Global Demographic Change, Labour Force Growth and Economic Performance*

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Revised May 2006

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* Funding for the research described in this paper is from Australian Rural Industries Research and Development Corporation Research Contract No. ANU-51A and from Australian Research Council Discovery Grant No. DP0557889. Thanks are due to Heather Booth, Siew Ean Khoo and Ming Ming Chan for helpful discussions about the demography, to Jeff Davis, Brett Graham, Ron Duncan, Robert McDougall and Hom Pant for their constructive comments on the economic analysis and to Terrie Walmsley for technical assistance with the GTAP Database as well as useful discussions on the subject of base line simulations. Useful comments were also received at the *Conference on Global Economic Analysis* in June 2005 from Dominique van der Mensbrugghe and Nico van Leeuwen. Jahnvi Vedi and Jyoti Pant provided research assistance in the later stages of the study.

*A chapter based on this working paper is included in the forthcoming book *"Global Economic Analysis: Dynamic Modelling and Applications"* by Elena Ianchovichina, Robert McDougall and Terrie Walmsley.

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Abstract:

The fertility declines associated with the final phase of the global demographic transition have led to accelerated ageing of populations in developed countries and in several advanced developing countries. This paper introduces a global demographic sub-model, from which emerge the global implications of these changes for population sizes, age distributions and gender compositions. Corresponding changes are inferred in labour force size, and in patterns of consumption and saving and these are then analysed by incorporating the demographic sub-model into a correspondingly global economic model, based originally on GTAP-Dynamic, in which regional households are disaggregated by age group and gender. As an application of the combined model the effects of increased longevity are explored on a global scale. Growth in real per capita incomes is slowed by this change, average saving rates fall and the distribution of global economic activity alters to favour those regions with high aged labour force participation.

1. Introduction

Recent changes in global demographic behaviour, including to fertility, mortality, migration and the sex ratio at birth, have been considerable and many of these were not widely anticipated in recent decades. In most countries, consistent with the central phase of the global demographic transition, infant mortality fell through the course of the last century and adult life expectancy increased, causing a surge of population growth. The declines in birth rates anticipated as part of the final phase of this transition have been particularly sharp, first in developed countries and recently in many developing countries.[1] Before this century is half over, populations in Japan and some European countries are likely to be smaller than they were in 1990, with these declines in total populations being preceded by declines in the number and proportion of people of working age.[2]

The economic implications of these demographic trends and uncertainties are the subject of an already substantial global literature.[3] Recent macroeconomic studies of demographic change have been global in scope, emphasising the effects of ageing on average saving rates and financial flows (Bryant and McKibbin 1998, 2001; Faruqee and Muhleisen

[1] IMF (2004: Chapter 3), Lee (2003).
[2] Bryant and McKibbin (1998), United Nations Population Division (2003).
[3] At minimum, this literature spans demography (McDonald and Kippen 2001, Booth et al. 2002), population economics (Lee 2003; Mason 2003), public economics (OECD 1996, 1998), economic history (Bloom and Williamson 1997; Williamson 1998) and growth economics (Barro and Becker 1989).

2002; Bryant et al. 2003).[4] This work has clearly demonstrated the substantial implications of demographic change in some regions for economic performance in others. It has, however, fallen short of the complete demographic modelling needed to capture the three principal avenues through which demographic change influences economic performance: labour force growth[5], average saving rates and age-specific consumption variation.

This paper examines the economic implications of population change using a complete demographic model on 14 regions, which is constructed as integral with a dynamic model of the global economy. The latter model is a development of *GTAP-Dynamic* in which regional households are disaggregated by age group and gender.[6] Our explicit incorporation of the demographic sub-model allows age-gender distributions, migration flows and, therefore, labour force participation rates, migration rates, average saving rates and the age-gender effects on consumption to be endogenised. It is constructed around a base line projection through 2030 in which populations and labour forces are projected to decline in Europe and Japan, and to begin declining before the end of this period in China and elsewhere in East Asia. Notably, as age distributions change, the trends in labour forces are shown to diverge substantially from those in total populations. The behaviour of the model is then illustrated by considering the effects of one alternative demographic scenario. In this case, we imagine that continued improvements in public health and medical science cause life expectancy beyond 60 to grow faster than anticipated in all regions of the world. This scenario causes significant departures from the base line and has important implications for overall economic performance.

In models of the Solow-Swan type, where endogenous growth takes the form of physical capital accumulation, the decelerating population growth that is prominent in our base line projection reduces the GDP growth rate but raises that of real per capita income. Multiple trading regions notwithstanding, this tendency is prominent in our model, too. There are two complicating effects of population deceleration, however. Age distributions change so that the average age rises. This alters the pattern of international financial flows and the distribution of global investment. And, because consumption preferences vary with age, the pattern of consumption also changes. Finally, on the supply side, changes in the size and

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[4] Much of this research was organised under a project coordinated by the Brookings Institution in the United States and involving staff from the International Monetary Fund. Finance is from the Economic and Social Research Institute of the Japanese Cabinet Office.

[5] Capturing the demographic influences on labour force change requires consideration of age and gender-specific participation rates and rates of part time employment, as well as age and gender-specific migration rates.

[6] The *GTAP-Dynamic* model is a development of its comparative static progenitor, *GTAP* (Hertel et al. 1997). Its dynamics is described by Ianchovichina and McDougall (2000).

composition of the population correspondingly change the size and composition of the labour force, though as we show, these changes are most often far from proportionate. Increased longevity complicates this picture by accelerating the ageing process on the one hand but raising population and labour force growth on the other. While it raises aged dependency everywhere, it tends to attract new investment to those regions whose elderly have high labour force participation rates.

In Section 2, the demographic sub-model is introduced and its population and labour force projections are briefly discussed. The extension of the *GTAP-Dynamic* model, to incorporate populations disaggregated by age and gender and then the full demographic sub-model, is then described. Section 3 discusses the construction of the base line scenario. The "accelerated ageing" scenario is described in Section 4 and the implications for the performance of the global economy are quantified through a comparison of its simulation results with the baseline. Section 5 offers brief concluding remarks.

2. Modelling Global Demographic Change

The approach adopted follows Tyers et al. (2005), in that it applies a complete demographic sub-model that is integrated within a dynamic numerical model of the global economy.[7] The economic model is a development of *GTAP-Dynamic*, the standard version of which has single households in each region and therefore no demographic structure.[8] The version used has regional households that are disaggregated by age group, gender and skill level.

2.1 Demography:

The demographic sub-model tracks populations in four age groups and two genders: a total of 8 population groups in each of 14 regions.[9] The four age groups are the dependent young, adults of fertile and working age, older working adults and the mostly-retired over 60s. The resulting age-gender structure is displayed in Figure 1. The population is further divided between households that provide production labour and those providing professional

[7] See also Shi and Tyers (2004) and Tyers et al. (2005).
[8] The *GTAP-Dynamic* model is a development of its comparative static progenitor, *GTAP* (Hertel et al. 1997). Its dynamics is described by Ianchovichina and McDougall (2000). Earlier applications of the standard model to the issues raised in this paper include those by Shi and Tyers (2004) and Duncan, Shi and Tyers (2005).
[9] The demographic sub-model has been used in stand alone mode for the analysis of trends in dependency ratios. For a more complete documentation of the sub-model, see Chan and Tyers (2006).

labour.[10] Each age-gender-skill group is a homogeneous sub-population with group-specific birth and death rates and rates of both immigration and emigration.[11] If the group spans *T* years, the survival rate to the next age group is the fraction *1/T* of its population, after group-specific deaths have been removed and its population has been adjusted for net migration.

The final age group (60+) has duration equal to measured life expectancy at 60, which varies across genders and regions. The key demographic parameters, then, are birth rates, sex ratios at birth, age and gender specific death, immigration and emigration rates and life expectancies at 60.[12] A further key parameter is the rate at which each region's education and social development structure transforms production worker families into professional worker families. Each year a particular proportion of the population in each production worker age-gender group is transferred to professional status. These proportions depend on the regions' levels of development, the associated capacities of their education systems and the relative sizes of the production and professional labour groups.

