text{if } i = 1 \\
  y_r^i,t + W_r^{i-1,t-1} & \text{if } 1 < i < I_R \\
  W_r^{i-1,t-1} & \text{if } i \geq I_R.
\end{cases}
\]

**Government Budget Constraint:** In each region \( r \), public expenditures and social security program are administered by the government under a unique consolidated intertemporal budget constraint. The government can raise revenues through its fiscal instruments \( (\tau_{c,t}^r, \tau_{a,t}^r, \tau_{w,t}^r) \) and can issue one-period risk-free debt \( B_r^t \). Government borrowing and tax revenues finance a stream of expenditures \( G_r^t \) and the PAYG social-security program described above. The consolidated government budget constraint reads

\[
G_r^t + (1 + r_t) B_r^t + \sum_{i=1}^I p_r^i,t \mu_r^i,t = \tau_{w,t}^r w_r^t \sum_{i=1}^{I_R-1} \mu_r^i,t \varepsilon_r^i,t A_r^i,t + \sum_{i=1}^I \mu_r^i,t \left( \tau_{a,t}^r a_r^i,t + \tau_{c,t}^r c_r^i,t \right) + B_r^{t+1}.
\]

**Commodities, Assets and Markets:** There are three goods in the world economy: a final good which can be used either for consumption or investment, the services of labor and the services of capital. The price of the final good (homogeneous across the two regions) is used as the world numeraire. Labor is immobile, thus wages are determined independently in regional labor markets. Physical capital is perfectly mobile across the two regions, so there is one world market for capital. We denote as \( N_t \) the external wealth of the North, i.e. the stock of capital productive in the South which is owned by households of the North, with the convention that a negative value denotes ownership of capital used for production in the North held by households of the South. Finally, in every region there is a financial market for government debt. The markets
where these goods and assets are traded are perfectly competitive. An intuitive no-arbitrage condition between assets and the absence of aggregate uncertainty imply that the return on both regional bonds is equal to the return on physical capital, as we have already implicitly assumed when we wrote the budget constraints of the government and households.

### 3.2 Equilibrium

Before stating the definition of equilibrium, it is useful to point out that, without further restrictions, the equilibrium path of the fiscal variables \( \{G^r_t, \kappa^r_t, \tau^a_{r,t}, \tau^c_{r,t}, B^r_t\}_{t=1}^{\infty} \) is indeterminate, as there is only one budget constraint we can operate on. In what follows, we define an equilibrium for the case where the paths of all fiscal variables are given, except for \( \{\tau^r_{w,t}\}_{t=1}^{\infty} \). This case corresponds to our baseline experiment. It is straightforward to extend this definition to the case where the path of a different set of government policies is given exogenously. Finally, for brevity we omit the definition of the closed-economy equilibrium and state directly the equilibrium conditions for the open economy.

A **Competitive Equilibrium of the Two-Region Economy**, for a given sequence of demographic matrices \( \{\Gamma^r_t\}_{t=1}^{\infty} \), and a given sequence of fiscal variables \( \{G^r_t, \kappa^r_t, \tau^a_{r,t}, \tau^c_{r,t}, B^r_t\}_{t=1}^{\infty} \), is (i) households’ choices \( \{\{c^r_{i,t}, a^r_{i,t}\}_{t=1}^{I_i}\}_{i=1}^{\infty} \), (ii) government policies \( \{\tau^r_{w,t}\}_{t=1}^{\infty} \), (iii) wage rates \( \{w^r_t\}_{t=1}^{\infty} \), (iv) aggregate variables \( \{K^r_t, H^r_t, X^r_t, C^r_t\}_{t=1}^{\infty} \) in each region \( r \), (v) a sequence of world interest rates \( \{r_t\}_{t=1}^{\infty} \), and (vi) external wealth of the North \( \{N_t\}_{t=1}^{\infty} \) such that:

1. Given prices \( \{w^n_t, w^s_t, r_t\}_{t=1}^{\infty} \) and fiscal variables \( \{G^r_t, \kappa^r_t, \tau^a_{r,t}, \tau^c_{r,t}, B^r_t\}_{t=1}^{\infty} \), households choose optimally consumption and wealth sequences \( \{\{c^r_{i,t}, a^r_{i,t}\}_{i=1}^{I_i}\}_{t=1}^{\infty} \), maximizing the objective function in (4) subject to the budget constraint (8), the income process (9), and the time allocation constraint (5).

2. Given prices \( \{w^n_t, w^s_t, r_t\}_{t=1}^{\infty} \), firms in each region maximize profits by setting the marginal product of each input equal to its price, i.e.

\[
w^r_t = F_H(Z^r_t, K^r_t, H^r_t) \text{ for } r = n, s, \tag{12}\n\]

\[
r_t + \delta = F_K(Z^n_t, K^n_t, H^n_t) = F_K(Z^s_t, K^s_t, H^s_t). \tag{13}\n\]
3. The regional labor markets clear at wage $w^r_t$ and aggregate human capital is given by

$$H^r_t = \sum_{i=1}^{I_{r-1}} \mu^r_{i,t} \varepsilon^r_{i,t} N^r_{i,t}. \quad (14)$$

4. The regional bond markets and the world capital market clear at the world interest rate $r_t$ and the aggregate stocks of capital in the two regions satisfy

$$K^n_t + N_t + B^n_t = \sum_{i=2}^{I} \mu^n_{i-1,t-1} a^n_{i,t},$$

$$K^s_t - N_t + B^s_t = \sum_{i=2}^{I} \mu^s_{i-1,t-1} a^s_{i,t}. \quad (15)$$

5. Given prices $\{w^n_t, w^s_t, r_t\}_{t=1}^\infty$, and fiscal variables $\{G^r_t, k^r_t, \tau^r_{a,t}, \tau^r_{c,t}, B^r_t\}_{t=1}^\infty$, the government policies $\{\tau^{r,w}_t\}_{t=1}^\infty$ satisfy the consolidated budget constraint (11) in each region.

6. The allocations are feasible in each region, i.e. they satisfy the regional aggregate resource constraints

$$K^n_{t+1} - (1 - \delta) K^n_t + N_{t+1} - (1 + r_t) N_t = F(Z^n_t, K^n_t, H^n_t) - C^n_t - G^n_t,$$

$$K^s_{t+1} - (1 - \delta) K^s_t - N_{t+1} + (1 + r_t) N_t = F(Z^s_t, K^s_t, H^s_t) - C^s_t - G^s_t. \quad (16)$$

It is useful to recall that aggregate investments in region $r$ are given by $X^r_t = K^r_{t+1} - (1 - \delta) K^r_t$, whereas regional savings in the North and in the South are respectively

$$S^n_t = F(Z^n_t, K^n_t, H^n_t) + r_t N_t - C^n_t - G^n_t,$$

$$S^s_t = F(Z^s_t, K^s_t, H^s_t) - r_t N_t - C^s_t - G^s_t. \quad (17)$$

As a result, the net capital outflow $\eta_t$ from the North (inflow into the South), or current account surplus in the North (deficit in the South), are respectively

$$S^n_t - X^n_t = \eta_t = N_{t+1} - N_t,$$

$$S^s_t - X^s_t = -\eta_t = -(N_{t+1} - N_t). \quad (18)$$
Appendix A contains a detailed description of the algorithm we use to compute the equilibrium transitional dynamics.

3.3 Discussion

The two-region model we have outlined above allows to quantify the importance of some factors that have been largely overlooked in the debate on social security reform. In particular, we want to determine the extent to which the existence of un-synchronized demographic trends, together with the existence of integrated capital markets affects the comparison of different policy alternatives. Computing numerically the transitional dynamics of this model economy is a non-trivial task, thus inevitably there are some aspects of reality that, albeit potentially important, play no role in our stylized model.

We are agnostic about the nature of the development process, which we model through exogenous TFP growth. Moreover, we do not allow the productivity of labor in the South to fully catch up to the levels observed in the North. This might be important as the effect of the presence of the South on factor prices depends on the ‘size’ of that economy, as measured by the number of labor efficiency units. A faster growth of labor productivity in the South would accentuate the effects observed in the last parts of the simulations.

We abstract from the effects of tax reforms on labor supply. That is we do not allow for the distortionary effects that increased taxation might have and that has received some attention in part of the literature (see Feldstein, 2005). However, we allow the model to capture the major long-run trend in labor supply, rising female participation, which we link, albeit mechanically, to the fall in fertility.

