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Population ageing and pension reform will have profound effects on international capital markets. In order to quantify these effects, we develop a computational general equilibrium model. We feed this multi-country overlapping-generations model with detailed long-term demographic projections for seven world regions. Our simulations indicate that capital flows from rapidly ageing regions to the rest of the world will initially be substantial, but that trends are reversed when households decumulate savings. We also conclude that closed-economy models of pension reform miss quantitatively important effects of international capital mobility.

INTRODUCTION

In the vast majority of countries populations are ageing, and demographic change will continue well into the twenty-first century. While population ageing is common to most countries, its extent and timing differ substantially, even within the industrialized countries. It is well known that within each country demographic change alters the time path of aggregate savings. In a world of closed economies, differential ageing will generate international differences in saving rates, investment and rates of return (in addition to differences for other reasons). These differences are likely to be accentuated when some countries implement fundamental pension reforms, i.e. shifts towards more pre-funding owing to the effects of population ageing on public pension budgets. In reality we have not closed economies, but global capital markets. To the extent that capital is internationally mobile, population ageing will induce capital flows between countries, and these capital flows will modify the effects of population ageing and pension reform in each county vis-à-vis a world of closed economies.

This paper presents a quantitative analysis of the capital and labour market effects, and in particular of international capital flows induced by differential ageing processes across countries and by pension reforms. To this end, we develop a stylized multi-country overlapping-generations (OLG) model and project macroeconomic aggregates such as international capital flows over a seventy-year horizon, using long-term demographic projections for different sets of countries and regions. Although all countries and regions are modelled symmetrically as large open economies, our presentation focuses on continental Europe as one of the world regions most severely affected by ageing. At the same time, pension systems in continental Europe are dominated by still relatively generous pay-as-you-go (PAYG)-financed public pensions.

We use a rich modelling framework which allows us to address different strands of the literature. First, we stress the ‘triangular’ relationship between
population ageing, pension reform and international capital markets that is receiving increasing attention in the academic literature (see Börsch-Supan et al. 2002, 2004; INGENUE 2001; and Fehr et al. 2003, 2004).

Second, our analysis is related to several recent papers that compare implications for capital flows predicted by OLG models with actual current account data (see e.g. Brooks 2003; Feroli, 2002; Henriksen 2002; Domeij and Floden 2006). Their analyses, and our own, show that calibrated OLG models explain a good proportion of the low frequency movements of international capital flows observed in the data. We further show that the existence of PAYG pension systems in different world regions adds an additional indirect channel to the interaction between capital flows and demographic change. This channel is of particular importance if countries severely affected by the impact of population ageing, such as the continental European countries, reform their pension systems.

Third, our paper adds to the discussion about the so-called ‘asset market meltdown hypothesis’. Several articles in the popular press have attributed recent turbulences in stock market prices to population ageing and have raised the fear that an asset market meltdown might occur when the baby boom generation decumulates its assets. In the academic literature, there is no consensus on the asset market meltdown hypothesis (see e.g. Poterba 2001; Abel 2001, 2003; and Brooks 2002). According to our view, the closed-economy models often used in the academic literature miss the important fact of international capital flows. We show that, because of international diversification, the dynamics of capital accumulation and rates of return are different from what would be predicted by closed-economy models. One of the main goals of this paper is to analyse and quantify these mechanisms.

Fourth, our paper sheds light on the effects of international diversification on savings behaviour and its interaction with pension reforms. This topic receives increasing attention as the pension reform debate progresses. Deardorff (1985) contains an early analysis, and Reisen (2000) provides a comprehensive overview of these issues. Reisen argues that there are pension-improving benefits of global asset diversification. In a theoretical paper, Pemberton (1999) highlights the importance of international externalities caused by the effects of national pension and savings policies on the world interest rate. Pemberton (2000) goes a step further and shows that an intergenerational Pareto improvement through coordinated pension reforms is possible. We will not tackle this policy issue; our welfare analysis is restricted to the direct welfare effects of population ageing, pension reform and capital mobility.

Finally, from an economic modelling perspective, this paper furthers our understanding of the various interactions among different features of calibrated OLG models. To this end, we present a sensitivity analysis that focuses on the role of including or excluding those features in our model, with a particular focus on endogenous labour supply.

Our simulations predict substantial capital flows arising from population ageing. Ageing results in decreases in saving rates when the baby boomers decumulate their assets. International capital flows follow this trend. The countries most affected by ageing, such as the European Union, will initially be capital exporters, while countries less affected by ageing, such as the United
States and other OECD regions, will import capital. However, since it is older households that decumulate their assets, capital exports from the rapidly ageing countries will decrease, and by around the year 2020 such countries are projected to become capital-importing countries. Pension reforms with higher degrees of pre-funding are likely to induce more capital exports; they should also increase labour supply considerably, while their effects on the rate of return to capital will be small. While the rate of return is projected to decline in response to population ageing, no devastating ‘asset market meltdown’ is foreseen.

The paper is structured as follows. Section I presents empirical evidence on, and theoretical explanations for, the effects of population ageing on international capital flows. In Section II we present a multi-country OLG model that allows us to evaluate these effects quantitatively. Section III describes the calibration of the model and displays indicators of ex post fit. Section IV contains ex ante simulation results for several pension policy and capital mobility scenarios. Section V presents a sensitivity analysis, while Section VI concludes.

I. BACKGROUND: POPULATION AGEING AND INTERNATIONAL CAPITAL FLOWS

Throughout the world, demographic processes are determined by the current demographic transition, which is characterized by falling mortality rates followed by a decline in birth rates, resulting in population ageing and a reduction in the population growth rate (in some countries even turning it negative). While demographic change occurs in almost all countries across the world, its extent and timing differ substantially. Europe and some Asian countries are almost at the closing stages of the demographic transition process, while Latin America and Africa are only at the beginning stages (Bloom and Williamson 1998; United Nations 2001).

From a macroeconomic point of view, population ageing will change the balance between capital and labour, particularly in industrialized countries. Labour supply will become scarce, whereas capital will be relatively abundant. This will drive up wages relative to the rate of return on capital, reducing households’ incentive to save (if the interest elasticity of saving is positive). In addition, a decreasing labour supply reduces demand for investment goods since less capital is needed.

From a microeconomic point of view, the life-cycle theory of consumption and savings (Modigliani and Brumberg 1954; Ando and Modigliani 1963) postulates higher saving rates for middle-aged individuals. The aggregation of individual, cohort-specific life-cycle savings profiles therefore leads to a decrease of national saving rates in an ageing economy. In a general equilibrium model of forward-looking individuals, it is not only the current demographic structure that alters the time path of aggregate savings, but also future demographic developments. In a closed economy, a decline in national savings leads to a decline in investment, by definition. In an open economy, the link between these two aggregates is broken to the extent that capital is internationally mobile.

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These theoretical mechanisms are reflected in the empirical evidence (see the review by Poterba 2001). Following earlier work by Higgins (1998) and others, Lührmann (2003) investigates whether demographic factors influenced international capital flows in the past, using a broad panel of 141 countries covering the period 1960–97. She confirms that cross-country capital flows are indeed influenced by current demographic variables. Moreover, she shows that future changes in the age structure of countries are important determinants of current saving and investment decisions, a finding that confirms forward-looking household behaviour.

The extent of international capital flows induced by population ageing depends crucially on the degree of capital mobility. There has been no shortage of empirical research on this issue since the famous puzzle of Feldstein and Horioka (1980).1 In their original contribution, Feldstein and Horioka show that national saving and investment rates are highly correlated in virtually all OECD countries. While the coefficient has fallen over time, it is still remarkably high. These findings have been interpreted as an indication that capital is imperfectly mobile. However, there exist several alternative explanations for the observed correlation. For example, high correlations between saving and investment rates are consistent with perfect capital mobility in a growth model with demographic change and technological progress, as pointed out by Obstfeld (1986); see also Baxter and Crucini (1993), Taylor (1994), Obstfeld and Rogoff (1996, 2000).

Even if capital is fully mobile, this does not necessarily imply that households do actually diversify their portfolios optimally. There is a large empirical literature on ‘home bias’ in international portfolio choice (e.g., French and Poterba 1991). Portes and Rey (2005) suggest that information asymmetries across countries are a major source of home bias effects and that capital flows are affected by both geographic and informational proximity. Applied to pension reform policies, this literature suggests that households might be more willing to invest their retirement savings in ‘similar’ countries, such as members of the EU or OECD, rather than in developing countries.