In any year, for each age group, *a*, gender group *g*, skill group *s*, region of origin, *r* and region of destination, *d*, the volume of migration flow is:

$$M^t_{a,g,s,r,d} = d^t_d M^R_{a,g,s,r,d} N^t_{a,g,s,d}, \quad \forall a,g,r,d \quad (1)$$

where d^t_d is a destination-specific factor reflecting immigration policy in region *d*, set to unity in all but counterfactual experiments, M^R_{agsrd} is the migration rate between *r* and *d* expressed as a proportion of the group population in region *d*, N_{agsd}.

Given the migration matrix, M_{agsrd}, the population in each age, gender and skill group and region can be constructed. We begin with the population of males aged 0-14 from professional families in region *d* (*a=014, g=m, s=sk, r=d*).

$$\begin{aligned} N^t_{014,m,sk,d} &= N^{t-1}_{014,m,sk,d} + \frac{S^t_d}{1+S^t_d} B^t_{sk,d} N^{t-1}_{1539,f,sk,d} \\ &- D^t_{014,m,sk,d} N^{t-1}_{014,m,sk,d} + \sum_r M^t_{014,m,sk,r,d} - \sum_r M^t_{014,m,sk,d,r} \\ &+ r_d N^{t-1}_{014,m,unsk,d} - \frac{1}{15}\left[N^{t-1}_{014,m,sk,d} - D^t_{014,m,sk,d} N^{t-1}_{014,m,sk,d} \right], \quad \forall d \end{aligned} \quad (2)$$

[10] The subdivision between production and professional labour accords with the ILO's occupation-based classification and is consistent with the labour division adopted in the GTAP Database. See Liu et al. (1998).

[11] Mothers in families providing production labour are assumed to produce children that will grow up to also provide production labour, while the children of mothers in professional families are correspondingly assumed to become professional workers.

[12] Immigration and emigration are also age and gender specific. The model represents a full matrix of global migration flows for each age and gender group. Each of these flows is currently set at a constant proportion of the population of its destination group. See Chan and Tyers (2006) and Vedi (2005) for further details.

where S_d^t is the sex ratio at birth (the ratio of male to female births) in region *d*, B_d^t is the birth rate, $D_{014,m,d}^t$ the death rate and r_d is the rate at which region *d*'s educational institutions and general development transform production into professional worker families. The final term is survival to the corresponding 15-39 age group. In the corresponding equation for young males from production worker families the penultimate term is negative.

For females in professional families in this age group the corresponding equation is:

$$
\begin{aligned}
N_{014,f,sk,d}^t = {} & N_{014,f,sk,d}^{t-1} + \frac{1}{1+S_d^t} B_{sk,d}^t N_{1539,f,sk,d}^{t-1} \\
& - D_{014,f,sk,d}^t N_{014,f,sk,d}^{t-1} + \sum\nolimits_r M_{014,f,sk,r,d}^t - \sum\nolimits_r M_{014,f,sk,d,r}^t \\
& + r_d N_{014,f,unsk,d}^{t-1} - \frac{1}{15}\left[N_{014,f,sk,d}^{t-1} - D_{014,f,sk,d}^t N_{014,f,sk,d}^{t-1} \right], \quad \forall d
\end{aligned}
\tag{3}
$$

For adults of gender *g* from professional families in the age group 15-39 the equation includes a survival term from the younger age group. It is:

$$
\begin{aligned}
N_{1539,g,sk,d}^t = {} & N_{1539,g,sk,d}^{t-1} + \frac{1}{15}\left[N_{014,g,sk,d}^{t-1} - D_{014,g,sk,d}^t N_{014,g,sk,d}^{t-1} \right] \\
& - D_{1539,g,sk,d}^t N_{1539,g,sk,d}^{t-1} + \sum\nolimits_r M_{1539,g,sk,r,d}^t - \sum\nolimits_r M_{1539,g,sk,d,r}^t \\
& + r_d N_{1539,g,unsk,d}^{t-1} - \frac{1}{25}\left[N_{1539,g,sk,d}^{t-1} - D_{1539,g,sk,d}^t N_{1539,g,sk,d}^{t-1} \right], \quad \forall g,d
\end{aligned}
\tag{4}
$$

where the second term is the surviving inflow from the 0-14 age group and the final term is the surviving outflow to the 40-59 age group. Again, the skill transformation term is negative in the case of the corresponding equation for production worker families. The population of professional adults of gender *g*, in age group 40-59 follows as:

$$
\begin{aligned}
N_{4059,g,sk,d}^t = {} & N_{4059,g,sk,d}^{t-1} + \frac{1}{25}\left[N_{1539,g,sk,d}^{t-1} - D_{1539,g,sk,d}^t N_{1539,g,sk,d}^{t-1} \right] \\
& - D_{4059,g,sk,d}^t N_{4059,g,sk,d}^{t-1} + \sum\nolimits_r M_{4059,g,sk,r,d}^t - \sum\nolimits_r M_{4059,g,sk,d,r}^t \\
& + r_d N_{4059,g,unsk,d}^{t-1} - \frac{1}{20}\left[N_{4059,g,sk,d}^{t-1} - D_{4059,g,sk,d}^t N_{4059,g,sk,d}^{t-1} \right], \quad \forall g,d
\end{aligned}
\tag{5}
$$

For adults in the 60+ age group, the corresponding relationship is:

$$
\begin{aligned}
N_{60+,g,sk,d}^t = {} & N_{60+,g,sk,d}^{t-1} + \frac{1}{20}\left[N_{4059,g,sk,d}^{t-1} - D_{4059,g,sk,d}^t N_{4059,g,sk,d}^{t-1} \right] \\
& + \sum\nolimits_r M_{60+,g,sk,r,d}^t - \sum\nolimits_r M_{60+,g,sk,d,r}^t \\
& + r_d N_{60+,g,unsk,d}^{t-1} - \frac{1}{L_{60+,g,sk,d}^t} N_{60+,g,sk,d}^{t-1}, \quad \forall g,d
\end{aligned}
\tag{6}
$$

where the final term indicates that deaths from this group each year depend on its life expectancy at 60, $L^t_{60+,g,sk,d}$. Again, the equation for aged production worker family members is the same except that the skill transformation term is negative.

Sources and structure:

Key parameters in the model are the migration rates, $M^R_{a,g,s,r,d}$, birth rates, $B^t_{s,r}$, sex ratios at birth, S^t_r, death rates, $D^t_{a,g,s,r}$, life expectancies at 60, $L^t_{60+,g,s,r}$ and the skill transformation rates r_d. The migration ***rates*** are based on recent migration records and are held constant through time.[13] The skill transformation rates are based on changes during the decade prior to the base year, 1997, in the composition of aggregate regional labour forces as between production and professional workers. These are also held constant through time.[14]

Asymptotic trends in other parameters:

The birth rates, life expectancy at 60 and the age specific mortality rates all trend through time asymptotically. For each age group, *a*, gender group, *g*, and region, *r*, a target rate is identified.[15] The parameters then approach these target rates with initial growth rates determined by historical observation. In year *t* the birth rate of region *r* is:

(7) $$B_r^t = B_r^0 + \left(B_{Tgt}^0 - B_r^0\right)\left(1 - e^{bt}\right) ,$$

where the rate of approach, *β*, is calibrated from the historical growth rate:

(8) $$\hat{B}_r^0 = \frac{B_r^1 - B_r^0}{P_r^0} = \frac{\left(B_{Tgt}^0 - B_r^0\right)\left(1 - e^{b}\right)}{B_r^0}, \text{ so that}$$

(9) $$b = \ln\left[1 - \frac{B_r^0 \hat{P}_r^0}{B_{Tgt}^0 - B_r^0}\right] .$$

The birth rates and death rates, thus calculated, are summarised in Tables 1 and 2. The corresponding life expectancies at 60 are listed in Table 3.

[13] The migration rates and the corresponding birth rates are listed in detail in Chan and Tyers (2006: Tables 2-5) and Vedi (2005).
[14] Note that, as regions become more advanced and populations in the production worker families become comparatively small, the skill transformation rate has a diminishing effect on the professional population.
[15] In this discussion the skill index, s, is omitted because birth and death rates, and life expectancies at 60 do not vary by skill category in the version of the model used.