We also ignore intra-cohort heterogeneity and idiosyncratic risk of either transitory or permanent nature. There is only one type of human capital in the model, and no returns to education. Furthermore, given the absence of risk or other frictions, there is a single asset in the economy (except for the pension system). Given these features the model can only address inter-generational redistributional issues. Moreover, the agents in our model do not face portfolio choices of the type discussed in Abel (2001a) or Diamond and Geanakoplos (2003).

Rather than modelling altruism explicitly, we assume the existence of annuity markets. This assumption has the convenient property that it eliminates accidental bequests and greatly simplifies the numerical solution. Abel (2001b) discusses the potential importance of a bequest motive
and concludes that its presence is not quantitatively important for the dynamics of factor prices following the retirement of the baby boom generation.

We assume that, once the demographic steady state is (unexpectedly) perturbed in 1950 by the baby boom and the subsequent baby bust, households anticipate these events perfectly and, consequently, have perfect foresight on the path of future prices and taxes. While probably unrealistic, this is a common assumption when solving for transitional dynamics. See Lucas (2003) for a discussion on how to model expectations about long-run future policies in OLG economies.

We return on some of these assumptions in section 6, where we perform a robustness analysis. At this point, it is useful to recall that the objective of the paper is not determining what is the welfare-maximizing reform or what are the macroeconomic effects of a given reform in “absolute terms”. Rather, the contribution of the paper is to contrast a set of PAYG reforms in closed and open economy, providing a comparison between two benchmarks. In this sense, these abstractions are important only insofar as they would produce very different effects in the two benchmarks.

4 Calibration

**Preliminaries:** The common feature of all the policy experiments we perform is that our model economy replicates the observed and projected global demographic trends documented in section 2 and Figures 2 and 3. We calibrate the initial steady-state using demographic and economic variables for the 1950s in the two regions and we anchor our common final steady-state to match the long-run United Nations’ demographic projections. We assume that all demographic parameters in the two regions converge to the same values by 2200. We then let our world economy transit between the two steady-states by imposing the path of mortality, fertility and female participation rates modelled in section 2. The model’s period is set to 5 years.

**The Two Regions:** The North in our model corresponds to the UN’s set of “More Developed Regions” which includes North America, Europe, Japan, plus Australia and New Zealand. The South corresponds to the set of “Less Developed Regions”, which combines the rest of the world.

**Technological Parameters:** We choose a Cobb-Douglas specification

\[ F(Z_t^r, K_t^r, H_t^r) = Z_t^r(K_t^r)\alpha(H_t^r)^{1-\alpha}, \]
for the production function with capital share $\alpha = .30$ in both regions.

For TFP growth, based on the World Bank’s *World Development Indicators* (WDI), we obtain the target growth rates of output per capita in the two regions.\(^9\) The growth rate of TFP $\lambda^n$ in the North is set at the constant value of 1.78% so that the region achieves the target average per-capita output growth rate of 2.7% during 1950-2000, as computed from the WDI. We let the TFP in the South grow at rate $\lambda^s_t = 1.50\%$ so that output per capita grows at 2.2% during 1950-2000. After 2000, we let $\lambda^s_t$ converge smoothly to the TFP growth rate of the North. We set the initial value of TFP $Z^n_0 = 1.802$ in order to normalize income per capita in the North to 1 in the first steady state. Based upon the WDI, income per capita in the North in 1950-2000 was approximately 7 times larger than that of the South, requiring $Z^s_0 = 0.677$. The depreciation rate of capital is set to 5% per year in both regions, implying a value of $\delta = 0.2262$.

**Demographic Parameters:** Since each model-period corresponds to five years, we set $I^d = 3$ so that agents become adults and economically active at age 17 and we set $I = \bar{I} - I^d = 24 - 3 = 21$, so that households can live a maximum of 24 periods (120 years). We also set the retirement age $I^R = 11$ which corresponds to age 67. All these parameters are common in both regions.

Our main source of demographic data is the *United Nations World Population Database (2002 Revision)*. The database provides historical and projected demographic data across countries for the period 1950-2050. The relative population size of the two regions is a key determinant of the interest rate in the open economy model. We normalize the total population in the South in 1950 to one and set the initial population size for the North to 0.476, based on the UN data. During the transition away from the initial steady-state, the population size in both regions is determined by the evolution of age-specific fertility rates $\phi^r_{i,t}$ and survival rates $s^r_{i,t}$ described in section 2. By 2200, the relative size of the population in the North falls to 0.164.

**Preferences and Endowments Parameters:** Preferences are common between the two regions. Following the bulk of the literature on consumption (see Attanasio (1999), for a survey), we set $\theta = 2$. We set $\beta = 1.036$ to match the target capital-output ratio of 2.5 in the North on an annual basis in 2000. The weight parameter of children in the utility of adult parents is

\(^9\)For the North, we used the aggregate of individual countries called “High Income Countries” in the WDI, corresponding to the UN definition of “More Developed Regions”. For the South, we used the aggregate called “Low and Middle Income Countries” in the WDI, the equivalent of the UN’s “Less Developed Regions”.

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set to match the commonly used consumption adult-equivalent scales. The micro-evidence on
equivalence scales summarized in Fernandez-Villaverde and Krueger (2004, Table 3.2.1) points at
a ratio between the consumption of a household with 1, 2 and 3 children compared to a household
without children of 1.231, 1.470, and 1.694, respectively. Using equation (2), it is easy to see
that our function \( \omega(d_{i,t}^r) \) should satisfy the three moment conditions
\[
\omega(0.5)^{\frac{1}{\theta}} = (1.231 - 1) / 0.5, \\
\omega(1)^{\frac{1}{\theta}} = (1.470 - 1), \\
\omega(1.5)^{\frac{1}{\theta}} = (1.694 - 1) / 1.5.
\]
Note that we need to make an adjustment for the fact that in our model children come in pairs.
Given \( \theta = 2 \), setting \( \omega = 0.216 \) independently of the number of children yields an excellent fit.

The calibration of the age profile of efficiency units is done separately for the North and
the South. The age-efficiency profile for the North is estimated on weekly wage data from the
U.S. Consumer Expenditure Survey (CEX) for the period 1982-1999. For the South, we have
estimated an age-efficiency profile on Mexican data—precisely from the Encuesta Nacional de
Ingreso y Gasto de los Hogares (ENIGH), which is the equivalent of the U.S. CEX, using the
1989, 1992, 1994, 1996, 1998, and 2000 waves.\(^{10}\) The sample, across both surveys, is the universe
of married couples headed by males and aged 17-69 and the derived “household wage” is an
average of male and female wage weighted by hours worked.

The estimated efficiency profile for the North shows a twofold rise from the initial value to its
peak (age \( i = 7 \) or 47 years old) and then it settles at 20% below the peak before retirement. We
found that in Mexico the profile rises up to 90% above the initial value and it settles roughly 30%
below the peak. This flatter pattern is exactly what we expected on the grounds that households
in the North have higher educational levels and work in occupations with lower content of physical
labor.

The function \( \Lambda_i^r(d_{i,t}^r) \) measures the participation rate of the households, i.e. its time endowment net of time spent for child care. We normalize the time endowment of the household to 1 unit and assume that males work full time. Hence, \( \Lambda_i^r(d_{i,t}^r) = 0.5 \left[ 1 + P_i^r(d_{i,t}^r) \right] \), where \( P_i^r(d_{i,t}^r) \in (0, 1) \) denotes the fraction of time a female worker of age \( i \) supplies to the labor market in region \( r \) at time \( t \). The model for the dynamics of \( P_i^r(d_{i,t}^r) \) is described in section 2 and Appendix B.