These background facts and empirical insights motivate our modelling strategy, which is detailed in the following section, and our calibration choices described in Section III.

II. A Dynamic, Open-Economy Macroeconomic Model

We construct a dynamic macroeconomic model that allows us to analyse the effects of population ageing and of a shift from a pay-as-you-go system to a (partially) funded pension system, induced by the pressure of population ageing on public pension budgets. The model is based on a version of the overlapping-generations (OLG) model (Samuelson 1958; Diamond 1965) introduced by Auerbach and Kotlikoff (1987, chapter 3). OLG models are well suited to study the effects of population ageing on social security systems, because they are based on households’ and firms’ optimal reactions to movements in the demographic structure and public policy measures.

Overlapping-generations models have also been used to analyse international capital flows since the seminal contribution by Buitier (1981). More recently, several authors developed large-scale multi-country OLG models to

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Our paper improves on the existing literature in several dimensions. The above papers do not model PAYG pension systems, and accordingly do not address the important issue of pension reform with its associated changes in saving patterns which in turn have implications on international capital flows. Issues related to pension reform are also addressed by INGENUE (2001) and Fehr et al. (2003, 2004). We improve on these papers by using more detailed demographic projections which model the various dimensions of demographic change, and by carefully distinguishing between the effects of population ageing and population shrinkage. Our work shows that the delicate effects of the differential timing of demographic change across countries on macro-economic aggregates and capital flows can be assessed only with realistic demographic forecasts; they are largely ignored in the stylized demographic transition schemes used in other work. We explicitly take three European countries (France, Germany and Italy) as examples of countries that are differently affected by population ageing within Europe. France is ageing much less than Germany and Italy. Accordingly, we analyse not only capital flows from Europe to the rest of the world, but also the resulting intra-European capital flows. Furthermore, we account for differences in the generosity of pension systems and simulate the impact of a stylized pension reform in the regions of our model.

An earlier version of the model used in this study was presented by Börsch-Supan et al. (2002). Here we modify and improve this earlier model along several dimensions. First, we extend the focus of our analysis to the entire European Union and no longer focus exclusively on Germany. Second, we model endogenous labour supply decisions and hence implement important feedback effects arising from differences in the relative returns on capital and labour that result from population ageing. Third, we follow Abel (2001, 2003), Altig et al. (2001) and Fehr et al. (2003, 2004) by including adjustment costs to capital in our analysis, which allows us to study the time pattern of the price of capital. Fourth, we allow for lifetime uncertainty in the household optimization problem, and we explicitly model age-specific productivity. Fifth, we start our calculations with a phase-in period of 150 years in order to relax the contrafactual assumption of a steady state in 2002, the reference year of the simulations we present. This is important for two reasons. First, it allows us to analyse how our model matches empirical counterparts of long time-series of data, especially international capital flows and labour supply. Second, we avoid distortions arising from adjustments of the model towards an equilibrium path resulting from the arbitrary imposition of an initial steady state or other initial conditions.

The model has three building blocks: a demographic projection, a stylized pension system, and a macroeconomic overlapping-generations model which generates the general equilibrium of the internationally linked economies. Initial values and parameters for these building blocks will be described in Section III.

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The demographic projection model

Detailed demographic projections form the background of our analysis. Demography is taken as exogenous and represents the main driving force of our simulation model. In each country, the size of population of age \( j \) in period \( t \), \( N_{t,j,i} \), is given recursively by

\[
N_{t+1,j+1,i} = N_{t,j,i}(s_{t,j,i} + m_{t,j,i}) \quad \text{for } j > 0 \quad \text{and} \quad N_{t+1,0,i} = \sum_{j=15}^{50} f_{t,j,i} N_{t,j,i}
\]

where \( s_{t,j,i} \) denotes the age-specific conditional survival rate, \( m_{t,j,i} \) the net migration ratio and \( f_{t,j,i} \) the age-specific fertility rate.

The individuals in our model economies enter economic life at age 20, which we denote by \( a = 1 \). The maximum age as implied by the demographic projections is 104 years. Accordingly, the maximum economic age, denoted by \( Z \), is 85. To simplify calculations in our economic model, we assume that all migration takes place at the initial age of 20. This simplifying assumption allows us to treat all ‘newborns’—immigrants and natives—in our economic model alike.

The stylized pension systems

Each region is assumed to have a two-tier pension system. The first tier represents a conventional public pay-as-you-go (PAYG) system characterized by country-specific contribution and replacement rates. More precisely, for each region \( i \), the exogenous policy variable is the time-specific gross replacement rate, \( b_{t,i} \), defined as the ratio of average gross pension to average gross wage income at time \( t \). The budget of the PAYG pension system is balanced at any time \( t \) and determines the contribution rate, \( \tau_{t,i} \), by the budget identity

\[
\tau_{t,i} \sum_{a=1}^{Z} w_{t,a,i} l_{t,a,i} N_{t,a,i} = \sum_{a=1}^{Z} p_{t,a,i}(E_{t,i} - l_{t,a,i}) N_{t,a,i},
\]

where the pension benefits, \( p_{t,a,i} \), are computed as

\[
p_{t,a,i} = b_{t,i} \lambda_{t,a,i} w_{t,a,i}^g
\]

\( E_{t,i} \) denotes the time endowment of households which we explain below. On the revenue side, \( w_{t,a,i}^g \) denotes age-specific gross wages. Net wages are given by \( w_{t,a,i} = w_{t,a,i}^g(1 - \tau_{t,i}/2) \), where half the contributions are paid by the employee and the other half by the employer. This latter half will be taken into account when firms maximize profits. As further specified below, age-specific gross wages are given by \( w_{t,a,i}^g = w_{t,a}^g e_a \), where \( e_a \) is age-specific productivity and \( w_{t,a}^g \) is the aggregate gross wage resulting from profit maximization (see below). \( l_{t,a,i} \) denotes labour supply resulting from optimal household decisions, and \( l_{t,a,i} N_{t,a,i} \) the number of contributors of age \( a \) at time \( t \) in country \( i \).

On the benefit side of the budget equation, pensions are defined by a product of three terms: the general replacement rate, \( b_{t,i} \); aggregate gross wages, \( w_{t,j,i}^g \); and ‘earning points’, \( \lambda_{t,a,i} \). For each year of labour force participation, workers are credited points according to their relative earnings. If their annual earnings are equal to the annual average, 1/45 point is credited;
if a worker earns 50% more than the average, \((1.5 \div 45)\) point is credited; etc. Points are summed up over the work history, i.e. to 1 for a 45-year span of work history. The recursive representation of \(\lambda_{t,a,i}\) is then given by

\[
\lambda_{t+1,a+1,i} = \lambda_{t,a,i} + \frac{1}{45} \frac{e_a w_{t,i}^f I_{t,a,i}}{\Phi_{t,i}} = \lambda_{t,a,i} + \frac{1}{45} \frac{e_a I_{t,a,i}}{\Phi_{t,i}},
\]

(4)

where

\[
\Phi_{t,i} = \sum_{a=1}^{Z} \frac{e_a I_{t,a,i} N_{t,a,i}}{\sum_{a=1}^{Z} I_{t,a,i} N_{t,a,i}}
\]

This stylized ‘point system’ is an approximation of the actual benefit formulas in France, Germany and Italy and takes into account that early retirees receive only a fraction of full pension income. Benefits are not taxed, and we ignore interactions with other social protection systems such as health insurance. We assume that all persons in each region participate in the same pension system.

The second tier of the stylized pension system represents pre-funded private pensions. We do not model this funded component of the pension system explicitly—it simply consists of voluntary private savings. These savings are determined by households’ optimal life-cycle decisions, taken under an intertemporal budget constraint that includes the benefit level of public pensions. Rational forward-looking behaviour of households implies that households adjust their voluntary savings in response to variations in the public pension replacement rates induced by demographic change or a pension reform.

To separate the direct effects of population ageing on capital markets and potential feedback effects from pension reform, we present projections for two future hypothetical pension system scenarios which we apply to the three large continental European countries.

(a) Under the ‘old system scenario’, the 2006 replacement rates are maintained throughout the projection period, which, as a result of population ageing, results in rising contribution rates.

(b) Under the ‘reform scenario’, contribution rates are frozen at their 2006 level, which results in decreasing replacement rates. We assume that this pension reform is announced in 2004 and implemented in 2006. This leaves households with an adjustment period of two years prior to implementation of the reform.