Labour force projections:

To evaluate the number of "full-time equivalent" workers we first construct labour force participation rates, $P_{a,g,r}$ by gender and age group for each region from ILO statistics on the "economically active population". We then investigate the proportion of workers that are part time and the hours they work relative to each regional standard for full time work. The result is the number of full time equivalents per worker, $F_{a,g,r}$. The labour force in region $\boldsymbol{r}$ is then:

$$(7) \qquad \overline{L}_r^t = \sum_{a=1539}^{60+} \sum_{g=m}^{f} \sum_{s=sk}^{unsk} L_{a,g,s,r}^t \quad \text{where} \quad L_{a,g,s,r}^t = m_{a,r}^t P_{a,g,r}^t F_{a,g,r} N_{a,g,s,r}^t \ .$$

Here $m_{a,r}^t$ is a shift parameter reflecting the influence of policy on participation rates. The time superscript on $P_{a,g,r}^t$ refers to the extrapolation of observed trends in these parameters.[16]

Asymptotic trends in labour force participation:

For each age group, a, gender group, g, and region, r, a target country is identified whose participation rate is approached asymptotically. The rate of this approach is determined by the initial rate of change. Thus, the participation rate takes the form:

$$(8) \qquad P_{a,g,r}^t = P_{a,g,r}^0 + \left(P_{Tgt}^0 - P_{a,g,r}^0\right)\left(1 - e^{b\,t}\right) \ ,$$

where the rate of approach, β, is calibrated from the initial participation growth rate:

$$(9) \qquad \hat{P}_{a,g,r}^0 = \frac{P_{a,g,r}^1 - P_{a,g,r}^0}{P_{a,g,r}^0} = \frac{\left(P_{Tgt}^0 - P_{a,g,r}^0\right)\left(1 - e^{b}\right)}{P_{a,g,r}^0} \text{, so that}$$

$$(10) \qquad b = \ln\left[1 - \frac{P_{a,g,r}^0 \hat{P}_{a,g,r}^0}{P_{Tgt}^0 - P_{a,g,r}^0}\right] \ .$$

Target rates are chosen from countries considered "advanced" in terms of trends in participation rates. Where female participation rates are rising, therefore, Norway provides a commonly chosen target because its female labour force participation rates are higher than for other countries.[17]

Accounting for part time work:

For each age group, a, gender, g, and region, r, full-time equivalency depends on the fraction of participants working full time, $f_{a,g,r}$, and, for those working part time, the ratio of

[16] Although part time hours may well also be trending through time, we hold F constant in the current version of the model.

[17] The resulting participation rates are listed by Chan and Tyers (2005: Table 10).

average part time hours to full time hours for that gender group and region, $r_{g,r}$. For each group, the ratio of full time equivalent workers to total labour force participants is then

(11) $$F_{a,g,r} = f_{a,g,r} + \left(1 - f_{a,g,r}\right) r_{g,r} .$$

Preliminary estimates of $f_{a,g,r}$ and $r_{g,r}$ are approximated from OECD (1999: Table 1.A.4) and OECD (2002: Statistical Annex, Table F).[18]

The aged dependency ratio:

We define and calculate four dependency ratios: 1) a youth dependency ratio is the number of children per full time equivalent worker, 2) an aged dependency ratio is the number of persons over 60 per full time equivalent worker, 3) a non-working aged dependency ratio is the number of non-working persons over 60 per full time equivalent worker, and 4) a more general dependency ratio is defined that takes as its numerator the total non-working population, including children.[19] That of used here is the one of most widespread policy interest, the non-working aged dependency ratio:

(12) $$R_{r,t}^{ANW} = \frac{\sum_{g=m}^{f} \sum_{s=sk}^{unsk} \left(N_{60+,g,sk,r}^{t} - L_{60+,g,sk,r}^{t} \right)}{\bar{L}_{r}^{t}} .$$

2.2 The Global Economic Model

GTAP-Dynamic is a multi-region, multi-product dynamic simulation model of the world economy. It is a microeconomic model, in that assets and money are not represented and prices are set relative to a global numeraire. In the version used, the world is subdivided into 14 regions, one of which is China. Industries are aggregated into just three sectors, food (including processed foods), industry (mining and manufacturing) and services. To reflect composition differences between regions, these products are differentiated by region of origin. This means that the "food" produced in one region is not the same as that produced in others. Consumers substitute imperfectly between foods and other products from different regions. A consequence of this is that, even without border distortions, the time paths of the prices of food in different regions can diverge, depending on regional differences in overall economic performance and the elasticity of substitution in consumption between the different regional foods.

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[18] No data has yet been sought on part time work in non-OECD member countries. In these cases the diversity of OECD estimates is used to draw parallels between countries and regions and thus to make educated guesses. The results are listed by Chan and Tyers (2006: Tables 11 and 12).

[19] All these dependency ratios are defined in detail by Chan and Tyers (2006).

As in other dynamic models of the global economy, in *GTAP-Dynamic* the endogenous component of simulated economic growth is due to physical capital accumulation. Technical change is introduced in the form of exogenous trends. A consequence of this is that it exhibits the property of dynamic models of the Solow-Swan type, namely that an increase in the growth rate of the population raises the growth rate of real GDP but reduces the level of real per capita income. Compared with other economy-wide models, however, the standard version of *GTAP-Dynamic* has a number of idiosyncrasies.

First, it has recursive multi-regional dynamics. Unlike the McKibbin models[20] it incorporates no forward-looking agents. Instead, investors have adaptive expectations about the real net rates of return on installed capital in each region. These drive the distribution of investment across regions. In each, the level of investment is determined by a comparison of net rates of return with borrowing rates yielded by a global trust to which each region's saving contributes. The analytical details, and the empirical testing, of the investment system are provided elsewhere.[21]

Second, the base period equilibrium is not usually a steady state and there are no restrictions on the steady states ultimately reached following shocks or even that the simulations should eventually yield steady states. All regional households consume within their budget constraints, and hence all inter-regional payments always balance. Yet, should a region's savings fall relative to its investment, the gap between them is financed by foreign savings and this can cause secular trends in current account balances. Finally, the process of physical capital accumulation is region-wide and not sector-specific. This requires the assumption that physical capital is perfectly mobile between industries in the very short run.[22]

To capture the full effects of demographic change, including those of ageing, the standard model has been modified to include multiple age, gender and skill groups in line with the structure of the demographic sub-model. In the adapted model, these 16 groups differ in their consumption preferences, saving rates and their labour supply behaviour. Unlike the standard *GTAP* models, in which regional incomes are split between private consumption, government consumption and total saving via an upper level Cobb-Douglas utility function that implies fixed regional saving rates, this adaptation first divides regional

[20] See, for example, Bryant and McKibbin (2001) and Batini et al. (2006).
[21] See Ianchovichina and McDougall (2000) and Gollub (2005).
[22] Most global dynamic models make this assumption. An exception at the regional level is Australia's MONASH model (Dixon and Rimmer 2002). This model has very substantial sectoral detail and physical capital accumulation is sector-specific. As yet, this behaviour has not been given global scope.

incomes between government consumption and total private disposable income. The implicit assumption is that governments balance their budgets while private groups save or borrow.

Private disposable income is then split between the eight age-gender groups in a manner informed by empirical studies of age and gender specific consumption behaviour. For each age-gender group we then use a Keynesian consumption equation to split disposable income between saving and consumption expenditure. Group private saving rates then become endogenous, depending on real disposable income and the real interest rate, thereby relaxing the fixed average saving rate assumption in the standard model. Once group consumption expenditures are known, the standard *GTAP* CDE[23] consumption preferences are applied to each, with preference parameters varying to reflect age-gender differences in tastes. Finally, consumption volumes are totalled across groups to obtain final demand for each product and consumption expenditures are subtracted from group disposable incomes to obtain group saving levels, which are then totalled across groups to obtain regional saving.

Income Splitting:

The first step is to split government from private disposable income. For this we retain the original Cobb-Douglas system, this time in a two-way split, and the governments' income shares from the original database.[24] Total regional disposable income is then split between the eight age-gender groups. For this we draw from other studies the distribution of disposable income between age-gender groups for "typical" advanced and developing countries. To ensure that changes in the age-gender distribution of each region's population alter the corresponding age-gender distribution of income, we define a set of weights, $W_{a,g,r}$, that represent the ratio of the per capita disposable income of group (*a*, *g*), to that of the (15-39, *m*) group, chosen as an arbitrary standard.[25] The share of the disposable income of region ***r*** enjoyed by people of gender ***g***, and age group ***a*** is thus:

$$\text{(13)} \qquad \frac{Y^D_{a,g,r}}{Y^D_r} = \frac{W_{a,g,r} N_{a,g,r}}{\sum_{a=0-15}^{60+} \sum_{g=m}^{f} W_{a,g,r} N_{a,g,r}} \ .$$

[23] This refers to the "constant difference of elasticities of substitution" demand system. See Hertel et al. (1997) and, in particular, Huff et al. (1997).