\(^{10}\)See Attanasio and Szekely (1999) for a detailed description of the Mexican survey data.
**Government Policy Parameters:** Government debt and expenditures as a fraction of GDP for the North and the South are computed from the World Bank’s *World Development Indicators* (WDI) as time-averages over the period 1970-2000. For the North, we obtain a ratio of government debt $B^n_t$ to GDP equal to 35.5%, and a ratio of government expenditures $G^n_t$ to GDP equal to 26.5%. For the South, the WDI yields a government expenditures-GDP ratio in the South around 20% over the sample period, and a debt-GDP ratio of 50%.\(^{11}\)

Based on the study in Whitehouse (2003) who report replacement rate of average past earnings in nine OECD countries, for the North we set $\kappa_n^t = 46.7\%$.\(^{12}\) From the tax data collected by Mendoza, Razin and Tesar (1994) for seven OECD countries, in the North we set $\tau^n_c = 9\%$ for the consumption tax, and $\tau^n_a = 38\%$ for the capital income tax. The labor income tax adjusts in the equilibrium of the model to balance the government budget. We obtain $\tau^n_w = 26.3\%$ as the average during 1950-2000, which is very close to the 27.9% reported for the labor income tax by Mendoza, et al. (1994).\(^{13}\)

Unfortunately, similar systematic studies on the tax structure and the replacement rates for developing countries are not available. The WDI reports, for Low and Middle Income countries, that social security tax revenues represent only 0.3% of income. Using the calibrated labor share of 70%, one obtains an average social security tax of 0.5%. Assuming that the social security system is self-financing, the model delivers a replacement ratio of average past earnings for the South of $\kappa_s^t = 10.1\%$ in the first steady-state.

This much lower value for the replacement ratio, compared to the North, is mainly due to two factors. First, the disproportionate role of self-employment and informal production means that a vast part of the working population is not covered by a pension system. Second, the involvement of Southern governments in the pension sphere is limited: in Asia, only Korea and Taiwan operate a defined benefits PAYG scheme with universal coverage; Latin America is the region with the

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\(^{11}\)The government expenditures data for the South are only available starting from 1981. The government debt data are not available for the Low Income countries, but only for the Middle Income countries. Luckily, they are reported separately for Lower-middle Income countries and Upper-middle Income countries. The debt-GDP ratio for the former region is 50%, and for the latter it equals 40%. One would expect the Low Income countries to be even more heavily indebted, hence we chose 50% for the aggregate of the South.

\(^{12}\)The countries in the study by Whitehouse (2003) are: U.S., Canada, U.K., Germany, Italy, Japan, Finland, Netherlands and Sweden and the data refer to the mid to late 1990s. Our replacement rate rate is a GDP-weighted average.

\(^{13}\)The countries in the study by Mendoza, et al (1994) are: U.S., Canada, U.K., France, Germany, Italy and Japan. The original data refer to the period 1965-1988. We used an unpublished extension up to 1996 available on Mendoza’s web page. Our tax rates are averages over the sample period and over countries, weighted by GDP.
largest number of pension system already reformed towards substantial privatization (see Mohan, 2004, for the Asian experience, and Corbo, 2004, for the Latin American experience).

Heady (2002) argues that, because of the importance of the informal sector, governments in the South rely much more on indirect taxation, compared to the developed world. From their estimates, we conclude that an appropriate value for the consumption tax in the South could be $\tau^c_n = 15\%$. Finally, we set the capital income tax at the same level of the North and let the wage tax adjust in equilibrium. The model implies $\tau^w_n = 6.04\%$ as the average labor income tax in the South during 1950-2000.

5 Computational Experiments on Social Security Reform

In 1950 the world economy is in the initial steady-state; then, the demographic transition in the two regions kicks in and continues until 2200, when the demographics in the two regions converge to a common set of parameters, i.e. a common matrix $\Gamma$. The change in demographics makes the Social Security system in place in the North unsustainable, given the current legislation. In the model, the government intertemporal budget constraint has to hold, somehow. We consider different ways to balance the accounts.

Our objective is to compare the macroeconomic and welfare implications of various (more or less radical) social security reforms in the North under two alternative scenarios: the two-region open economy and the closed economy –the latter being the standard approach in the existing literature.

**Policy Experiments:** We run two types of policy experiments. In the first set of experiments, the North maintains the current PAYG social security system and we present alternative ways to finance this transfer system through the demographic transition. In the second set of policy simulations, the North privatizes social security by phasing out benefits and gradually moving towards a fully-funded system. We study alternative privatization schemes announced unexpectedly by the government in 2005. Across all these experiments, we keep per-capita government expenditures $G^a_t$ constant in the North and we allow no policy change in the South.\(^{14}\)

\(^{14}\)As explained earlier, in many countries in the South, pension systems only cover a small percentage of the labor force, given the importance of informal labor markets. Moreover, the tendency seems to be towards privatization and funding of the existing schemes, rather than the development of new PAYG. It seems safe, therefore, given the focus on the North, to assume that the schemes in the South stay as small as in the initial
**Benchmark Experiment and Welfare Calculation:** Our benchmark for every welfare calculation is the experiment where the additional benefit payments required by the PAYG during the demographic transition are financed by a rise in the wage tax. We compute the welfare change, cohort by cohort, associated to each one of our alternative social security reforms compared to this benchmark. Note that the benchmark happens to be an experiment where the ‘baby boomers’ fare relatively well: the benefits implied by the current system are preserved and their cost is passed on the future cohorts that will be in the labor market over the next 30 years. The alternatives will in general imply a welfare loss for the boomers in comparison to the benchmark. It should be remembered that our purpose here is not to assess the baby boomers’ welfare loss as a consequence of the demographic transition (which is done in our companion paper, see Attanasio, Kitao and Violante, 2005). Instead, we compare different social security reforms and how the tradeoffs implied by these alternatives are affected by an integrated world capital market.

Our welfare comparison is based on *ex-ante* lifetime utility, i.e. for each cohort we compute lifetime utility at birth under the benchmark transition and under the alternative policy reform and calculate the consumption equivalent variation, i.e. the percentage gain or loss in terms of lifetime consumption for that cohort. We always present two welfare computations, one for the closed economy and one for the open economy.

### 5.1 A First Look at the Results

The crucial difference between the two benchmarks is the equilibrium path of factor prices and in particular of the interest rate that households and government take as given. Behind different paths for the interest rate lie different domestic saving rates and, clearly, capital flows of diverse magnitudes. We begin by analyzing the dynamics of interest rate, saving rate and capital flows.

**Equilibrium Interest Rate Paths:** The first panel of Figure 4 plots the two equilibrium regional interest rates in the closed economy simulations and the unique open economy interest rate in our benchmark policy experiment.\(^{15}\) The decline in fertility rate reduces household consumption and the rise in life expectancy increases life-cycle savings. Both dimensions of the steady state.

\(^{15}\)Recall that in the benchmark, the additional pension transfers due to the demographic transition are financed by a rise in the payroll tax.
demographic transition lead to higher capital accumulation and a decline in the interest rate. Moreover, there is a reinforcing general-equilibrium effect: with our parameterization, a lower interest rate induces the agents to save more which, in turn, raises the capital-output ratio and pushes interest rates further down. In the North, the demographics tend to stabilize around 2040 and this is reflected in the path of the interest rate which falls by 2 points between 2000 and 2040 and levels off thereafter.

The open-economy interest rate lies just above the North closed-economy interest rate until 2035, then while the latter stabilizes due to the exhaustion of the demographic transition, the former keeps falling rapidly, by 1.8 additional points until 2100. The reason is that over time the South keeps growing both in terms of population size (due to the sharper demographic transition) and in terms of capital accumulation, since in the North, the PAYG displaces a large amount of life-cycle savings which, in contrast, are made in the South. Indeed, in the South, the rate of return is projected to fall by over 6 percentage points between 2000 and 2100.

The second panel of figure 4 plots the two equilibrium regional interest rates and the unique open economy interest rate in our benchmark privatization experiment. Note the sharp difference with the top panel: under the privatization scenario, households are forced to save more for retirement and capital accumulation increases so much in the North that the implicit interest rate declines at the same pace as in the South. In particular, note that the closed and open economy interest rates are very similar throughout the period.

**Domestic Saving Rates:** The bottom panel of figure 5 restates what we just discussed in the benchmark privatization scenario: the saving rate is projected to increase by roughly 1.5% per decade. The top panel, which refers to the benchmark PAYG experiment, shows that in the long-run savings increase due to the rise in life expectancy and the decline in the interest rate (general-equilibrium effect). In the medium-run, the aggregate saving rate is forecasted to fall significantly (nearly by 3%) because of the retirement of the baby-boomers, i.e. there will be a

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16Recall that along the transition there is also a rise in (female) participation rates which increases aggregate labor input and counteracts the fall in the interest rate, but its overall effect is rather small. In absence of the rise in participation rates, the decline in the interest rate in the North beyond 2000 would be almost unchanged, since as shown in Figure 3, the participation rate transition is essentially exhausted by the year 2000.