These two pension system scenarios are extreme cases. While they are both counterfactual, they help us sharpen the effects of pension reform. The ‘old system scenario’ projects the dominant and monolithic PAYG systems of the 1990s into the future. In fact, however, substantive reform steps are under way in France, Germany and Italy. In turn, the ‘reform scenario’ introduces faster and deeper transitions to partially funded multi-pillar pension systems than are currently envisaged in the three countries.
The overlapping-generations model

The two core elements of the macroeconomic general equilibrium model are
the production and the household sectors.

The production sector in each country consists of a representative firm that
uses a Cobb–Douglas production function given by

\[ Y_{t,i} = F(\Omega_i, K_{t,i}, L_{t,i}) = \Omega_i K_{t,i}^{\alpha} L_{t,i}^{1-\alpha}, \]

where \( K_{t,i} \) denotes the capital stock and \( L_{t,i} \) the labour supply of country \( i \) at
time \( t \). Labour supply, \( L_{t,i} \), is measured in efficiency units. \( \alpha \) is the capital share.

Production efficiency of a household of age \( a \) at time \( t \) in country \( i \) has a
factorial structure with three elements, relating to age, time and country. On
the micro level, where households are distinguished by their age, labour
productivity changes over the life-cycle according to age-specific productivity
parameters \( e_a \). Hence the age-specific gross wage is \( w_{t,a,i} = e_a w_{t,i} \) and the
aggregate labour supply is \( L_{t,i} = \sum_{a=1}^{Z} e_a l_{t,a,i} N_{t,a,i} \), where \( l_{t,a,i} \) denotes a single
household’s labour supply.

Second, aggregate and individual labour supply (\( L_{t,i} \) and \( l_{t,a,i} \)) are measured
in efficiency units relative to a time endowment \( E_{t,i} \). The actual age-specific
labour supply that corresponds to what is observed in the data is therefore
given by

\[ L_{t,a,i} = \frac{l_{t,a,i} N_{t,a,i}}{E_{t,i}}. \]

The time endowment grows at a constant rate, \( g \). This ‘growth in time
endowment’ specification is equivalent to the standard labour-augmenting
technological change specification for the production sector and has useful
properties for the specification of the household sector; see below.

Third, \( \Omega_i \) is the technology level of country \( i \). We calibrate \( \Omega_i \) such that
aggregate detrended GDP averaged over the calibration period is replicated in
each country; see below.

We assume that investment is subject to convex adjustment costs
(Hayashi 1982) with a proportionality factor \( \psi \). The dynamic problem of the
firm is given by

\[ \max_{\{K_{t,i}\}_{t=1}^{\infty}, \{L_{t,i}\}_{t=1}^{\infty}, \{I_{t,i}\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} d_{t,i} F(\Omega_i, K_{t,i}, L_{t,i}) - I_{t,i} - C(I_{t,i}, K_{t,i}) \]

subject to

\[ C(I_{t,i}, K_{t,i}) = \frac{\psi I_{t,i}^2}{2 K_{t,i}^2}, \]

\[ I_{t,i} = K_{t+1,i} - K_{t,i}(1 - \delta), \]

where \( d_{t,i} \) is the firm’s discount factor defined by \( d_{t,i} = \prod_{s=1}^{t} (1 + r_{s,i})^{-1} \) and
\( \delta \) is the rate of depreciation of capital. The adjustment cost formulation in (7) is
the standard quadratic term, and the term \( 1/(1 + \tau_{s,i}/2) \) in (6) reflects the fact
that 50% of social security contributions are paid by the employer.

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The first-order conditions resulting from profit maximization give the following expressions for equilibrium wages and interest rates and for the equilibrium price of capital:

\[ w_{g,t,i} = (1 - \alpha_{t,i}) \frac{Y_{t,i}}{1 + \tau_{t,i}/2 L_{t,i}} \]

\[ q_{t,i} = 1 + \psi \frac{I_{t,i}}{K_{t,i}} \]

\[ r_{t,i} = \frac{F_{K_{t,i}} + (1 - \delta)\Delta q_{t,i} + \psi \left( \frac{I_{t,i}}{K_{t,i}} \right)^2}{q_{t-1,i}} - \delta, \]

where \( q_{t,i} \) denotes the Lagrangian factor of the net investment equation (8), i.e. the total marginal costs of investment, which in this formulation also equals Tobin’s \( q \) (Tobin 1969; Hayashi 1982). \( F_K \) denotes the marginal product of capital. Equation (11) is the familiar arbitrage condition for the rate of return on financial and physical investment: the return on financial investment, \( r_{t,i} \), must be equal to the return on one unit of physical investment at a price of \( q_{t-1,i} \) in each country. The latter equals the marginal product of capital plus capital gains on non-depreciated capital plus the reduction in marginal adjustment costs minus depreciation. If \( \psi = 0 \), i.e. if there are no adjustment costs to capital, then (11) reduces to the standard static condition, \( r_{t,i} = F_K - \delta \).

In order to determine aggregate consumption, we next consider optimal household behaviour derived from intertemporal utility maximization. By choosing an optimal consumption path, each cohort maximizes, at any point in time \( t \) and age \( a \), the sum of discounted future utility. The within-period utility function exhibits constant relative risk aversion, and preferences are additive and separable over time. The maximization problem of a cohort at \( a = 1 \) is given by

\[ \max_{\{C_{t+a-1,a,i}\}_{a=1}^{Z},\{l_{t+a-1,a,i}\}_{a=1}^{Z}} \sum_{a=1}^{Z} \frac{1}{(1 + \rho)^a} \pi_{t,a,i} U(C_{t+a-1,a,i}, E_{t+a-1,i} - l_{t+a-1,a,i}), \]

where \( \rho \) is the pure time discount rate. In addition to pure discounting, households discount future utility with their unconditional survival probability in period \( t \):

\[ \pi_{t,a,i} = \prod_{j=1}^{\alpha} S_{t+j-1,i,j}. \]

\( C_{t,a,i} \) denotes consumption and \( l_{t,a,i} \) labour supply of the household. Remember that the latter is measured in efficiency units relative to the time endowment \( E_{t,i} \). We assume that the period-specific utility function is of the standard CES form given by

\[ U(C_{t,a,i}, E_{t,i} - l_{t,a,i}) = \frac{1}{1 - \sigma} \left\{ \left( \left( \omega_{a,i} C_{t,a,i}^{-\gamma} + (1 - \omega_{a,i})(E_{t,i} - l_{t,a,i})^{-\gamma} \right)^{-1} \right)^{1 - \sigma} - 1 \right\}, \]
where $\sigma$ is the coefficient of relative risk aversion; $\omega_{a,i}$ is the consumption share parameter, i.e. the weight of consumption relative to leisure in the household’s utility which varies both across countries and across age; and $\xi = 1/(1 + \gamma)$ is the intratemporal substitution elasticity between consumption and leisure.

A feature of our model is uncertainty about the time of death expressed in the term $\pi_{t,a,i}$ in equation (13). We assume perfect annuity markets, which implies that accidental bequests are distributed implicitly, as in the life insurance framework by Yaari (1965; see also Rios-Rull 1996, 2001). We do not include intended bequests in our model.

Denoting total wealth by $A_{t,a,i}$, maximization of the household’s intertemporal utility is subject to a dynamic budget constraint given by

$$ A_{t+1,a+1,i} = \frac{1}{s_{t,a,i}} (A_{t,a,i}(1 + r_{t+1,i}) + l_{t,a,i}w_{t,a,i}^p + (E_{t,i} - l_{t,a,i})p_{t,a,i} - C_{t,a,i}). $$

The term $l/s_{t,a,i}$ reflects how accidental bequests are dissipated through the annuity market. Income consists of asset income, net wages and pensions.

Furthermore, maximization is subject to equation (4) and to the constraint that leisure may not exceed time endowment (and may not be negative), i.e.

$$ 0 \leq l_{t,a,i} \leq E_{t,a,i}. $$

The solution to the optimization problem is characterized by an intertemporal equation for the marginal utility of consumption,

$$ \frac{\partial u}{\partial C_{t,a,i}} = \frac{1 + r_{t+1,i}}{1 + \rho} \frac{\partial u}{\partial C_{t+1,a+1,i}}, $$

and an intratemporal equation relating the marginal utility of leisure to the marginal utility of consumption,

$$ \frac{\partial u}{\partial E_{t,i} - l_{t,a,i}} = \frac{\partial u}{\partial C_{t,a,i}} (w_{t,a,i}^p - p_{t,a,i} + \mu_{t,a,i}) - s_{t,a,i} \frac{1}{1 + \rho} \frac{e_{a,i}}{45} \frac{\partial V_{t+1,a+1,i}}{\partial \lambda_{t+1,a+1,i}}, $$

where $\mu_{c,a,i} \geq 0$ is the shadow value of leisure. The last term reflects the increase in the value function resulting from an additional unit of labour supply.