[24] This implies the assumption that all governments balance their budgets and that all saving in the original database is private.

[25] To date we have not realised the opportunity to have the age-gender distribution of income depend on the income's factor origin. Despite intuition suggesting a link, such as that the aged in advanced countries receive retirement income stemming from capital ownership, consistent empirical work on this distribution is unavailable.

The adopted values of $W_{a,g,r}$ are listed in Table 4. Their selection is guided by the empirical studies of the age distribution of income and consumption noted in the table.

Splitting savings and consumption expenditure from group disposable income:

Our reduced form approach to the intertemporal optimisation problem faced by each individual centres on an exponential consumption equation that links group per capita consumption expenditure to per capita disposable income and the real interest rate, *r*:

$$(14)\qquad c_{a,g,r} = \frac{C_{a,g,r}}{N_{a,g,r}P^{C}_{a,g,r}} = A\left(\frac{Y^{D}_{a,g,r}}{N_{a,g,r}P^{C}_{a,g,r}}\right)^{e_c} r_r^{e_r} \ ,$$

where $P^{C}_{a,g,r}$ is a group consumption price index, group consumption expenditure is $C_{a,g,r}$ and parameters e_c and e_r are income and interest elasticities. This equation is calibrated for each group and region based on the set of initial (1997) age-specific saving rates from per capita real disposable income listed in Table 5. These estimates are drawn from the same empirical studies of the age distribution of income and consumption as the income weights of Table 4. They are recalibrated for consistency with the overall private saving rate in each region indicated in the GTAP database.[26]

Consumption preferences:

The construction of the CDE demand system requires the calibration of two sets of parameters by the method detailed by Huff et al. (1997). Its advantage over the CES, or constant elasticity of substitution, system is that it is non-homothetic and therefore allows income elasticities of demand to vary between commodities. Elasticities of demand then

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[26] The elasticities of consumption expenditure to disposable income suggested by the empirical literature seem to be poor choices as reduced forms for saving behaviour in the long term since they imply high marginal saving rates. We calibrate these elasticities according to the following scenario: (a) North American per capita disposable income grows at 3%/yr for 100 years, (b) growth in all other regions is sufficient to attain North America's per capita disposable income levels within that period, (c) when the other regions catch up, all regions attain identical group-specific saving rates, and (d) the income, consumption and saving transitions are smooth and exponential. Our reduced form consumption equation (14) can be simplified for a single age-gender group to: $c = A\,y^{e_c} r^{e_r}$, where *c* is per capita consumption expenditure, *y* is per capita disposable income and *r* is the real interest rate. To focus on the key elasticity, e_c, imagine that the real interest rate is constant through time, so that the interest term can be embedded in the constant. Then, if per capita disposable income grows at rate, g_y, the rate of growth of consumption expenditure is $e_c\,g_y$. And, if per capita consumption expenditure is initially c_0 and per capita disposable income is initially y_0,we can calculate the group's average saving rate in period *t* and invert the resulting expression to find the elasticity that is consistent with the target saving rate after *T* years: $e_c = 1 + \frac{1}{g_y T}\ln\left(\frac{1-s_T}{1-s_0}\right)$. For further detail, see Tyers et al. (2005).

depend on CDE "expansion" and "substitution" parameters, which are calibrated for each region's aggregate household in the GTAP Database. We retain the calibrated values of these parameters for the eight age-gender groups. To complete the demand system we then need expenditure shares for each of the eight different age-gender groups in each region.

For these shares we turn, once again, to the consumption analysis literature. Studies of consumption preferences by age group are available for a few of the identified countries and those are used as a guide in the construction of the complete matrix of expenditure shares listed in Table 6. That by Weber et al. (2002) is the most detailed and it shows only very modest variation in expenditure shares by age group when commodities are highly aggregated. Although there is considerable variation when comparisons are at a high level of detail, such as between fresh food and restaurant meals or between health and other services, the broad shares are remarkably similar.[27] For presentational economy, we focus in this paper on the three product version.[28] Age-gender group expenditure shares are drawn initially from the literature indicated in Table 6, then rendered consistent with group expenditures on the one hand and *GTAP* Database values for aggregate expenditure shares on the other by using RAS techniques to concord the shares with row and column sums in the matrix of expenditures.

Elasticities of substitution:

It is well known that general equilibrium simulation results are particularly sensitive to the assumed degree of differentiation between home and foreign goods and services. In models such as this one, where products are highly aggregated, some of this differentiation reflects regional differences in sectoral product composition. Both the complementarity of product compositions and true regional product differentiation are therefore represented in the model via the choice of the elasticities of substitution between home and foreign products. Controversy has raged over the merits of various estimates and the view is commonly expressed that the "standard" GTAP estimates, which range between 1.0 and 4.0, are too small. We concur with this view since, when these elasticities are used, our base line simulation yields substantial divergence between the paths of home and trading prices in different regions. In the absence of any new trade distortions, global markets appear far more

[27] It is of concern that some expenditure shares for detailed products and services appear to be changing very rapidly through time. Weber et al. show that the health share is rising rapidly for the aged and that this is associated with very rapid growth in the share of expenditure on drugs by all groups but particularly the aged.
[28] The *GTAP* commodity classification is production-oriented, based on the International Standard Industrial Classification (ISIC), and so it differs from the classification used in expenditure surveys. We use the *GTAP* commodities throughout, weakening the sensitivity of our analysis to differences in preferences.

segmented in 2030 than they are at present. Newer estimates by Harrigan (1995), Trefler and Lai (1999) and Obstfeld and Rogoff (2000) all support much higher values. We therefore use 7.0 for food products, 4.0 for manufactures and 2.2 for the less tradeable services, and we retain the traditional "rule of two" for substitutability of imports by region of origin.

3. Constructing the Base Line Scenario

The base line scenario represents a "best judgement" projection of the global economy through 2030. Although policy analysis can be sensitive to the content of this scenario, our focus is on the extent of departures from it that would be caused by changes in demographic scenarios. Nonetheless, it is instructive to describe the base line for two reasons. First, all scenarios examined have in common a set of assumptions about future trends in productivity and, second, some exposition of the base line makes the construction of departures from it clearer.

Exogenous factor productivity growth

Exogenous sources of growth enter the model as factor productivity growth shocks, applied separately for each of the model's five factors of production (land, physical capital, natural resources, production labour and professional labour). Simulated growth rates are very sensitive to productivity growth rates since, the larger these are for a particular region, the larger is that region's marginal product of capital. The region therefore enjoys higher levels of investment and hence a double boost to its per capita real income growth rate. The importance of productivity notwithstanding, the empirical literature is inconsistent as to whether productivity growth has been faster in agriculture or in manufacturing and whether the gains in any sector have enhanced all primary factors or merely production labour. The single set of factor productivity growth rates assumed in all scenarios are drawn from a new survey of the relevant literature (Tyers et al. 2005). Agricultural productivity grows more rapidly than that in the other sectors in China, Australia, Indonesia, Other East Asia, India and Other South Asia. This is due to continued increases in labour productivity in agriculture and the associated shedding of labour to the other sectors. In the other industrialised regions, the process of labour relocation has slowed down and labour productivity growth is slower in agriculture. In the other developing regions, the relocation of workers from agriculture has tended not to be so rapid.

Investment interest premia

Aside from exogenous productivity growth, a key aspect of the base line projection is the allocation of investment across regions. The model takes no explicit account of investment risk and the segmented capital markets that are prevalent in developing countries and so tends to allocate investment to regions that have high marginal products of physical capital. These tend to be labour-abundant developing countries whose labour forces are still expanding rapidly, yet we know that capital market underdevelopment, capital controls and risk considerations limit the flow of foreign investment into these regions at present and that these considerations are likely to remain important in the future.