17Domeij and Floden (2004, Figure 1) report a fall of the equilibrium interest rate induced by demographic trends in the developed countries from 6.5% in 2000 to 5% in 2040, and then only a decline by half percentage point from 2040 to 2100. Thus, the path of our closed-economy North interest rate (the right one to compare to their model) is extremely similar to theirs.
large generation dissaving the wealth cumulated during the past 50 years. In open economy, the saving rate rises more steeply due to the general equilibrium effect of the sharper decline in the interest rate.

**Capital Flows:** The top panel of Figure 6 displays the implied equilibrium ratio of external wealth to total wealth in the South. We chose this statistics because Kraay, Loayza, Serven and Ventura (2004) collect data exactly on this ratio and document that they averaged −10% from 1960-1990. Our frictionless open economy model generates −35% over the same period - a larger number, as expected, given the absence of obstacles to capital flows in the model. The plot clearly shows the reversal in the sign of the stock of external wealth around 2040 (the flow changes direction a decade earlier) and predicts a large positive external wealth of the South, of the order of 25% of total wealth, by 2100.18

Interestingly, under the benchmark privatization scenario, there will be no reversal: capital is projected to flow from rich to poor countries throughout the 21st century, and level off at −10% in the long-run (see the bottom panel of Figure 6).

The model yields implicitly a measure of how sizeable the capital flows need to be, in absence of frictions, in order to equalize differences across regions stemming only from different demographic structure of the population. Taylor and Williamson (1994) have argued that 3/4 of the net capital inflows of Canada, Australia and Argentina in the early 20th century could have demographic origins. More recently, Domeij and Floden (2004) have shown that this demography-based approach can explain a non-negligible part of the post-war low-frequency current account dynamics among OECD countries. With respect to this debate, our contribution is to point out that structural reforms to the PAYG system will have a first-order effect on the sign and magnitude of these flows in the next 50 years.

Compared to the last 20 years of data, our model generates too much capital flowing between the North and the South. This is not surprising, given the assumption of frictionless global financial markets. In this sense, it is an extreme benchmark in the same way a pure closed-economy model without any capital flow is another (opposite) extreme. Country-level volatility associated

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18 Brooks (2003) solves a multi-region model of the world to make long-run predictions about capital flows generated by different demographic dynamics across regions. His model predicts a reversal in the direction of flows around 2020. Helliwell (2004) argues that the empirical results of several reduced-form exercises also imply that in a few decades the South will transfer resources to the North.
to political uncertainty, the risk of sovereign default, and expropriation risk are paramount in explaining why historically capital did not flow, as much as predicted by the standard growth model (Lucas, 1990), towards poor countries.

However, when thinking about the future, two considerations become important. First, important steps have been taken in the past few years with respect to “financial engineering” of emerging markets, so one may expect capital to flow freely and more safely in the years to come. Second, recall that under all the policy experiments where the PAYG is preserved, there is a reversal in the direction of flows from South to North. Arguably, country-specific risks are smaller in the North, since political uncertainty is lower, financial institutions are more developed, and property rights better protected. As a consequence, one may expect the frictionless benchmark to better predict future capital flows compared to past flows.

5.2 Financing the PAYG System during the Demographic Transition

We consider five different options to finance the PAYG pension system during the demographic transition:

(FW) The government covers all the additional social security expenditures associated with the demographic changes by adjusting the wage income tax $\tau_n^w$. Every other policy variable is fixed at its 2005 level. This will be our benchmark for the welfare calculations (Figure 7).

(FC) The government covers all the additional expenditures by adjusting the consumption tax. Every other policy variable is fixed at its 2005 level (Figure 8).

(FD) The government raises the public borrowing to finance the expenditures. The debt $B^w$ to GDP ratio increases linearly from the current level of 35.5% and doubles up to 71% by 2050. The wage tax adjusts to balance the budget (Figure 9).

(FR) The government in 2005 announces that in 2020 it will raise the compulsory retirement age $I^R$ by 5 years, from 67 to 72 years-old. The wage tax $\tau_n^w$ adjusts to balance the budget residually (Figure 10).

(FB) The government reduces pension benefits by lowering the replacement rate $\kappa_n$ in order to keep the budget balanced. Every other policy variable is fixed at its 2005 level (Figure 11).
Tables 1a and 1b report the initial and final steady-state values of the key aggregate and policy variables in each experiment.

5.2.1 Results I: Macroeconomic Aggregates and Policy Variables

**Benchmark (FW):** In the open economy model, the capital stock in the North grows faster in the long-run because domestic saving rates are higher and because of the capital inflows. As a consequence, both wages and output per capita grow at a more rapid rate in open economy. However, surprisingly, there is very little difference in the time path of the payroll tax between the closed economy and the two-region model. The wage tax $\tau_w^n$ rises by 12.7% in closed economy (from 28.0% to 40.7%) and by 15.5% in open economy from 2000 to 2100. Why such similar evolutions of our key policy variable notwithstanding the large differences in macroeconomic aggregates? The reason is that in open economy there is a sharper fall in the interest rate and a larger rise in the wage rate: the fraction of fiscal revenues raised from the capital income tax $\tau_k^n$ decline by 8 percentage points and the fiscal revenues of the payroll tax $\tau_w^n$ rise by a comparable amount.\(^{19}\) Finally, it is worth reporting that De Nardi, Imrohoroglu and Sargent (1999) report a comparable long-run rise in the payroll tax (17%) in order to finance the system throughout the demographic transition, in closed economy.\(^{20}\)

**Financing by Consumption Tax (FC):** The macroeconomic aggregates behave very similarly to the benchmark in this experiment. Capital and output per capita grow slightly more than in the benchmark, a feature that will affect our welfare calculations. For the same reasons explained above, the rise in the consumption tax $\tau_c^n$ is similar across closed and open economy simulations. In the closed economy, the required increase is roughly from 9% to 23% in 2100. In the open economy experiment, the rise in consumption taxation is a couple of points larger, like in the benchmark case, suggesting that the lost capital income tax revenues just outweigh the proceedings gained from labor income taxation.

**Financing by Debt (FD):** The rise in government debt severely displaces private capital accumulation in the closed economy. In the long-run, capital per capita does not grow much and output per capita falls by 15%. The inflow of capital from the South guarantees the rise in

\(^{19}\)The proceedings of the consumption tax $\tau_c^n$ are very stable across the two experiments.

\(^{20}\)To be precise, in our model, from 2100 to the final steady-state the wage tax keeps increasing, slowly, by an additional 3%, making the total rise since 2005 equal to 15% (see Table 1b).
wages and prevents average income to decline in open economy. Notwithstanding the fact that debt doubles, the wage tax has to climb by 12 percentage points to balance the budget. This magnitude is almost as large as in the benchmark (FW) experiment since now the government must also finance the higher interests on debt through the labor income tax. The same general equilibrium effect on the government budget discussed earlier explains why the path of the wage tax is remarkably similar in closed and open economy.

**Financing by a Rise in the Retirement Age (FA):** The dynamics of the macroeconomic variables in this experiment is similar to the benchmark, except for a discrete jump in 2020 corresponding to the year where a whole new cohort (those aged 65-69) remains active in the labor market for the first time. From a fiscal perspective, the simulation yields an important number: postponing retirement by 5 years translates into a permanent reduction (compared to the benchmark) of the payroll tax around 7 percentage points both in closed and open economy.

**Financing by a Fall in Benefits (FB):** The reduction in benefits in the North triggers huge capital accumulation in the form of retirement savings. The path of the interest rate in the closed economy equilibrium falls more rapidly, compared to the other experiments, but still not as much as in the open economy equilibrium. Both the closed and open economy simulations suggest that if the government were to leave payroll taxes unchanged, the replacement rate would have to decline sharply, from over 40% to below 20%. Once again, the similar dynamics of the policy variable between closed and open economy are explained by the offsetting dynamics of fiscal revenues from labor and capital income taxation.