Ignoring the last term in (17), since it is second-order and numerically small, we arrive at an approximate solution of the household problem given by

$$ C_{t+1,a+1,i} = C_{t,a,i} \left( \frac{1 + r_{t+1,i}}{1 + \rho} \right)^{1/\sigma} \left( \frac{v_{t+1,a+1,i}}{v_{t,a,i}} \right)^{1/\sigma}, $$

where

$$ v_{t,a,i} = (\omega_{a,i} + (1 - \omega_{a,i}) lcrc_{a,i})^{1+\gamma} \gamma. $$

The leisure–consumption ratio, $lcr_{c,a,i}$, is defined by

$$ E_{t,i} - l_{t,a,i} = \left( \frac{1 - \omega_{a,i}}{\omega_{a,i}} w_{t,a,i} + \mu_{t,a,i} - p_{t,a,i} \right)^{1/\gamma} C_{t,a,i} = lcr_{t,a,i} C_{t,a,i}. $$

In equation (19) and elsewhere, we do not distinguish explicitly between workers and pensioners. Each cohort is represented by a single household which supplies $l_{t,a,i}$ units of labour. As a result of optimal household behaviour
under the public pension rules defined in the previous section, the time endowment spent for active work, \( l_{t,a,i} \), decreases over the life cycle. The representative household thus receives a mix of a net wage \( w_{t,a,i} \) and a public pension \( p_{t,a,i} \), where the mix shifts from all wages to all pensions.

As described above, variations in the time endowment, \( E_{t,i} \), reflect labour-augmenting technological change. In the household sector households become more efficient in using their entire time; i.e., not only labour but also leisure becomes more efficient. This specification of technological change goes back to Altig et al. (2001) and, as discussed there, permits a flexible choice of the substitution elasticity between consumption and leisure \( \zeta = 1/(1 + \gamma) \).

**Equilibrium**

We define the dynamic general equilibrium of the model economy sequentially.9

**Definition 1.** The approximate competitive equilibrium of the economy is defined as a sequence of disaggregate variables:

\[ \{C_{t,a,i}, l_{t,a,i}, A_{t,a,i}\}, \text{ aggregate variables;} \]

\[ \{C_{t,i}, L_{t,i}, K_{t,i}\}, \text{ prices for capital and labour;} \]

\[ \{q_{t,i}, w_{t,i}\} \text{ in each country } I, \text{ and a common world interest rate } \{r_t\} \text{ such that} \]

(i) the allocations are feasible; i.e.

\[ Y_{t,i} + r_i F_{t,i} = S^n_{t,i} + C_{t,i} + D_{t,i} = S^n_{t,i} + C_{t,i} = \]

\[ \sum_{a=1}^{Z} \left( s_{t,a,i} A_{t+1,a+1,i} - A_{t,a,i} \right) N_{t,a,i} + \sum_{a=1}^{Z} C_{t,a,i} N_{t,a,i} \]

\[ + \left( \delta - (1 - \delta) \frac{\Delta q_{t,i}}{q_{t-1,i}} \right) q_{t-1,i} K_{t,i} \]

where \( F_{t,i} \) is the amount of foreign assets, \( D_t \) is depreciation of capital valued in units of consumption and accounting for gains on non-depreciated capital, and \( S^n_{t,i} (S^n_{t,i}) \) is net (gross) savings.

(ii) Factor prices equal their marginal productivities as given in (9)–(11).

(iii) Firms and households behave optimally; i.e., firms maximize profits in (6) subject to the constraints in (7) and (8), and households maximize lifetime utility given by (12) subject to the constraints in (14) and (15).

(iv) All markets clear; market-clearing on national markets requires that

\[ S^n_{t,i} = \sum_{a=1}^{Z} S^n_{t,a,i} N_{t,a,i}; \quad C_{t,i} = \sum_{a=1}^{Z} C_{t,a,i} N_{t,a,i}; \quad A_{t,i} = \sum_{a=1}^{Z} A_{t,a,i} N_{t,a,i}; \]

\[ L_{t,i} = \sum_{a=1}^{Z} l_{t,a,i} N_{t,a,i} \]

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Market-clearing on the international capital market, and the assumption of perfect capital mobility across regions, require that the rate of return on financial investment is equalized across all countries, i.e. $r_{t,i} = r_t$, and that the sum of all foreign assets across all world regions equals zero, i.e. $\sum_{i=1}^R F_{t,i} = 0$. Hence in equilibrium world output is equal to

$$Y_t = \sum_{i=1}^R Y_{t,i} = \sum_{i=1}^R (S^u_{t,i} + C_{t,i} + D_{t,i}).$$

Foreign assets are defined as the difference between total and home assets that are equal to the value of the home capital stock:

$$F_{t,i} = A_{t,i} - H_{t,i} = A_{t,i} - q_{t-1,i}K_{t,i},$$

and international capital flows are defined by the difference between gross savings and investment:

$$CA_{t,i} = S^g_{t,i} - q_{t,i}I_{t,i},$$

where $q_{t,i}I_{t,i}$ is physical investment valued in terms of consumption units, which in turn is given by

$$q_{t,i}I_{t,i} = q_{t,i}(K_{t+1,i} - (1 - \delta)K_{t,i}) = q_{t,i}K_{t+1,i} - q_{t-1,i}K_{t,i}$$

$$+ \left( \delta - (1 - \delta) \frac{\Delta q_{t,i}}{q_{t-1,i}} \right) q_{t-1,i}K_{t,i}.$$  

The last term on the right-hand side of (21) reflects depreciation net of capital gains.\(^{10}\)

Finally, and for further reference, it is useful to define the household saving rate as total savings net of depreciation, divided by disposable income from domestic and foreign sources:

$$sr_{t,i} = \frac{S^u_{t,i}}{Y_{t,i} + r_t F_{t,i}}.$$  

**Numerical implementation**

Our time line has four periods: a phase-in period, a calibration period, a projection period and a phase-out period. We start calculations 110 years before the calibration period begins with an initial steady state. The period between 1960 and 2001 is then used as calibration period in order to determine the structural parameters of the model. Our projections run from 2002 to 2100.\(^{11}\) The phase-out period after 2100 has two parts: a transition to a steady-state population in 2200, and an additional 100-year period until the model reaches a final steady state in 2300.

We determine the equilibrium path of the overlapping-generations model by using a first-order tatonnement iteration (see Auerbach and Kotlikoff 1987). The algorithm searches for equilibrium paths of capital–output ratios and labour supply in each country and is described in detail in Ludwig (2006).
III. Calibration

In order to capture projected international differences in demographic change and the generosity of public pension systems, we distinguish seven world regions in the benchmark scenario: (i) France, (ii) Germany and (iii) Italy as three large European countries severely affected by population ageing; (iv) the remainder of the European Union; (v) North America (the United States and Canada); (vi) the remaining OECD countries; and (vii) all other countries in the world. While we treat France, Germany and Italy as separate regions in the simulations, we simplify the presentation of most of our simulation results by aggregating them into a combined France–Germany–Italy region.

Our demographic model for these regions is calibrated to fit the United Nations (2002) projections. These projections end in 2050. Between 2050 and 2100, we continue the linear increase in life expectancy assumed by the UN and impose constant fertility rates at the levels reached in 2050. During the phase-out period of the model beyond 2100, demographic processes stabilize such that stable populations are reached at 2200.\(^{12}\)

In order to solve the pension system equations (1) and (2) for each country, we assume that net replacement rates are constant over time at current levels. We then solve for the associated time paths of the contribution rates. We calibrate the pension systems with data on gross replacement rates taken from Palacios and Pallarès-Miralles (2000) and employees’ social security contributions taken from OECD (2001). Finally, we solve for equilibrium contribution rates using the budget constraint in equation (1).

Further parameters of the model are the households’ preference parameters, the parameters of the production function, and values of the age-specific productivity profile. For the latter, we use the cohort-corrected nonlinear regression estimates by Fitzenberger et al. (2001); this provides us with a representative age-wage profile that peaks at the age of 52 and then decreases slightly.