To account for this we have constructed a "pre-base line" simulation in which we maintain the relative growth rates of investment across regions. In this simulation, global investment rises and falls but its allocation between regions is thus controlled. To do this an interest premium variable (*GTAP Dynamic* variable *SDRORT*) is made endogenous. This creates wedges between the international and regional interest rates the scale of which is indicated in Figure 2. They show high premia for the populous developing regions of Sub-Saharan Africa, the Middle East and North Africa and India. Premia tend to fall in regions where labour forces are falling or growing more slowly, such as Japan, and the East Asian regions. Most spectacular is the secular fall in the Chinese premium. This is because investment growth is maintained in China despite the eventual decline in its labour force.[29] The final base line simulation then frees up investment. It and the subsequent simulations not only maintain endogenous investment but to do this they have the time paths of the regional interest premia set as exogenous to the levels indicated in the figure.

The base line population projection:

Notwithstanding their dependence on a comparatively simple four age group demographic model, regional population levels and age structures follow closely corresponding United Nations projections.[30] Base line projections of labour force levels and age structures are summarised in Table 7, which shows substantial ageing of labour forces in all regions. Indeed, the extent of the widespread ageing is especially clear from the trends in non-working aged dependency ratios listed in Table 8. Western Europe, Australia and Japan are the regions with the "oldest" population by 2030, in terms of the aged dependency ratio.

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[29] A possible consequence of this is that our base line investment in China, and therefore China's projected economic growth rate, is optimistic. A more detailed study of this issue is offered by Tyers and Golley (2006).

[30] See United Nations (2003) and the detailed comparison provided in Chan and Tyers (2005).

China's dependency ratio is the highest among the developing economies. In particular, it rises fairly rapidly during this period, suggesting a significant demographic transition for the economy. Finally, base line projections of total populations and labour forces for a selection of regions are displayed in Figure 3. These illustrate divergences in the growth paths of populations and labour forces that are important for economic performance. Particularly noteworthy are the declines in the labour forces of Japan, Western Europe and China, all of which precede their associated population declines as their populations age.

The base line economic projection

Overall base line economic performance is suggested by Table 9, which lists the projected increments to regional real per capita incomes by 2030. In part because of its comparatively young population and hence its continuing rapid labour force growth, India attracts substantial new investment and is projected to take over from China as the world's most rapidly expanding region. This investment, combined with exogenous factor productivity growth, ensures that India is also projected to deliver the largest improvement in its real per capita income through 2030. China's growth is slower in aggregate, because of its declining labour force, but its declining interest premium maintains a high level of investment growth sufficient to deliver the second largest proportional change in real per capita income. Indonesia and "other East Asia" are also strong performers, while the older industrial economies continue to grow more slowly. The African regions enjoy good GDP growth performance but their high population growth rates limit their performance in per capita terms.

As noted in the previous section, *GTAP-Dynamic* is a recursive model that is not forced to converge on any particular steady state. A consequence of this is that it is possible for the inter-regional distribution of asset ownership to change so as to cause current account deficits to widen relative to GDP. Some imbalances do widen, though the deficits and surpluses expand more slowly than the trend of the past two decades. Most notable are expanding deficits in Japan and China, whose ageing populations reduce saving through time and the deficits are required to finance continued investment. North American trends toward widening trade surplus though this belies comparatively large changes in the net factor income component of its current account, which actually goes into deficit, so that North America's overall current account deficit does not diverge significantly. Net factor income flows are less significant for the other regions.

Finally, the product composition of global output in the base line projection is suggested by Figure 4. Engel's Law drives increased resources into the industrial and services sectors relative to the food and agricultural sector. This emerges despite a relative increase in food prices, however, also shown in the figure. This result is not without controversy. Ever since the work of Lewis (1952), a measured trend toward declining prices of food commodities relative to traded manufactures has been prominent in the commodity trade literature. Grilli and Yang (1988) confirmed and updated the trend identified by Lewis, indicating a decline in relative commodity prices of half a per cent per year. This work was flawed, however, by its lack of consideration of improvements in the quality of manufactures over time. Lipsey (1994), after adjusting for quality changes, found that primary commodity prices actually ***increased*** by half a per cent per year in the last half of the 20th century. Our base line simulation reflects this result. It is worth recalling, however, that the purpose of the base line is to provide a non-controversial reference against which to compare the alternative scenario with different demographic behaviour. Our emphasis will therefore be on the departures of the alternative scenario from the base line.

4. The Impact of Accelerated Population Aging

The analysis to be presented is centred on the base line projection of populations, labour forces and their structures described in the previous section. This base line is compared with an alternative scenario that is identical in all respects except that ageing is accelerated in all regions via increases in the life expectancy at 60. In particular, life expectancies at 60 grow faster than in the base line case, by two per cent per year. This alternative "accelerated ageing" scenario is prompted by the conjecture of Booth (2004) that the standard demographic projections tend to ignore many new and potential developments in health science, which makes them pessimistic about future longevity.[31]

The effect of this is to raise the aged population in every region, while leaving younger populations the same as in the base line. This has two key implications. First, it raises projected overall populations so that it raises aggregate demand and second, to the extent that the aged continue to work it raises labour forces and so also bolsters the supply side. Because the departure from the base line only affects the aged population in each

[31] An alternative approach to the measurement of the effects of ageing is to compare the base line, which embodies projected changes in age distributions, with a hypothetical scenario in which aggregate populations grow at the same rates by age distributions do not change. This approach is adopted in Tyers and Shi (2006).

region, it also causes non-working aged dependency ratios to rise in all regions.[32] These demographic and labour supply effects are summarised in Table 10.

The absolute increase of each region's population and labour force depends upon the demographic structure of its population in the base year and the aged labour force participation rate at the time. As shown in Figure 5, Japan enjoys the largest labour force increase. This is because Japan began with the largest aged share of its population and also the largest aged labour force participation rate.[33] Because of its comparatively large aged population, Western Europe also enjoys substantially higher labour force growth. Amongst the regions at the other extreme is China, which has a proportionally smaller aged population and, compared with all the other regions, smaller aged labour force participation rates.[34]

The economic implications of accelerated ageing stem not only from the expanded consumption demand on the one hand and the larger labour forces on the other. In North America, Western Europe, Central Europe and the former Soviet Union and Australia, accelerated ageing raises the share of income in the hands of the over 60s, who tend to have negative saving rates. In these regions, therefore, average saving rates decline, as is also shown in Figure 5. Indeed, the savings effects of this demographic change is so significant that real savings in most regions fall, despite an increase in real GDP and hence real income of the private households. Capital returns are raised by the population driven demand increases and the expanded labour supplies, yet real financing costs also rise since proportionally less is saved worldwide. The net effect is slower growth in global investment, with the level achieved in 2030 emerging lower by more than 3 per cent, compared to the baseline.

The global investment slow-down notwithstanding, GDP tends to increase everywhere due to faster-growing albeit aged labour forces (Table 11). The gains are not evenly distributed, however. Regions with most labour force expansion, and particularly Japan, enjoy higher capital returns relative to other regions. This raises their shares of global investment compared to that in the base line projection, particularly later in the simulation,

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[32] Our modelling to date ignores the fiscal implications of this change since governments are modelled as maintaining patterns of expenditure that do not depend on the age distributions of populations. Moreover, governments balance their budgets in all simulations. To capture fiscal implications it will be necessary to separate out such sectors as health and retirement services on the one hand and educational services on the other.
[33] Almost half of Japan's men aged 60+ are in the labour force. This is substantially higher than for other industrialized regions, though retirement is not a luxury enjoyed in most of the developing world. A full listing of participation rates is provided by Chan and Tyers (2006).
[34] In China, formal retirement was a tradition in the state-owned enterprises that dominated the economy until recently. Recorded aged labour force participation rates actually declined during the 1990s. With the rise in private sector employment, however, it is expected that aged labour force participation rates will rise, rather than fall, as is assumed in the analysis presented.

and hence it accelerates their GDP growth (Figure 6). This investment is reassigned mainly from China where investment falls by more than 8 per cent by 2030, and from Australia where investment falls close to 3 per cent. In both regions, labour forces are boosted the least because their aged populations have lower labour force participation rates.