We conclude that, surprisingly, the evolution of the policy variables between closed and open economy models is almost identical, quantitatively. This is not due to the fact that the two economies are “close”, but to general equilibrium effects. The evolution of the macroeconomic quantities and prices are markedly different between closed and open economy. In general, capital accumulation and output grow much more in open economy: wages grow by 10%-15% more and interest rates fall by 2% more in the long-run, with most of the divergence occurring after 2030 in concurrence with the reversal of capital flows towards the North. However, the effects of a larger wage income tax base and a smaller capital income tax base, in the open economy, offset each other almost exactly in equilibrium, and the paths of policy variables end up being extremely similar.
5.2.2 Results II: Welfare Effects

The top and bottom panels of Figure 12 report welfare changes of each experiment in closed and open economy, respectively. Compared to the benchmark rise in the payroll tax, financing the PAYG through the demographic transition via higher consumption taxes (FC) or via lower benefits (FB) hurts the older generations at the time of the reform (who consume most of their income and are retired) and yields a gain to the future generations who find themselves with a higher capital stock and higher wages. Instead, using public debt (FD) hurts, in relative terms, more the future generations: public debt crowds out private capital, lowering future wages compared to the benchmark.\textsuperscript{21}

The comparison between closed and open economy is interesting, since the quantitative differences in welfare can be very large, especially for cohorts appearing in the next two-three decades. For example, in the case of the benefits experiment (FB), the maximum welfare gain, occurring for the generations born between 2030-2040, is 2.6\% in open economy and 7.3\% in closed economy. In the case of public debt (FD), the maximum welfare loss is −3.2\% for the cohort born around 2060 in closed economy and only −2.0\% in open economy.

In general, the open economy dampens both welfare gains and welfare losses. The key reason is that, in open economy, social security reform has a smaller impact on wage rates and interest rates in the North, since capital can flow into the North when domestic savings are low, keeping wages of the future generations high.

Therefore, in spite of similar patterns in the fiscal variables, the experiments show that there are sizeable differences in the welfare effects of various reforms between closed and open economy.

5.3 Social Security Privatization during the Demographic Transition

We assume that the government announces the reform in 2005 and begins its implementation in 2015. In 2015, the intergenerational transfer system implicit in the PAYG scheme is dismantled completely, except for those who are already retired in 2015 who will keep receiving the promised benefits as long as they survive.

The government acknowledges that the households not yet retired in 2015 (i.e. with age \(i < I^R\)) have contributed to the system throughout the years and have accumulated pension

\textsuperscript{21}We do not report welfare calculations for the experiment where we increase the retirement age \(I^R\) because they are not too meaningful, given the absence of disutility from leisure.
rights. To compensate these cohorts, the government credits a “recognition bond” to these workers upon retirement.\textsuperscript{22}

Every year \( t > t^* = 2015 \), a bond \( \Omega_t \) is paid to the cohort that at \( t^* \) has age \( i = t^* + I^R - t \). For example, in year \( t + 1 \) the bond is paid to the cohort that at \( t^* \) was one year from retirement (age \( i = I^R - 1 \)); in the last year of the reform \( t = t^* + I^R - 1 \), the bond is paid to the workers who had age \( i = 1 \) at \( t^* \). The value of the cumulated pension wealth in the old system for a cohort that retires (and receives the bond) at time \( t \) is given by the formula

\[
\Omega_t = \rho \left[ \frac{\kappa_{\text{old}} W_{t^* + I^R - t, t^*}}{I^R - 1} \right] \left[ 1 + \sum_{i=1}^{I^R} \prod_{j=1}^{i} \left( \frac{R^R_j + s_{I^R, t, t+j}}{R^\text{old}_t} \right) \right],
\]

where \( \rho \) is a parameter measuring how much of the cumulated pension rights the government is willing to pay back; \( \kappa_{\text{old}} \) is the replacement rate under the PAYG system; \( \{R^\text{old}_t\} \) is the sequence of equilibrium interest rates computed in the benchmark transition (the economy without privatization and with the payroll tax adjusting). Under the privatization, the path of equilibrium interest rates will be different from the benchmark –we expect returns to capital to be lower– so it would be inappropriate to use the new interest rates, as we need to compute the value of pension rights households cumulated under the “old system”.

To maintain the government budget balanced during the transition, we consider three alternatives.

\textbf{(PW)} The government changes the wage tax \( \tau_w^n \) during the privatization to balance the budget.

Every other policy variable (except retirement benefits, of course) remains constant at its 2005 level (Figure 13).

\textbf{(PC)} The government changes the consumption tax \( \tau_c^n \) during the privatization to balance the budget. Every other policy variable remains constant at its 2005 level (Figure 14).

\textbf{(PD)} The government changes the level of public debt \( B^n \) during the privatization to finance the promised payments of benefits. Every other policy variable remains constant at its 2005 level (Figure 15).

In every experiment, we assume full replacement of the pension rights, i.e. \( \rho = 1 \).

\textsuperscript{22}The recognition bond is a scheme that was used, successfully, in the Chilean reform of 1981 to finance the transition towards a fully-funded system. See Edwards (1998) for a detailed description of the Chilean experience.
5.3.1 Results I: Macroeconomic Aggregates and Policy Variables

**Privatization with Wage Tax Changes (PW):** In the closed economy, the rapid phasing out of benefits leads to a huge increase in aggregate life-cycle savings (recall Figure 5): capital per capita in both economies is projected to rise by a factor of 2.5 in the next century. This capital deepening is so pronounced that the privatization-induced decrease in the closed-economy interest rate (and the rise in wages) in the North has roughly the same magnitude as the demographics-induced changes in the South. In particular, there is no longer a reversal of capital flows.

Since aggregate variables and prices have such similar dynamics in closed and open economy, the wage tax would behave similarly in the two scenarios. It would first increase dramatically to pay for the recognition bonds and then fall, relative to the initial level, by approximately 7 percentage points.

**Privatization with Consumption Tax Changes (PC):** The qualitative dynamics of aggregate variables and prices are similar to the wage tax case. The consumption tax must rise from 9% to 22% by 2020 to finance the recognition bonds and then it slowly declines towards the new long-run value near zero. Once again, closed an open economy dynamics are very close.

**Privatization with Public Debt (PD):** In order to finance payment of recognition bonds, public debt to GDP ratio has to increase by a staggering factor of 11 in closed economy and by a factor of 16 in open economy. The induced crowding out of private capital accumulation is so extensive that capital in closed economy remains stagnant and output decreases by 10% in the long run. In the two-region model, even though the capital inflow from the South substantially mitigates this displacement effect, capital still grows much less than under the other privatization experiments. The surge in debt keeps the interest rate high, so in open economy around 2030, capital begins flowing from the poor to the rich countries, exactly like in the previous set of experiments.

In conclusion, when taxation is used to finance the PAYG privatization, most of the demographics-driven divergence in the speed of decline of the interest rate between closed and open economy are offset by the extent of capital deepening in the North. What is due to the demographic transition in the South occurs in the North because of the social security transition towards a fully-funded system.
5.3.2 Results II: Welfare Effects

Recall that the benchmark is, both in closed and open economy, the PAYG transition financed by the payroll tax (FW). The two panels of Figure 16 report welfare changes of each experiment in closed and open economy.

Notice first that when the system is privatized and taxes are used to finance the transition (PW) and (PC) the losses of the generations currently alive are much larger than in the first set of experiments, notwithstanding the payment of the recognition bond. The reason is twofold: first, those born between 1970 and 2000 will suffer particularly harshly from the jump in the taxes around 2020; second, as they age, they face a lower interest rate than in the benchmark.

The cohorts born in the 1980’s experience a loss of -13% under the (PW) experiment, -8% under the (PC) experiment, and -3% in the (PB) experiment, in closed economy. In open economy, these welfare losses are reduced by 2%. The winners are the cohorts born around 2040 who experience welfare gains of 3% and 5% under (PW) and (PC) in closed economy, thanks to the higher labor productivity and wages, and lower tax rates. In open economy, these gains are reduced by roughly 3%.

As in the previous set of policy simulations, in open economy the welfare effects are considerably dampened since capital accumulation (the rise in wages and the fall of interest rates) takes place independently of the pension reform.

The welfare effects of the (PD) experiment are particularly interesting. Here, the welfare change of every cohort born after 1980 in open economy is negative and larger than in closed economy. The crowding-out force of public debt in limiting capital accumulation has a more negative impact in open economy, where it jeopardizes the wage growth that can be achieved under the benchmark policy experiment.

6 Robustness Analysis

We investigate the sensitivity of our experiment results under alternative assumptions about some key parameters of the model.

Development process and TFP growth: Recall that in the benchmark, we assume exogenous TFP growth rates to match the historical observation of economic growth in the two regions of the world: the growth rate of TFP in the North is set so that the model achieves the
average per-capita output growth rate of 2.7% during 1950-2000. For the South, the TFP during 1950-2000 is calibrated to match the growth rate of 2.2%, and we let it converge gradually to the North level by 2100. During the transition, the average GDP per capita of the South rises from 1/7 of GDP per capita of the North to almost 1/5.