With two exceptions, technological and preference parameters are assumed to be constant and equal across all countries. The values of these parameters are standard in the literature and summarized in Table 1. The growth rate of productivity, \(g\), is set to 1.5 percentage points, which is slightly higher than the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(z): output share of capital in CES production function</td>
<td>0.35</td>
</tr>
<tr>
<td>(g): growth rate of labor productivity</td>
<td>0.015</td>
</tr>
<tr>
<td>(\delta): depreciation rate of capital</td>
<td>0.05</td>
</tr>
<tr>
<td>(\psi): adjustment costs parameter</td>
<td>1.5</td>
</tr>
<tr>
<td>(\rho): rate of time preference</td>
<td>0.011</td>
</tr>
<tr>
<td>(\sigma): coefficient of relative risk aversion</td>
<td>2</td>
</tr>
<tr>
<td>(\zeta): intratemporal substitution elasticity</td>
<td>0.8</td>
</tr>
<tr>
<td>(\Omega): technology level</td>
<td>0.05–0.07</td>
</tr>
<tr>
<td>(\omega): consumption share parameter</td>
<td>0.535–0.665</td>
</tr>
<tr>
<td>(\Delta\omega): increment of consumption share parameter</td>
<td>0.015–0.02</td>
</tr>
</tbody>
</table>

TABLE 1

Calibration of parameters in the overlapping generations model
value of 1.4 percentage points suggested by Cutler et al. (1990) and closer to the long-run projections suggested by the OECD. The capital share parameter, $z$, is usually set to a value between 0.3 and 0.4. We set it to the intermediate value of 0.35. The annual depreciation rate, $\delta$, is assumed to be 5 percentage points per year.

The adjustment cost parameter, $\psi$, deserves more discussion. In a model without depreciation but with capital taxation, and with a lower growth rate $g$ of 1 percentage point, the value of 10 for $\psi$ chosen by Altig et al. (2001) results in a steady state $q$-value of 1.04. The empirical study by Oliner et al. (1995) finds an equilibrium $q$-value of 1.13. In our model, with a productivity growth rate of 1.5 percentage points and a depreciation rate of 5 percentage points, the value of $\psi = 1.5$ that we choose results in a steady state $q$-value of 1.0975, which is just in between these two values used in the literature. As we show in an extensive sensitivity analysis (Börsch-Supan et al. 2004), adjustment costs, while allowing us to study the time path of the price of capital, do not otherwise affect our results much.

The discount rate in all countries, $r$, is set to 0.01, which is close to the estimate 0.011 of Hurd (1989). With this choice—and given all the other parameter values—our model produces an average capital–output ratio of about 2.9 for the region ‘European Union’ in the calibration period 1960–2001. While comparable capital–output ratios for a large cross-section of countries are not available, a value of 2.9 is reasonable for many countries (OECD 2003). The coefficient of relative risk aversion is set to 2, which is within the standard range of 1–4. We follow Altig et al. (2001) in choosing the value for the intratemporal substitution elasticity $\xi = 1/(1 + \gamma) = 0.8$.

Levels of total factor productivity, $\Omega_i$, vary across countries and are calibrated such that the model replicates output data in each country for the period 1960–2001.\textsuperscript{13} Consumption share parameters, $\omega_{i,a}$, vary across country and age. We define the functional form of $\omega_{i,a}$ in each country as

$$\omega_{a,i} = \begin{cases} \bar{\omega}_I & \forall a \leq A^l \\
\bar{\omega}_I - \Delta \omega_I (a - A^l) & \forall A^l < a \leq A^h \\
\omega_I = \bar{\omega}_I - \Delta \omega_I (A^h - A^l) & \forall a > A^h \end{cases}$$

i.e. the consumption share parameter is assumed to be constant for ages $a \leq A^l$, then to decrease linearly until it is constant again for ages $a > A^h$. $A^l$ is set to 54, beyond which empirically observed labour supply starts to decrease; and $A^h$ is set to 80, since labour supply is essentially zero in all countries beyond the age of 80. While we hold the age boundaries constant across all countries, we calibrate $\bar{\omega}_I$ and $\Delta \omega_I$ such that the simulation model approximately replicates both aggregate labour supply and labour supply profiles across ages on average in each country for the period 1960–2001.\textsuperscript{14}

A final remark concerns the initial values of the model for the year 2002 under the different capital mobility scenarios. Conceptually, it is problematic to simulate a calibrated macroeconomic model under policy scenarios other than the one for which it was calibrated. In our case, the world for which we calibrate the model changes with the number of regions considered in the capital mobility scenarios. On the one hand, it would make sense to adjust the calibration parameters each time we change the number of regions that we
consider. On the other hand, this would change households’ reactions to changes in policy, and it would therefore be more difficult to interpret our results with respect to a reform of the public pension system. For that reason, and since we are interested primarily in the reaction of households to demographic change and fundamental pension reform, we keep parameter values constant across all capital mobility scenarios. We calibrate the model under the assumption that the ‘OECD’ capital mobility scenario correctly reflects the ‘true’ world, and therefore that all other capital mobility scenarios are ‘counterfactual’ worlds. Readers will note that this procedure results in differences in the values of the simulated variables in 2002, the base year of our simulations.

IV. SIMULATION RESULTS FOR ALTERNATIVE PENSION AND CAPITAL MOBILITY SCENARIOS

In this section we present our main results. How will demographic change affect key macroeconomic variables? Since the speed and extent of demographic change vary across the world regions, we would expect to observe differential impacts of demographic change on rates of return to capital in each region if the regions were closed economies.

In a world of open economies, however, these differences in rates of return will induce international capital flows, which will reduce such differentials. To illustrate the influence of free capital mobility across regions, we created four capital mobility scenarios from the point of view of the three largest economies in continental Europe (France, Germany and Italy). The first scenario corresponds to a closed economy, where all investment in France, Germany and Italy takes place within these three countries. The other three capital mobility scenarios open up this closed economy sequentially: France, Germany and Italy diversify their investments (i) across all countries of the European Union, (ii) across all OECD countries and (iii) across the entire world. The results in Figures 2–5 display four lines representing these capital mobility scenarios. The benchmark scenario assumes that capital mobility is restricted to the OECD area.15

In addition to these direct effects of demographic change, there are indirect effects arising from the presence of (partially) PAYG-financed social security systems. In order to separate the direct effects of population ageing on capital markets and potential feedback effects from the existence of pension systems and pension reform, we present our main results for two hypothetical pension policy scenarios described above: (a) the ‘old system scenario’, which maintains these countries’ current generous public pension systems, and (b) the ‘reform scenario’, which introduces a transition to a partially funded pension system by freezing contribution rates in the three countries. The other regions’ pension systems remain unchanged. By comparing these polar scenarios, we can show that a good portion of the capital market effects of population ageing arise even without a fundamental pension reform. Accordingly, Figures 2–5 each have two panels. Panel (a) corresponds to the ‘old system scenario’, i.e. the direct effects of demographic change, and panel (b) shows the differences between the two scenarios, i.e. the indirect effects of a fundamental pension reform induced by demographic change.

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The interplay between these direct and indirect effects of population ageing on macroeconomic variables is complicated because they involve changes in both levels and trends. Direct-level effects are due to differences in the levels of working-age population ratios across countries. Younger economies, i.e. those with higher working-age population ratios, have higher marginal productivities of capital which will be arbitraged away by international capital flows. Over time, direct-trend effects, which are related to the speed of demographic change, will affect the dynamics of macroeconomic variables: working-age population ratios will decrease, capital–output ratios will therefore increase, and both rates of return and savings rates will decline.

The indirect effects of PAYG-financed pension systems are due to their ‘crowding out’ effect on private savings by providing old-age pension income, and their distortionary taxation of labour income. By replacing private savings, the indirect-level effect of PAYG-financed pension income works in the opposite direction to that of the direct effect of demographic change. Compared with the situation where no PAYG-financed pension system applies, the indirect effect decreases the differences in saving rates and rates of return between countries. Over time, old-age dependency ratios increase, and therefore contribution rates to the PAYG pension system increase as well (taking PAYG replacement rates as given, as we do in the old system scenario). This indirect-trend effect is stronger in the older regions, which are more severely affected by the impact of demographic change.