The redistribution of investment expands the mismatch between the location of physical capita and its ownership, causing a corresponding divergence between GDP and GNP growth. The regions that expand more rapidly as a consequence of the accelerated ageing tend also to be those with slower saving growth and so these regions experience outflows of factor income on their current accounts. When this is combined with the tendency, due to diminishing returns, for labour expansions to reduce per capita income, declines in real per capita GNP are observed in all regions (Figure 7 and Table 11).

Turning, finally, to the effects on the global product mix, as Table 6 demonstrates when the array of products and services is aggregated into just three groups the differences between the consumption preferences of the old and the young are not substantial. Overall, the effect of accelerated ageing is to raise the production of food and agricultural products relative to the others and that of services relative to industrial products (Figure 7). The rise in food production is due primarily to the declines in per capita incomes and Engel's Law, while the relative rise in services production does appear to be a response to ageing preferences. Supply side effects, via declines in real wages (Table 11), advantage comparatively labour-intensive manufacturing, but these seem insufficient for the change in manufacturing output to outpace that in services.

5. Conclusion

Global population and labour force changes that are already built into regional age distributions will cause the populations in several key regions, including Western Europe, Japan and China, to decline in the near future and their labour forces to decline sooner and more dramatically. Associated with these changes will be the ageing of the populations in all regions. This will not only affect their economic performance but also the regional distribution of global investment and saving, and hence capital account flows, as well as regional production costs, comparative advantage and therefore the pattern of global trade.

To address these issues, standard *GTAP-Dynamic* is modified to accommodate eight age-gender groups within each regional household. A full demographic sub-model is then incorporated and a base line projection constructed through 2030. To illustrate the use of this model in the analysis of demographic change an alternative scenario is constructed in which advances in health science cause life expectancies at 60 to rise more quickly in all regions. This accelerates the ageing of all populations and, because the aged also contribute to the labour force, there is a relative expansion in global labour supply. This expansion is largest in regions with either large aged shares of their populations at the outset or high aged labour force participation rates, or both. It is therefore particularly strong for Japan. The labour supply expansions tend to cause some redistribution of global investment in favour of ageing regions with high labour force participation rates. The volume of that investment is made smaller, however, by reduced global saving. Nonetheless, most regions enjoy net expansions in GDP.

Because the capital attracted to the expanding regions tends to be owned elsewhere, the boost to regional GNP levels is more modest. Moreover, diminishing returns ensure that the effects on real per capita regional incomes are consistently negative. Hardest hit are Western and Central Europe and China, where aged participation rates are low, so that their populations age and expand yet this does not increase their labour supplies and therefore their capital growth. Reduced per capita incomes ensure that global food output is boosted relative to that of both industrial products and services. And because the consumption preferences of the old become more prominent, service output is accelerates relative to that of industrial products.

In the form presented here, the model offers little role for governments in the ageing process and its consequences. Governments balance their budgets and age-related service expenditures are not identified explicitly. A number of potential improvements therefore arise. First, increased product variety would make it possible to better reflect differences in consumption preferences across age groups. Second, health and retirement services could be identified in the model, with contributions to their supply from both governments and regional private sectors. These improvements would facilitate the analysis of the fiscal implications of ageing and of changes in health and retirement sector productivity.

References

Attanasio, O.P. and J. Banks (1998), "Trends in household saving don't justify tax incentives to boost saving", *Economic Policy: A European Forum* 10(27): 547-583, October.

________, J. Banks and C. Meghir, G. Weber (1999), "Humps and bumps in lifetime consumption", *Journal of Business and Economic Statistics* 17(1): 22-35, January.

________ and M. Szekely (1998), "Household savings and income distribution in Mexico", Inter-American Development Bank, Office of the Chief Economist, Documento de Trabajo No.390, December.

Abdel-Ghani, M. and D.L. Sharpe (1997), "Consumption patterns among the young-old and old-old", *The Journal of Consumer Affairs* 31(1): 90-112.

Barro, R. J., Becker, Gary S. (1989). "Fertility choice in a model of economic growth." *Econometrica* 57(2): 481-501.

Batini, N., T. Callen and W. McKibbin (2006), "The global impact of demographic change", IMF Working Paper WP/06/9, Washington DC, January.

Blisard, N. (2001a), "Food spending in American households, 1997-98", Economic Research Service Statistical Bulletin 972, US Department of Agriculture, Washington DC.

_________ (2001b), "Income and food expenditures decomposed by cohort, age and time effects", Electronic Report from the Economic Research Service, US Department of Agriculture, August, www.ers.usda.gov.

Blisard, N., J.N. Variyam, and J. Cromartie. (2003). "Food 3expenditures by U.S. households: looking ahead to 2020", Electronic Report from the Economic Research Service, US Department of Agriculture, February, www.ers.usda.gov.

Bloom, D.E. and J.G. Williamson (1997), "Demographic transitions, human resource development and economic miracles in emerging Asia", in J. Sachs and D. Bloom (eds.), *Emerging Asia*, Manila: Asian Development Bank.

Booth, H.T. (2004), "On the importance of being uncertain: forecasting population futures for Australia", *People and Place* 12(2): 1-12.

_________, J. Maindonald and L. Smith (2002), "Applying Lee-Carter under conditions of variable mortality decline", *Population Studies* 56(3): 325-336.

_________ and L. Tickle (2003), "The future aged: new projections of Australia's elderly population", *Australasian Journal of Ageing* 22(4): 196-202.

Bryant, R.C., H. Faruqee, D. Veculescu and E. Arbatli, (2003), "Fertility declines and youth dependency: implications for the global economy", Brookings Institution, Washington DC, February.

Bryant, R.C. and W.J. McKibbin (1998), "Issues in modelling the global dimensions of demographic change", http://www.sensiblepolicy.com/wmhp/home1.htm .

________ (2001), "Incorporating demographic change in multi-country demographic models: some preliminary results", http://www.sensiblepolicy.com/wmhp/home1.htm .

Case, A. and A. Deaton (2002), "Consumption, health, gender and poverty", Research Program in Development Studies, Princeton University, May.

Chan, M.M. and R. Tyers (2006), "Global demographic change and labour force growth: projections to 2020", Centre for Economic Policy Research Discussion Paper, Research School of Social Sciences (RSSS), Australian National University, December.

Dixon, P.B. and M. Rimmer (2002), *Dynamic General Equilibrium Modelling for Forecasting and Economic Policy*, No. 256 in the Contributions for Economic Analysis series, published by Elsevier North Holland.

Duncan, R., Q. Shi and R. Tyers (2005), *Global Demographic Change and Demand for Food in Australia*, Rural Industries Research and Development Corporation Report No 05/014, RIRDC, Canberra, 2005.

Faruqee, H. and M. Muhleisen (2002), "Population ageing in Japan: demographic shock and fiscal sustainability", *Japan and the World Economy*, 15: 185-210.

Gibson, J. and G. Scobie (2001), "A cohort analysis of household income, consumption and savings", *New Zealand Economic Papers* 35(2): 196-216, December.

Gollub, A, T. Hertel and E. Ianchovichina (2005), "Capital mobility parameters in the Dynamic GTAP model", presented at the 8th Annual Conference on Global Economic Analysis, Lubeck, Germany, July, GTAP Resource #1763, www.gtap.agecon.purdue.edu.

Grilli, E. and M.C.Yang (1988), "Primary Commodity Prices, Manufactured Goods Prices and the Terms of Trade of Developing Countries: What the Long Run Shows", *World Bank Economic Review*, 2(1), January.

Harrigan, J. (1995), "The volume of trade in differentiated products: theory and evidence", *Review of Economics and Statistics* 77(2): 283-293, May.

Hertel, T.W. (ed.), *Global Trade Analysis Using the GTAP Model*, New York: Cambridge University Press, 1997 (http://www.agecon.purdue.edu/gtap).

Huff, K.M., K. Hanslow, T.W. Hertel and M.E. Tsigas, "GTAP behavioural parameters", Chapter 4 in T.W. Hertel (ed.) *op cit* 1997.

Ianchovichina, E. and R. McDougall (2000), "Theoretical structure of Dynamic GTAP", GTAP Technical Paper No.17, Purdue University, December (http://www.agecon.purdue.edu/gtap/GTAP-Dyn).

IMF (2004), *World Economic Outlook*, International Monetary Fund, Washington, DC, September.