In the first robustness experiment, we let the TFP growth rate of the South converge immediately to the level of the North in 2000, instead of having it grow gradually by 2050. This alternative assumption has almost no effect on factor prices and experiment results remain unchanged.

In a second robustness experiment, we allow the South economy to grow and fully catch up with the North in terms of per-capita output. We assume the the South will experience a higher growth rate of TFP during 2000-2200, then converging to the value of the North after 2200.

Under this alternative assumption, the “size” of the South economy relative to the North will be larger than in the benchmark. However, the difference does not generate any significant change in our experiment results and any of our qualitative findings. Faster growth of labor productivity in the South leads to a higher interest rate in the long-run in its closed economy. The path of interest rates in open economy is much closer to that of the South due to its increased relative size. With these two effects offsetting each other, the path interest rates that the North faces in the open economy closely resembles the one in the benchmark. As a result, experiment results are extremely robust to this alternative assumption of the TFP growth rate.

**Risk aversion:** We depart from the benchmark calibration with respect to the coefficient of relative risk aversion $\theta$, to which we assigned a value of 2 in the benchmark. We conduct two experiments with $\theta = 1.5$ and 2.5. To control for the capital-output ratio and prevent it from making the comparison difficult, we also adjust the subjective discount factor $\beta$ to match the target capital-output ratio of 2.5 in the North, as in the benchmark. All the other parameter values are the same as in the benchmark model.

A higher value of $\theta$ implies a lower elasticity of intertemporal substitution and induces more savings and higher output. With $\theta = 2.5$, interest rates are slightly lower than in the benchmark and wage rates go in the opposite direction. The paths of the policy variables, however, are almost identical to the benchmark simulations. Lower interest rates reduce the revenues from

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23Calibrated values of the discount factor $\beta$ in the experiments are $0.954$ ($0.991$ per year) when $\theta$ is 1.5 and $1.143$ ($1.027$ per year) when $\theta$ is 2.5.
capital income tax, but the higher wage rates increase the labor income tax and the two effects offset each other, leaving the relevant policy variable to adjust just as in the benchmark. Similarly when we lower the value of \( \theta \), experiment results are found to be robust.

**The role of China and India:** In a recent paper, Fehr, Jokisch and Kotlikoff (2005) found that the impact of the demographic transition on the dynamics of U.S. wages crucially depends on the inclusion of China in their multi-country model: when capital is allowed to move between the U.S. and China, U.S. wages at the end of the 21st century are 8% higher. We run a similar experiment in our model, excluding from the South both China and India—two largest countries. In Figure 17 we report the simulations of the benchmark economy with and without China and India. The results confirm that these two countries play an important role in determining the growth of labor productivity in the North: in their absence, at the end of the century, the capital flows towards the North would be halved and wages would be lower by 7%. Since we have excluded India as well, our findings are somewhat less dramatic than those in Fehr et al. (2005), but confirm their conclusion that the degree of capital market liberalization in China and India is a decisive factor in determining the fortunes of the developed world. Coherently with the rest of the paper, we also find that the dynamics of the payroll tax in the North are unaffected by the exclusion of China and India, since the fall in the interest rate would be less severe.

**Frictional capital markets:** As illustrated in Figure 6, for the period 1970-1990, the model predicts capital flows across the two regions much larger than those observed. We have also solved the model by imposing the existence of a transaction cost in the world capital market that reduces the return to the capital invested by the North in the South. This is a simple reduced form to capture country-specific expropriation risk typical of less developed financial markets, and can be thought of as the probability that the interests on the foreign investment will not be paid back.

We model the transaction cost as a smooth concave function of the external wealth of the North as follows

\[
\chi(N_t) = \begin{cases} 
\bar{\chi}N_t^{0.5} & \text{if } N_t > 0, \\
0 & \text{if } N_t \leq 0.
\end{cases}
\]

and set the parameter \( \bar{\chi} \) to 1.47 to match the Kraay and Ventura data of Figure 6. This parameterization implies a transaction cost of 17%, on average, in the period 1970-1990. The new
indifference condition for households in the North between investing domestically and in foreign assets becomes: \( r^* = r^*_t (1 - \chi (N_t)) \), where \( r^*_t \) and \( r^*_t \) are the interest rates paid to domestic investors in each region.

In Figure 18 we contrast the benchmark economy with perfect and frictional capital markets. The differences in the dynamics of aggregate variables are rather small, mainly because after 2040 the stock of external wealth of the North turns negative and the capital market friction becomes irrelevant.

7 Concluding Remarks

The sustainability of PAYG pension systems in developed countries, in the face of the projected transformations in the demographic structure of the population, is at risk. The current political and economic debate is centered on how to reform the system in order to avoid large welfare losses for the cohorts alive today. The typical approach, when quantifying these effects, is studying transitional dynamics within an OLG model, under the assumption of closed economy.

In this paper, we asked whether the results of typical policy experiments differ if we consider a different benchmark, a two-region model of the world where the unsynchronized demographic patterns between the two regions lead to an adjustment through capital flows.

We argued that the answer depends on what the precise focus of the question is. If one is interested in forecasting the required changes in certain key policy variables (like the payroll tax, the consumption tax, etc.) needed to finance the transition, the answer is “no”, due to general equilibrium effects. If one is interested in computing the welfare effects of various policy reforms, then the answer is “yes”, with the welfare impact in open economy being typically smaller in absolute value.

We do not necessarily believe that our two-region benchmark with frictionless capital flows is more appropriate than the closed-economy benchmark. It is just the opposite end of the spectrum, and actual economies lie somewhere in the middle. As such, it is at least as interesting as the closed economy model. And one could argue that the framework we propose, is becoming progressively more relevant. First, thanks also to the new information and communication technology, the extent of global linkage across markets is rapidly growing. Second, our model as well as several other demographics-based model of current account dynamics, predict that
capital flows will soon start flowing from poor to rich countries. Then the typical criticism of neoclassical open-economy models, i.e. that they overpredicts the size of external wealth, will become irrelevant since, arguably, sovereign risk, political uncertainty, and expropriation risk are much smaller in the developed world thanks to better institutions.
A Computation of the Equilibrium

We start by stationarizing the economy using the long-run productivity growth $\lambda$ and the long-run population growth rate $\gamma$, common to both regions. In all our experiments, we study the transition between two steady-states of the world economy induced by secular changes in the demographic structure (fertility rates, surviving rates and participation rates) in the two regions.

We present the description of the computation of the equilibrium for an example where the only fiscal variable that needs to adjust to satisfy the government budget constraint (thus the only fiscal variable to be determined in equilibrium) is the sequence of labor income taxes $\tau_{w,t} \equiv \{\tau_{w,t}^r\}_{t=1}^\infty$. All the other policy variables either remain fixed throughout the transition or move deterministically, i.e. they can be thought of as parameters.

**Step 1 (Steady-State):** Compute the initial and final steady-states of the model. Set $T$, the length of the transition to a very large number. Truncating the transition at $T = 180$ or beyond does not affect the results.

**Step 2 (Initial Guess):** Guess two $T$-dimensional vectors for the world interest rate and the labor income tax rate in both regions, and denote these initial guesses by $\{r_0, \tau_{w,0}^r\}$. The first and last entry of these vectors are the initial and final stationary equilibrium values computed in Step 1. Given the path for $r_0$, using the CRS property of $F$ and the optimization conditions for the firm (12) and (13), we can derive initial sequences of wages in each region $w^r_0$. Given prices and the sequence of policies $\tau_{w,0}^r$, one can solve the problem of the households in both regions.