In order to illustrate the complicated superimposition of all these direct and indirect-level and trend effects, we present our results in several steps. Throughout, we focus on the economic consequences of ageing and of fundamental pension reform on the continental European region consisting of France, Germany and Italy. As our point of departure, we analyse the impact of the exogenous demographic change on working-age population and old-age dependency ratios. We then analyse the two channels of reaction of households to demographic change and fundamental pension reforms by analysing how labour supply and savings patterns are affected. We next turn to the firm sector and analyse the evolution of wage rates and the return to capital as well as its price, Tobin’s $q$. Finally, we focus on the difference between national saving and investment, which generates international capital flows, and describes how they are affected by demographic change. While our results show substantial differences in international capital flow patterns between countries of the European Union and the other world regions, there are also significant differences between countries within the different world aggregates. To highlight this aspect, we further present results on saving patterns and international capital flows for the three European countries on which we focus (France, Germany and Italy). We conclude this section with a brief welfare analysis of households in Germany.

Point of departure: demographic change

Figure 1 shows the effects of demographic change on two central demographic measures: the share of persons in working age (the number of persons aged 15–65 as a percentage of total population) and the old-age dependency ratio (the number of persons older than 65 as a percentage of the working age population).
FIGURE 1. Projections of working-age population and old-age population ratios for different world regions. (a) Working-age population ratios. (b) Old-age dependency ratios

Notes: These figures show projections of the working-age population ratio (the number of people aged 15–65 as a percentage of total population) and the old-age dependency ratio (the number of people older than 65 as a percentage of the working-age population) for five different world regions: F + G + I: France, Germany and Italy; REST EU: remaining countries of the European Union; USA + CAN: United States and Canada; REST OECD: remaining OECD countries; REST WORLD: remaining world countries.

A number of lessons can be learned from these graphs. First, all world regions are affected by demographic change: the proportions of persons in working age will decrease and the old-age dependency ratios will increase. Second, while the shares of persons of working age were fairly similar in 2000 for the regions in the OECD, the course of population-ageing diverges in these regions. The decrease in the share of persons of working age is strongest for the EU countries, especially for the three-country group France, Germany and Italy. Third, this country group has also the highest old-age dependency ratio. Fourth, there are significant differences in the timing and the pattern of demographic change across regions. As we will see, these different patterns have profound implications for the evolution of saving rates, rates of return and international capital flows.

*Labour supply, contribution and replacement rates*

These demographic changes have immediate effects on labour supply and the balance of the pension system. Labour supply shares in the three European countries France, Germany and Italy should decrease from the present 42% to below 36% by 2050. The economic dependency ratio, defined as the ratio of pensioners to workers, is projected to increase, from roughly 50% in 2002 to about 80% in 2050.16

As a result of the decrease in labour supply shares and the resulting increase in the economic dependency ratio, the contribution rate to the PAYG pension system increases sharply under the ‘old system scenario’, i.e. current generous pension systems. These contribution rates are equilibrium rates such that the budget of the pension system of each country is balanced at every point in time (implicitly including tax subsidies to the pension system). The time patterns of net replacement and contribution rates for France, Germany and Italy that result from our procedure are summarized in Table 2.

If current generous replacement rates were to be maintained, our model predicts that the equilibrium contribution rate in Germany would increase from its current level of roughly 27% to 41% in 2050—a more than 50% increase. The stylized pension reform freezes contribution rates at the level reached in 2006, roughly 29%. As a result of this reform average pension levels

<table>
<thead>
<tr>
<th>Table 2</th>
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<tr>
<td>Predicted contribution and replacement rates of PAYG pension systems</td>
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<table>
<thead>
<tr>
<th></th>
<th>France 2000</th>
<th>France 2030</th>
<th>France 2050</th>
<th>Germany 2000</th>
<th>Germany 2030</th>
<th>Germany 2050</th>
<th>Italy 2000</th>
<th>Italy 2030</th>
<th>Italy 2050</th>
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<tr>
<td><strong>Old system scenario</strong></td>
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<td></td>
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</tr>
<tr>
<td>Contribution rates</td>
<td>0.275</td>
<td>0.356</td>
<td>0.375</td>
<td>0.268</td>
<td>0.375</td>
<td>0.415</td>
<td>0.325</td>
<td>0.476</td>
<td>0.534</td>
</tr>
<tr>
<td>Net replacement rates</td>
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<td>0.654</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.646</td>
<td>0.646</td>
<td>0.646</td>
</tr>
<tr>
<td><strong>Reform scenario</strong></td>
<td></td>
<td></td>
<td></td>
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<td>0.275</td>
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<td>0.294</td>
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<tr>
<td>Net replacement rates</td>
<td>0.654</td>
<td>0.549</td>
<td>0.513</td>
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<td>0.504</td>
<td>0.646</td>
<td>0.489</td>
<td>0.415</td>
</tr>
</tbody>
</table>

Notes: Figures shown in the table refer to the open economy scenario “OECD”.

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would decrease: the net pension replacement rate is projected to decrease from 70% in 2000 to about 50% in 2050. Hence, for Germany our model predicts a one-third transition towards pre-funding until 2050. Results for the other countries are similar, as can be seen in Table 2.

Households respond to these decreases in pension benefit levels not only by increasing savings, but also by increasing labour supply. The stylized pension reform would lead to quite substantial increases in aggregate labour supply. Labour supply shares are predicted to increase by more than 6.5%, or 2.5 percentage points, until 2050. This increase is roughly the same for all capital mobility scenarios. For instance, labour supply shares in the France–Germany–Italy region increase from about 36% in 2050 under the ‘old system scenario’ to 38.5% under the ‘reform scenario’. As a consequence, the economic dependency ratio is projected to decrease by almost six percentage points. Endogenous labour supply is therefore a helpful mechanism for dampening the effects of population ageing. This effect holds over the entire range of the crucial elasticity parameters in the OLG model (Börsch-Supan et al. 2004).

Savings and capital stock

Panel (a) of Figure 2 shows the aggregate average saving rate of France, Germany and Italy in the four capital mobility scenarios. In the year 2000, savings rates are substantially higher in the open-economy scenarios than in the closed France–Germany–Italy (F + G + I) region. This is in line with the higher rates of return realized in an open economy (see next sub-section). An open economy diversifies a great deal of the demographic effects (such as a large share of older persons) that create lower saving rates and rates of return.

This direct level effect is superseded by the demographic changes during the 2000–2070 prediction window. Saving rates decrease until 2050 across all capital mobility scenarios as the baby boom generation decumulates assets. Saving rates are projected to rebound after 2050. The decrease in the saving rate caused by population ageing—the difference between the value in 2000 and the minimum reached just after 2040—is roughly 4.5 percentage points if capital mobility is restricted at most to the EU region (scenarios ‘F + G + I’ and ‘EU’). If we allow for capital mobility within the OECD or the entire world, this decrease is 6.5 or 8 percentage points, respectively. This larger decrease in the open-economy scenarios is explained by the indirect-trend effect described above. The diversification advantages of worldwide capital mobility thus decline, and saving rates respond accordingly.

Projected aggregate saving rates under a fundamental pension reform are substantially higher, and the effect of a pension reform is stronger, in the OECD/world open-economy scenarios. (The saving rate is projected to increase by slightly more than one percentage point in the EU scenario, compared with 2 percentage points in the OECD/world scenarios.) An increase in national savings leads to an increase in the capital stock and thereby to a decrease in the rate of return to capital, which then crowds out further savings. In those scenarios with a larger international capital market, substantially more savings are generated, since (as we show below) the rate of return decreases by much less. These projections show that optimal life-cycle

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FIGURE 2. Saving rates. (a) Old system scenario. (b) Difference between reform and old system scenario

Notes: These figures show the projected aggregate saving rates of households in France, Germany and Italy. Scenario F + G + I: perfect capital mobility within France, Germany and Italy; scenario EU: perfect capital mobility within the European Union; scenario OECD: perfect capital mobility with the OECD; scenario WORLD: perfect capital mobility across all world regions.

Source: United Nations (2002); World Bank (2003), own calculations.
behaviour generates additional saving under a fundamental pension reform: in our model it is not the case that additional retirement saving induced by a pension reform crowds out other saving totally, as has often been claimed.

We also accumulate aggregate savings to obtain the world’s asset holdings and capital stocks and the related capital–output ratios (figures not shown). As a consequence of decreasing labour supply, the capital–output ratio increases from its current level of about 3 until it reaches a level of about 3.25 in around 2040, and then decreases slightly when baby boomers decumulate assets (capital mobility scenario ‘OECD’). This decrease is much more pronounced if we restrict the international capital market to the EU area only. The simultaneous fundamental pension reform of France, Germany and Italy leads to substantial increases in the capital–output ratio if we restrict capital mobility to these countries or the EU area. The increase is much lower if we relax this constraint, which suggests that the additional savings shown in Figure 2 are largely invested abroad.