Kitamura, U., N. Takayama and F. Arita (2001), "Household savings and wealth distribution in Japan", Discussion Paper No.38, Project on Intergenerational Equity, Institute of Economic Research, Hitotsubashi University, Tokyo, September.

Lee, R. D. (2003), "The demographic transition: three centuries of fundamental change", *Journal of Economic Perspectives* 17(4): 167-190.

Lewis, W.A. (1952) "World Production, Prices and Trade, 1870- 1960", *Manchester School of Economic and Social Sciences*, 20(2):105-38, May.

Liu, J. N. Van Leeuwen, T.T. Vo, R. Tyers, and T.W. Hertel, "Disaggregating Labor Payments by Skill Level in GTAP", Technical Paper No.11, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University, West Lafayette, September 1998 (http://www.agecon.purdue.edu/gtap/techpapr/tp-11.htm)

Lipsey, R.E. (1994) "Quality Change and Other Influences on Measures of Export Prices of Manufactured Goods" World Bank Policy Research Working Paper 1348, Washington DC.

McDonald, P. and R. Kippen (2001), "Labour supply prospects in 16 developed countries", *Population and Development Review* 27(1): 1-32, March.

Mason, A., ed. (2003), *Population Change and Economic Development in East Asia*: *Challenges Met and Opportunities Seized*, Stanford University Press.

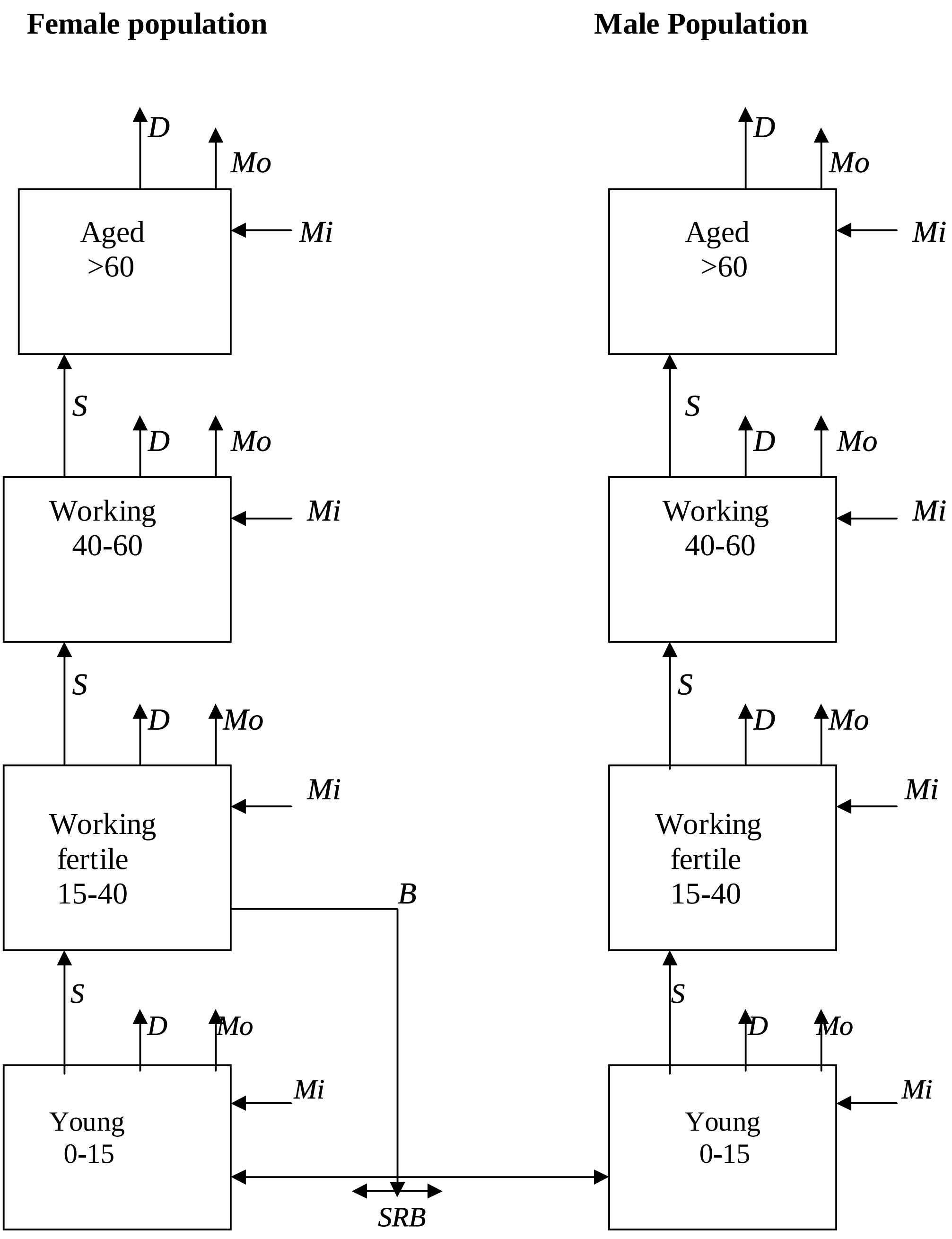
Obstfeld, M. and K. Rogoff (2000), "The six major puzzles in international macroeconomics: is there a common cause?" in B. Bernanke and K. Rogoff (eds.), *NBER Macroeconomics Annual 2000*, Cambridge: NBER and the MIT Press.

OECD (1996), *Ageing in OECD Countries*, Social Policy Studies No.20, Paris: Organisation for Economic Cooperation and Development.

_______ (1998), *Maintaining Prosperity in an Ageing Society*, Paris: Organisation for Economic Cooperation and Development.

_______ (1999), *Employment Outlook*, Paris: Organisation for Economic Cooperation and Development, June.
_______ (2002), *Employment Outlook*, Paris: Organisation for Economic Cooperation and Development, June.
Paulin, G.D. (2000), "Expenditure patterns of older Americans, 1984-97", *Monthly Labour Review* 123(5): 3-28, May.
Productivity Commission (1999), *Microeconomic Reforms and Australian Productivity: Exploring the Links*, Commission Research Paper, Government of Australia, Melbourne, November.
________ (2001), Resource Movements and Labour Productivity, An Australian Illustration 1994-95 to 1997-98, , Staff Research Paper, April.
Regmi, A., M.S. Deepak, J.L. Seale Jr. and J. Bernstein (2001), "Cross country analysis of food consumption patterns", Economic Research Service WRS-01-1, US Department of Agriculture, Washington DC.
Shi, Q. and R. Tyers (2004), "Global population forecast errors, economic performance and Australian food export demand", Working Papers in Economics and Econometrics No.439, Australian National University (http://ecocomm.anu.edu.au/ecopapers).
Trefler, D. and H. Lai (1999), "Gains from trade: standard errors with the CUS monopolistic competition model", University of Toronto.
Tyers, R. and J. Golley, "China's Growth to 2030: The Roles of Demographic Change and Investment Risk", presented at the conference on *WTO, China and the Asian Economies IV: Economic Integration and Development*, University of International Business and Economics, Beijing, China, June 24-25, 2006.
_______ and Shi (2006) "Global demographic change, policy responses and their economic implications", forthcoming in *The World Economy*.
_______, Q. Shi and M.M. Chan (2005), "Global demographic change and economic performance: implications for the food sector"; Report to the Rural Industries Research and Development Corporation, Canberra, September.
United Nations (2000), *Replacement Migration: is it a Solution to Declining and Ageing Populations?*, UN Population Division, UN Secretariat, March.
______ (2003), *World Population Prospects: The 2002 Revision*, UN Population Division, February (www.un.org/esa/population/publications/wpp2002).
United Nations Population Division, *World Population Prospects, The 2002 Revision: Population Database- Assumptions underlying the results of the 2002 Revision of World Population Prospects*" [Online] http://esa.un.org/unpp/assumptions.html
Vedi, J. (2005), "The global economic effects of expanded skilled migration", Honours dissertation, School of Economics, College of Business and Economics, Australian National University.
Weber, G., R. Miniaci and C. Monfardini (2002), "Changing consumption patterns", in H. Siebert (ed.) *Economic Policy for Ageing Societies*, Berlin: Springer Verlag: 53-76.
WHO (2003), "*Mortality Database: Table One: Number of Registered Deaths*" Geneva: World Health Organisation (http://www3.who.int/whosis/menu.cfm?path=whosis,inds,mort&language=english
Williamson, J.G. (1998), "Growth, distribution and demography: some lessons from history", *Explorations in Economic History* 35(3): 241-271.