**Step 3 (Household Problem):** Consider the budget constraint of the agent at time $t$ who, conditional on surviving, receives the savings of the deceased:

$$(1 + \tau^r_{c,t}) c_{i,t} + a_{i+1,t+1} = y_{i,t} + \left[1 + (1 - \tau^r_{a,t}) r_t \right] a_{i,t} + (1 - s_{i+1,t+1}) a_{i+1,t+1}.$$  

Using this expression for the annuity, we can rewrite the budget constraint as:

$$(1 + \tau^r_{c,t}) c_{i,t} + s_{i+1,t+1} a_{i+1,t+1} = y_{i,t} + \left[1 + (1 - \tau^r_{a,t}) r_t \right] a_{i,t}. \quad (19)$$  

For convenience, denote net-of-taxes gross interest rate as

$$R^r_t \equiv 1 + (1 - \tau^r_{a,t}) r_t.$$  

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From the FONCs with respect to asset holdings next period, we obtain

\[
\frac{c_{i+1,t+1}}{c_{i,t}} = \left[ \beta \frac{\Omega_{i+1,t+1}}{\Omega_{i,t}} \frac{1 + \tau_{c,t}}{1 + \tau_{c,t+1}} R_{t+1} \right]^{\frac{1}{\gamma}} \equiv g_{i+1,t+1},
\]

(20)

which is the optimal growth rate of consumption between age \(i\) and \(i+1\) and between time \(t\) and \(t+1\). Iterating backward over (20), we obtain that

\[
c_{i+1,t+i} = c_{1,t} \prod_{j=1}^{i} g_{j+1,t+j}.
\]

Thus, we can obtain the discounted present value of the total (gross of taxes) lifetime consumption expenditures of the household of age 1 at time \(t\) as

\[
\overline{c}_{1,t} = c_{1,t} \left[ (1 + \tau_{c,t}) + \sum_{i=1}^{t-1} (1 + \tau_{c,t+i}) \prod_{j=1}^{i} \frac{s_{j+1,t+j}}{R_{t+j}} g_{j+1,t+j} \right],
\]

(21)

and, in general, the expression for the discounted present value of the total (gross of taxes) lifetime consumption expenditures of the household of age \(i^*\) at time \(t\) is

\[
\overline{c}_{i^*,t} = c_{i^*,t} \left[ (1 + \tau_{c,t}) + \sum_{i=i^*}^{t-1} (1 + \tau_{c,t+(i-i^*+1)}) \prod_{j=i^*}^{i} \frac{s_{j+1,t+(j-i^*+1)}}{R_{t+(j-i^*+1)}} g_{j+1,t+(j-i^*+1)} \right].
\]

(22)

The discounted present value of the total (net of taxes) lifetime earnings of a household of age 1 at time \(t\) is:

\[
\overline{y}_{1,t} = y_{1,t} + \sum_{i=1}^{t-1} \left( \prod_{j=1}^{i} \frac{s_{j+1,t+j}}{R_{t+j}} \right) y_{i+1,t+i},
\]

(23)

where we are implicitly imposing the initial condition \(a_1 = 0\). The discounted present value of the total (net of taxes) lifetime earnings of a household of age \(i^*\) at time \(t\) is:

\[
\overline{y}_{i^*,t} = y_{i^*,t} + \sum_{i=i^*}^{t-1} \left( \prod_{j=i^*}^{i} \frac{s_{j+1,t+(j-i^*+1)}}{R_{t+(j-i^*+1)}} \right) y_{i+1,t+(i-i^*+1)} + R_t a_{i^*,t}.
\]

(24)

Since individual optimization requires \(\overline{c}_{i^*,t} = \overline{y}_{i^*,t}\) for each age \(i^*\) and time \(t\), from (22) and (24), we obtain \(c_{i^*,t}\) as

\[
c_{i^*,t} = \frac{\overline{y}_{i^*,t}}{\left[ (1 + \tau_{c,t}) + \sum_{i=i^*}^{t-1} (1 + \tau_{c,t+(i-i^*+1)}) \prod_{j=i^*}^{i} \frac{s_{j+1,t+(j-i^*+1)}}{R_{t+(j-i^*+1)}} g_{j+1,t+(j-i^*+1)} \right]}.
\]
Note that $a_{i^*,t}$ in equation (24) is computed residually from $c_{i-1^*,t-1}$ and the budget constraint (8):

$$a_{i^*,t} = \frac{1}{s_{i^*,t}} \left[ y^r_{i^*-1,t-1} + R_{t-1} a_{i^*-1,t-1} - \left( 1 + \tau^r_{c,t-1} \right) c_{i^*-1,t-1} \right].$$

**Step 4 (Updating):** Aggregating asset holdings across age groups and using equation (15) for the North, we obtain the implied sequence for external wealth of the North $N^n_0$. Using $N^n_0$ into equation (15) for the South, we obtain the sequence of capital stock for the South $K^s_0$. Using the labor market clearing condition for the South and the implied sequence of human capital stocks $H^s_0$, together with $K^s_0$ and the world capital market clearing condition (13), we arrive at a new guess for the world interest rate $r_1$. Finally, we use the government budget constraints (11) in each region with price sequences $r_0$ to update our guess for the tax rate to $\tau^r_{w1}$. If convergence is not reached, we restart from Step 3 with the new vector of guesses $\{r_1, \tau^r_{w1}\}$.

**B Construction of Demographic Variables**

**Fertility Rates** – The UN data provide age-specific fertility rates for 1995-2050. We need to construct age-specific fertility rates for the years before 1995 and after 2050, for which only total fertility rates are available. For the years before 1995, we adjust the age-specific rates available for 1995 proportionately in order to match the total fertility rate in each period. We use exactly the same rule for both regions. For the years after 2050, we use the projection from United Nations (2004) of total fertility rates for 2100 and 2200 as the benchmark. For the North, we extrapolate the data using the average change in fertility rate over the past 20 years for each age group up to the year 2100 and obtain total fertility rates that closely match the UN projections. For the period beyond 2100, we impose that age-specific fertility rates are constant at their 2100 values.

For the South, we use slightly different rules of adjustment. We assume that age-specific fertility rates in the South in 2100 converge to those projected for the North in 2050 and let them adjust smoothly during 2050-2100 starting from the actual data available for 2050. For 2100-2150, we apply the same extrapolation rule used for North in 2050-2100. From 2150 and
onward, we impose that age-specific fertility rates are constant at their 2150 values (equal to the values for the North from 2100 onward).

**Surviving Probabilities** – We use actual and projected population data from the UN database to compute surviving probabilities for 1950-2050. We do not model migration across regions, but we implicitly account for it in the demographic dynamics of two regions, insofar as they appear in the UN data. To obtain the conditional surviving probability between age $i - 1$ and age $i$ at time $t$, we divide the population of age $i$ in period $t$ by the population of age $i - 1$ in period $t - 1$.

For the years beyond 2050, we estimate the surviving rates of the two regions to match the following demographic moments based on the projections in United Nations (2004).

<table>
<thead>
<tr>
<th></th>
<th>2100</th>
<th>2200</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median age</td>
<td>44.63</td>
<td>47.65</td>
</tr>
<tr>
<td>Fraction of the old over 60 (%)</td>
<td>33.15</td>
<td>37.09</td>
</tr>
<tr>
<td>Population growth rate (%)</td>
<td>0.0525</td>
<td>0.0787</td>
</tr>
<tr>
<td><strong>South</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median age</td>
<td>43.89</td>
<td>45.15</td>
</tr>
<tr>
<td>Fraction of the old over 60 (%)</td>
<td>30.05</td>
<td>33.67</td>
</tr>
<tr>
<td>Population growth rate (%)</td>
<td>-0.1573</td>
<td>-0.0115</td>
</tr>
</tbody>
</table>

The population growth rates in the bottom rows are the UN projections of the average annual growth rate for the years 2100-2150 and 2150-2200 in each region.

We assume that after 2050 the age-specific surviving probabilities grow over time at a rate which is a given polynomial function of age and time. We estimate the function so to minimize the distance between the implied demographic moments and the above targets. For the South, we use the same method, and for the years closer to 2200, we let the surviving probabilities of each age group grow at a constant rate so that they converge smoothly to the final same-steady states as the North by the year 2200. Remember that, while we assume convergence of demographic variables (fertility rates and mortality) in two regions by 2200, it takes longer for the age-structure of the population and other demographic moments to fully converge.

**Participation Function** – Let $\Lambda_{r,i,t}$ be the fraction of the time endowment (normalized to one) worked by the household, i.e. $\Lambda_{r,i,t} = 0.5 \left[ 1 + P_{r,i,t}^r \right]$, where the husband is assumed to work full time and where $P_{r,i,t}^r \in (0, 1)$ denotes the fraction of time a woman of age $i$ supplies to the
labor market in region r at time t. Let \( d_{i,j,t}^r \) be the number of children of age \( j \) present in her households, and \( d_{i,t}^r \) be the vector with typical entry \( d_{i,j,t}^r \). As described in the main text, we use CEX data to estimate the marginal effects \( \alpha_j \) of the presence in the household of one dependent child in age-group \( j \) (0-4, 5-9, 10-14 years old, in the data) on women’s probability of participation \( P_{i,t} \), controlling for several other observable individual characteristics (age, race, education). This Probit regression yields \( \hat{\alpha}_{0-4} = -0.146 \), \( \hat{\alpha}_{5-9} = -0.0960 \), and \( \hat{\alpha}_{10-14} = -0.0464 \). As expected, all coefficients are negative and significant and the newborn child has the strongest impact on the probability of participation.