The rate of return and the price of capital

Much of the political and academic debate on the capital market consequences of demographic change and of pension reforms has focused on the rate of return to capital, to which we turn next. First, we observe the same level effects as described in the previous section. It is noteworthy that the demographic effect is larger than a second-level effect. Since the PAYG systems are slimmer in the aggregate rest-of-the-world region than in France, Germany and Italy, the capital stock accumulated for retirement savings is larger, which depresses rates of return.

Second, as a consequence of population ageing and the resulting increase in capital–output ratios, our model predicts that the rate of return to capital will decrease by slightly less than one percentage point if capital moves freely within the OECD (see Figure 3). This decrease is less than would be associated with a ‘meltdown of asset prices’. Third, while the rate of return decreases across all capital mobility scenarios, substantial gains would be possible by shifting investments to ‘younger’ countries, since our model predicts higher returns if we allow for free capital mobility across all world regions. However, as demographic processes are highly correlated across countries (compare Figure 1), differences in demographic processes across countries more or less affect only the level of the rate of return. Furthermore, diversification advantages decrease over time, since the above mentioned indirect trend effects are at work as well.

As panel (b) of Figure 3 suggests, there would be an additional decrease in the rate of return to capital if France, Germany and Italy simultaneously reformed their pension systems in a fundamental way. This decrease would amount to about 0.25 percentage point until 2070 if capital were freely mobile only within these countries. Owing to the increase in labour supply, this long-run decrease in the rate of return is lower than a model with exogenous labour supply would suggest—see Section V. In contrast to a model of exogenous labour supply, the present model even predicts an increase in the rate of return until about 2030 or 2040 (as a result of the endogenous labour supply reaction). While saving rates immediately start to increase after the reform, labour supply
FIGURE 3. Rate of return. (a) Old system scenario. (b) Difference between reform and old system scenario.

Notes: These figures show the projected rate of return of the aggregate capital stock in France, Germany and Italy. Scenario F+G+I: perfect capital mobility within France, Germany and Italy; scenario EU: perfect capital mobility within the European Union; scenario OECD: perfect capital mobility with the OECD; scenario WORLD: perfect capital mobility across all world regions.

Source: United Nations (2002); World Bank (2003), own calculations.
increases as well. As a net effect, this initially leads to a decrease in the capital–
output ratio and to an associated initial increase in the rate of return to capital. 
Moreover, and in line with our earlier results (Börsch-Supan et al. 2002), the 
decrease in rate of return is negligibly small if capital moves freely across 
OECD countries (or the entire world).

Tobin’s $q$, the price of capital, also decreases as a consequence of 
population ageing, but its level is higher in the demographically younger 
regions. Results on Tobin’s $q$ for the France–Germany–Italy region are 
depicted in Figure 4. Notice that the relative decrease of $q$-values is lower under 
the pure PAYG scenario if the capital mobility region is broadened (panel (a)). 
As a consequence of fundamental pension reforms, $q$-values are predicted to 
increase slightly, since the investment to capital ratio increases (panel (b)). The 
long-run effect is stronger if capital mobility is restricted to a smaller region.

International capital flows

International capital outflows from France, Germany and Italy to other 
OECD countries roughly follow the pattern of savings and decrease steadily 
until 2050 (see Figure 5). In the OECD and world capital mobility scenarios, 
they are initially positive at about 2 and 3.2 percentage points and turn 
negative to $-2$ and $-2.5$ percentage points in 2050, respectively (panel (a)). 
Hence the model predicts reversals in current account positions for rapidly 
ageing countries such as France, Germany and Italy.

So far, our analysis has concentrated on France, Germany and Italy as a 
country aggregate. However, there are substantial differences across countries, 
even within continental Europe. To highlight this aspect, we next analyse 
savings patterns and international capital flows within the region of EU 
countries under the assumption that the international capital market is 
restricted to the OECD area.

Figure 6(a) shows saving rates for France, Germany and Italy, the 
remaining EU countries, and the EU average. The time pattern of German 
saving rates roughly equals the EU average. Germany’s saving rate is projected 
to decrease from current levels of 7% to about 2% in 2050. In France, the 
demographically youngest among the three regions, decreases in savings rate 
continue only until 2030 and the overall decrease is smaller than in other EU 
countries. Italy, faced with the strongest population ageing process within 
Europe, is at the other extreme: Italian households’ saving rates are projected 
to become substantially negative in 2050.

Welfare analysis

Figure 7 shows the effects of the fundamental pension reform on remaining 
lifetime utility for different cohorts. We follow Altig et al. (2001) and measure 
the change in remaining lifetime utility as the equivalent variation of full 
lifetime income. The index measures the present value of remaining lifetime 
resources, relative to current full lifetime resources, that a household would 
have to receive (pay) under the new system to make it indifferent between the 
old and new systems. An index number greater (smaller) than one, therefore, 
has to be interpreted as loss (gain) in remaining lifetime utility.
FIGURE 4. Tobin’s q. (a) Old system scenario. (b) Difference between reform and old system scenario

Notes: These figures show the projected q-values in France, Germany and Italy. Scenario F + G + I: perfect capital mobility within France, Germany and Italy; scenario EU: perfect capital mobility within the European Union; scenario OECD: perfect capital mobility with the OECD; scenario WORLD: perfect capital mobility across all world regions.

Source: United Nations (2002); World Bank (2003), own calculations.
FIGURE 5. Current account–output ratios. (a) Old system scenario. (b) Difference between reform and old system scenario

Notes: These figures show the projected current account–output ratio in France, Germany and Italy. Scenario EU: perfect capital mobility within the European Union; scenario OECD: perfect capital mobility within the OECD; scenario WORLD: perfect capital mobility across all world regions.

The results show that the remaining lifetime utility of a large number of generations should decrease as a consequence of the fundamental pension reform. Cohorts born between the years 1928 and 1982 will experience losses in remaining lifetime utility. Welfare losses are slightly higher if we restrict capital flows in the European Union for the OECD scenario. (a) Saving rate (old system scenario). (b) Current account–output ratio (old system scenario).

Notes: These figures show the projected saving rates and the current account–output ratios within countries of the European Union if capital mobility is restricted to the OECD area. EU average: average of all EU countries; Rest EU: all EU countries excluding France, Germany and Italy.


The results show that the remaining lifetime utility of a large number of generations should decrease as a consequence of the fundamental pension reform. Cohorts born between the years 1928 and 1982 will experience losses in remaining lifetime utility. Welfare losses are slightly higher if we restrict capital flows.
to be mobile only within the EU. While substantial welfare gains are possible in the long run in all capital mobility scenarios, the figure also illustrates that fewer cohorts experience losses if the capital mobility regions is widened. However, the difference between the capital mobility scenarios is not large.

V. SENSITIVITY ANALYSIS

One of the weaknesses of computational general equilibrium analysis is the dependence of the results on modelling strategies and parameter values. The usual response is an extensive sensitivity analysis. The existing literature has concentrated mostly on sensitivity analysis of simulation results with regard to values of structural (deep) model parameters (see e.g. Altig et al. 2002). We provide such ‘standard’ sensitivity analysis in a longer version of this paper (Börsch-Supan et al. 2004). This sensitivity analysis shows that results change very little when we vary the main elasticity parameters in their usual ranges. Probably our politically most contentious conclusion, the absence of a serious asset market meltdown, is robust with respect to the choice of these elasticity parameters.

In addition to this conventional sensitivity analysis, we also investigate the robustness of our results with respect to four key dimensions of our model.
specification: (i) What difference does it make whether labour supply is endogenous or exogenous? (ii) Does investment incur adjustment costs? (iii) Do perfect annuity markets absorb all accidental bequests? (iv) Is part of retirement income provided by a PAYG pension system? We find that the first dimension—whether or not labour supply is endogenous—matters a lot for assessing the effects of a pension reform, while the other three dimensions—adjustment costs, annuity markets and accidental bequests—matter very little (see Börsch-Supan et al. 2004).

In the sequel, therefore, we report only on the role of endogenous labour supply. For simplicity, we ignore adjustment costs to capital and concentrate on a three-region rather than a seven-region model as in the previous section, condensing the world regions to (i) France, Germany and Italy, (ii) all other EU countries, and (iii) all other OECD countries. We focus on the differential effects between the old system and the reform scenario because this is were the endogeneity of labour supply matters most.

Figure 8 compares these effects on the saving rate and the rate of return generated by models with endogenous and exogenous labour supply. In the exogenous labour supply specification, we hold age-specific labour supply shares constant at levels obtained in the endogenous labour supply scenario in the year 2000. We first show the reaction of savings to the fundamental pension reform. As depicted in panel (a) of the figure, the increase in the saving rate is much larger if labour supply is exogenous. Unlike in the case of endogenous labour supply, households cannot simultaneously adjust their labour supply and saving behaviour to the change in policy: they can react only by decreasing consumption such that the saving rate immediately jumps to a higher level after the announcement of the reform.

This difference in behaviour translates directly into substantial differences in the time paths of the rate of return to capital, depicted in Figure 8(b). If labour supply is endogenous, the rate of return initially increases, since households increase their labour supply as a reaction to the change in policy. This effect is absent when labour supply is exogenous. Hence the rate of return to capital immediately decreases. As a result, the overall decrease of the rate of return to capital is much larger.

Of course, the size of this endogenous labour supply effect depends on the elasticity of substitution between consumption and leisure, \( \xi \). This is shown in Figure 9, where we vary \( \xi \) by \( \pm 0.2 \) around its benchmark value of 0.8 and re-calibrate \( \bar{w} \), the consumption share parameter, such that initial labour supply shares are held constant. We thereby focus on the case where capital mobility is restricted to the France–Germany–Italy region. We choose this case because it exhibits the strongest sensitivity (see Figure 8). In this closed-economy case, the increase of labour supply resulting from the fundamental pension reform is only slightly higher if \( \xi = 1 \) (Cobb–Douglas utility), but is quite significantly lower if \( \xi = 0.6 \). As a result, the decrease in the rate of return to capital is much stronger for \( \xi = 0.6 \) than for the benchmark calibration of \( \xi = 0.8 \).

VI. CONCLUSIONS

We have presented a quantitative analysis of the effects of population ageing and pension reform on international capital markets, using several modifica-
Population ageing works through various mechanisms. First, demographic change alters the time path of aggregate savings within each country. Second, this process may be amplified when a pension reform, induced by the demographic change, shifts old-age provision from pure pay-as-you-go towards more pre-funding. Third, while the patterns of population ageing are similar in most countries, their timing and initial conditions differ substantially. Hence, to the extent that capital is internationally mobile, population ageing will induce capital flows between countries.

All three effects influence the rate of return to capital and interact with the demand for capital in production and with labour supply. Our simulations predict substantial capital flows resulting from population ageing. Population

Notes: These figures show projections of the differential effects of the fundamental pension reform on saving rates and rates of return for the endogenous and the exogenous labour supply models of Section V. F + G + I: France, Germany and Italy; REST EU: remaining countries of the European Union; USA + CAN: United States and Canada; REST OECD: remaining OECD countries.

Endogenous labour supply: the role of the intratemporal substitution elasticity. (a) Difference in labour supply: freezing versus pure PAYG. (b) Difference in rate of return: freezing versus pure PAYG.

Notes: These figures show projected differences in labour supply and the rate of return to capital between the freezing and pure PAYG scenarios under the assumption that capital mobility is restricted to the France–Germany–Italy region. Results are shown for alternative parameterizations of the intratemporal substitution elasticity between consumption and leisure, $\xi$.
ageing results in decreases in the capital–output ratio when the baby boomers decumulate their assets; international capital flows follow this trend. The countries most affected by ageing, such as those in the European Union, will initially be capital exporters, while countries less affected by ageing, such as the United States and other OECD regions, will import capital. This pattern will be reversed in about the year 2020, when baby boomers decumulate assets and the rapidly ageing economies thereby become capital import regions. Pension reforms with higher degrees of pre-funding are likely to induce the highest amount of capital exports. They will also increase labour supply considerably, while their effects on the rate of return to capital will be small. While the rate of return to capital declines in response to population ageing, there is no devastating ‘asset market meltdown’.

The timing of these adjustment processes is complex, and one has carefully to distinguish level effects from changes over time. In the initial year of our projections (2002), savings rates in the France–Germany–Italy region were substantially higher in the open-economy scenarios than under a closed-economy assumption. This is in line with higher rates of return in economies with a smaller proportion of older persons. Open economies are able to diversify a great deal of the demographic effects that depress savings and the rate of return to capital.

This level effect is superseded by the demographic changes during the 2002–2070 prediction window. Saving rates decrease until 2050 across all capital mobility scenarios, since the baby boom generation decumulates assets. Saving rates are projected to rebound after the year 2050. Since PAYG pension systems partially crowd out private savings, decreases of saving rates are stronger in the older regions. As a result, the decrease in the rate of return would be lower in these regions than in regions with less generous pension systems if these regions were closed economies. Diversification advantages of worldwide capital mobility thus decline, and saving rates respond accordingly. We should stress that population projections are reliable one generation ahead, while the projection error increases substantially thereafter. Consequently, results for the post-2030 period should be interpreted with care.

Finally, our paper shows the importance of the interplay between saving and labour supply adjustments in response to population ageing. Saving rates, rates of return and international capital flows react substantially less to demographic change once households absorb some part of the demographic shock by working more.

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NOTES

1. See Obstfeld and Rogoff (1996) and Coakley et al. (1998) for surveys of the literature.
2. An exception is Domeij and Floden (2006), who model pension systems but do not address pension reforms.
3. We are aware that in the long run neither fertility nor mortality is exogenous to economic growth. Migration reacts to international income differences also in the short run. The literature, however, has so far not provided robust estimates of the elasticities of demographic movements to economic circumstances suitable for inclusion in this OLG model. This is an important area for further research.
4. Both groups—newborns and immigrants—enter the economic model with zero assets. Furthermore, there are no skill differences between the two groups as analysed by, e.g. Razin and Sadka (1999) and Storesletten (2000).
5. This comes closest to the French system. Germany actually does not have an upper limit to earnings points, while the new entrants’ system in Italy has a notionally defined contribution system which gives credits to earnings according to a more complicated formula.
6. In the language of the World Bank, this second tier corresponds to the ‘third pillar’.
7. One might object to the counterfactual assumption of perfect annuity markets and the absence of explicitly defined accidental bequests. As we show in a detailed sensitivity analysis, allowing for accidental bequests and using alternative redistribution schemes turns out not to significantly alter our simulation results; see Börsch-Supan et al. (2004).
8. An additional equation of motion recursively describes the evolution of the marginal value of earning points: \( \frac{\partial V_{i,a,i}}{\partial l_{t,a,i}} \).
9. Our definition of equilibrium as sequential is consistent with our computational method. The equilibrium can be computed numerically since the model economy converges to a steady state and becomes a well behaved system with a small number of equations.
10. Throughout these accounting definitions, we made use of our simplifying assumption that all migration is concentrated at age \( a = 1 \). Since initial wealth is zero, we therefore do not have to account for transfers of assets resulting from migration.
11. Results are displayed through the year 2070 to show the main period of population ageing.
12. Population data for 1950–2050 are given at an annual frequency for five-year age groups. Further input data such as age-specific mortality rates, life expectancy and aggregate migration are given only quinquennially. We interpolate between age groups and time intervals and ‘backfit’ our population model to the UN population data for the time period 1950–2050.
13. Since there is no government consumption in our theoretical model, we define output as the difference between actual GDP and government consumption.
14. As shown in the working paper version of this paper (Börsch-Supan et al. 2004), this parsimonious parameterization of the consumption share parameters results in a decent fit of empirically observed labour supply profiles. As further discussed there, the model replicates the broad trends of international capital flows across regions.
15. We chose this capital mobility scenario as our benchmark scenario for two reasons. First, as noted in Section I, there is a broad consensus that capital is quite mobile among OECD countries, whereas this is much less clear for developing countries. Second, adding the additional countries of the region ‘Rest of the World’ does not affect patterns of aggregate variables much, because roughly 80% of world GDP is produced in the OECD and hence the additional weight of all other world regions is small in relative terms.
16. The total sum of pensioners (‘effective pensioners’) as used in this section is defined as the sum of actual pensioners weighted by their age-specific pension entitlements.
17. Labour supply is projected to increase also for other parameter constellations, see Section V below.

REFERENCES