Next, we enrich the female labor force participation function with an exponential trend to capture other forces that, beyond the decline in fertility, have contributed to the rise in women’s hours worked. The statistical model becomes

\[
P_{i,t}^r(d_{i,t}^r) = \beta_0^r + (P^r + T_i - \beta_0^r)\{1 - \exp[-\beta_1^r \ast (t - 1)]}\} + \sum_{j=1}^{I_d} \hat{\alpha}_j d_{i,j,t}^r, \tag{25}
\]

where the coefficient \( \beta_0^r \) measures the participation rate for a female worker with no children in the initial period (1950), which we can see by substituting \( t = 1 \) in (25); \( P^r = 0.721 \) is the long-run female labor participation rate (U.S. Census Bureau, 2003); \( T_i \) is the long-run value of the time devoted by a woman of age \( i \) to child care (common across the two regions) computed from the final steady-state value of the vector of dependent children and the estimated coefficients of the Probit regression, i.e. \( T_i = -\sum_{j=1}^{I_d} \hat{\alpha}_j \hat{d}_{i,j,\infty} \); the parameter \( \beta_1^r \) regulates the speed of convergence towards the long-run rate \( P^r \): as \( t \to \infty \), the average participation rate implied by the function \( P_{i,t}^r \) converges to \( P^r \).

We estimate the parameters \((\beta_0^r, \beta_1^r)\) for each region using historical and projected data on participation rates of the U.S. for the North, and on the average of four countries (Brazil, India, Korea and Mexico) for the South. The estimated parameters are as follows: \( \hat{\beta}_0^n = 0.386 \), \( \hat{\beta}_0^s = 0.290 \), \( \hat{\beta}_1^n = 0.189 \), \( \hat{\beta}_1^s = 0.077 \).
### Table 1a: Long-run steady states: closed economy

<table>
<thead>
<tr>
<th>Policy variable</th>
<th>wage rate (%)</th>
<th>capital output saving wage tax policy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benchmark</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1950</td>
<td>0.860</td>
<td>10.23</td>
</tr>
<tr>
<td>2005</td>
<td>1.000</td>
<td>6.57</td>
</tr>
<tr>
<td>Long-run</td>
<td>1.109</td>
<td>4.50</td>
</tr>
<tr>
<td><strong>PAYG system</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption tax</td>
<td>1.189</td>
<td>3.28</td>
</tr>
<tr>
<td>Government debt</td>
<td>1.082</td>
<td>4.96</td>
</tr>
<tr>
<td>Retirement age</td>
<td>1.120</td>
<td>4.32</td>
</tr>
<tr>
<td>Retirement benefit</td>
<td>1.307</td>
<td>1.84</td>
</tr>
<tr>
<td><strong>Privatization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wage tax</td>
<td>1.461</td>
<td>0.43</td>
</tr>
<tr>
<td>Consumption tax</td>
<td>1.412</td>
<td>0.84</td>
</tr>
<tr>
<td>Government debt</td>
<td>1.122</td>
<td>4.28</td>
</tr>
</tbody>
</table>

Wage, capital and output are normalized by their 2005 levels.

Policy variables from the top entry: consumption tax rate, the ratio of government debt to GDP, replacement ratio, consumption tax rate, and the ratio of government debt to GDP in the long-run steady state.

### Table 1b: Long-run steady states: open economy

<table>
<thead>
<tr>
<th>Policy variable</th>
<th>wage rate (%)</th>
<th>capital output saving wage tax policy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benchmark</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1950</td>
<td>0.890</td>
<td>10.23</td>
</tr>
<tr>
<td>2005</td>
<td>1.000</td>
<td>7.32</td>
</tr>
<tr>
<td>Long-run</td>
<td>1.322</td>
<td>2.16</td>
</tr>
<tr>
<td><strong>PAYG system</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption tax</td>
<td>1.363</td>
<td>1.73</td>
</tr>
<tr>
<td>Government debt</td>
<td>1.313</td>
<td>2.26</td>
</tr>
<tr>
<td>Retirement age</td>
<td>1.326</td>
<td>2.12</td>
</tr>
<tr>
<td>Retirement benefit</td>
<td>1.433</td>
<td>1.07</td>
</tr>
<tr>
<td><strong>Privatization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wage tax</td>
<td>1.477</td>
<td>0.70</td>
</tr>
<tr>
<td>Consumption tax</td>
<td>1.463</td>
<td>0.81</td>
</tr>
<tr>
<td>Government debt</td>
<td>1.284</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Wage, capital and output are normalized by their 2005 levels.

Policy variables from the top entry: consumption tax rate, the ratio of government debt to GDP, replacement ratio, consumption tax rate, and the ratio of government debt to GDP in the long-run steady state.
References


Figure 1: Changes in fertility rates by age-group

The top panel represents the North, the bottom panel the South.
Figure 2: Demographic transition in the North and the South

- Total fertility rates
  - South: UN (data/projection)
  - South: model
  - North: UN (data/projection)
  - North: model

- Median age
  - North: UN (data/projection)
  - North: model
  - South: UN (data/projection)
  - South: model

- Old dependency ratio (60 or above)
  - North: UN (data/projection)
  - North: model
  - South: UN (data/projection)
  - South: model

- Population growth
  - North: UN (data/projection)
  - North: model
  - South: UN (data/projection)
  - South: model
The bottom two panels depict the contribution of the decline in fertility to the rise in participation in the two regions.
The two panels depict the dynamics of the interest rate in the two regions in closed economy, and in open economy. The top panel refers to the benchmark PAYG experiment (FW); the bottom panel to the benchmark privatization experiment (PW).
The two panels depict the dynamics of the saving rate in the two regions in closed economy, and in open economy. The top panel refers to the benchmark PAYG experiment (FW); the bottom panel to the benchmark privatization experiment (PW).
The two panels depict the dynamics of the value of external wealth as a fraction of total wealth in the South (negative numbers mean that the North owns assets of the South). The dots represent the data points documented by Kraay, Loayza, Serven and Ventura (2004). The top panel refers to the benchmark PAYG experiment (FW); the bottom panel to the benchmark privatization experiment (PW).
Figure 7: Results of the benchmark experiment where PAYG is financed through the payroll tax

Solid lines represent closed economy and dotted lines represent open economy.
Figure 8: Results of the experiment where PAYG is financed through the consumption tax

Solid lines represent closed economy and dotted lines represent open economy.
Figure 9: Results of the experiment where PAYG is financed through a combination of higher debt and higher payroll taxes

Solid lines represent closed economy and dotted lines represent open economy.
Figure 10: Results of the experiment where PAYG is financed through a rise in retirement age.

Solid lines represent closed economy and dotted lines represent open economy.
Figure 11: Results of the experiment where PAYG is financed through a decline in benefits

Solid lines represent closed economy and dotted lines represent open economy.
Figure 12: Welfare effects of different policy options to finance the PAYG system

The top panel summarizes the welfare changes, cohort by cohort, in closed economy; the bottom panel refers to the open economy simulations.
Figure 13: Results of the benchmark privatization experiment where the transition towards a fully-funded system is financed through the payroll tax.

Solid lines represent closed economy and dotted lines represent open economy.
Figure 14: Results of the benchmark privatization experiment where the transition towards a fully-funded system is financed through the consumption tax.

Solid lines represent closed economy and dotted lines represent open economy.
Figure 15: Results of the benchmark privatization experiment where the transition towards a fully-funded system is financed through debt.

Solid lines represent closed economy and dotted lines represent open economy.
Figure 16: Welfare effects of different policy options to finance the transition of the PAYG system towards full privatization.

The top panel summarizes the welfare changes, cohort by cohort, in closed economy; the bottom panel refers to the open economy simulations.
Figure 17: The role of China and India in the world capital market

Solid lines depict the open economy where China and India are excluded from the South, dotted lines depict the economy where they are included. The simulation refers to the benchmark case.
Solid lines depict the open economy with transaction costs when capital flows from the North to the South. Dotted lines depict the economy with perfect international capital markets. The simulation refers to the benchmark case.