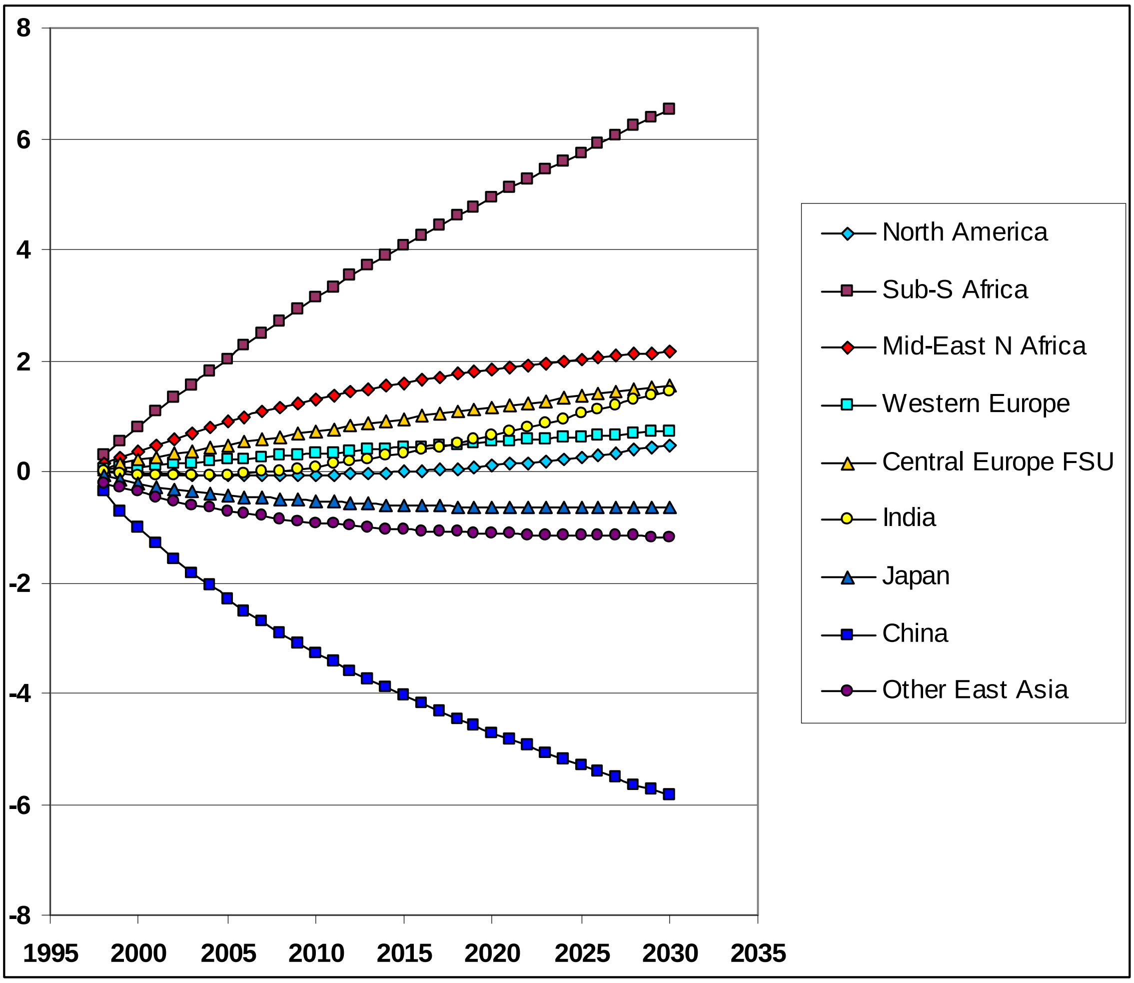
Figure 1: The Demographic Sub-Model



Glossary:

D	Deaths
S	Survival
B	Births
Mi	Immigration
Mo	Emmigration
SRB	Sex ratio at birth

Figure 2: Base Line Interest Premia[a]:



a These are simulated cumulative percentage point wedges between regional and global rates of return (DROR-DRORW), the global rate being that offered by the global trust. They are derived from a pre-base simulation in which investment is constrained to grow at the same rate in all regions.

Figure 3: Base Line Population and Labour Force Projections

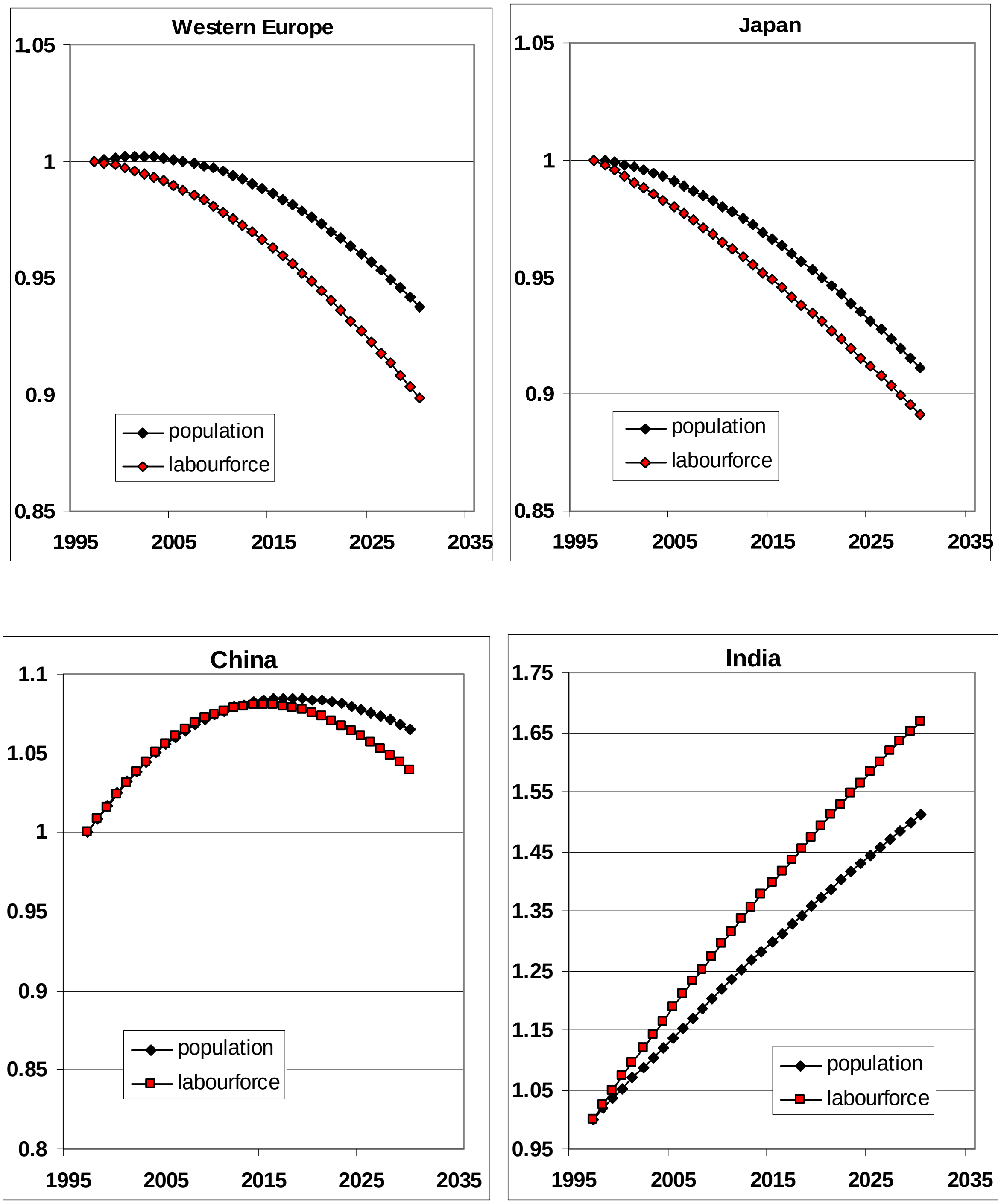
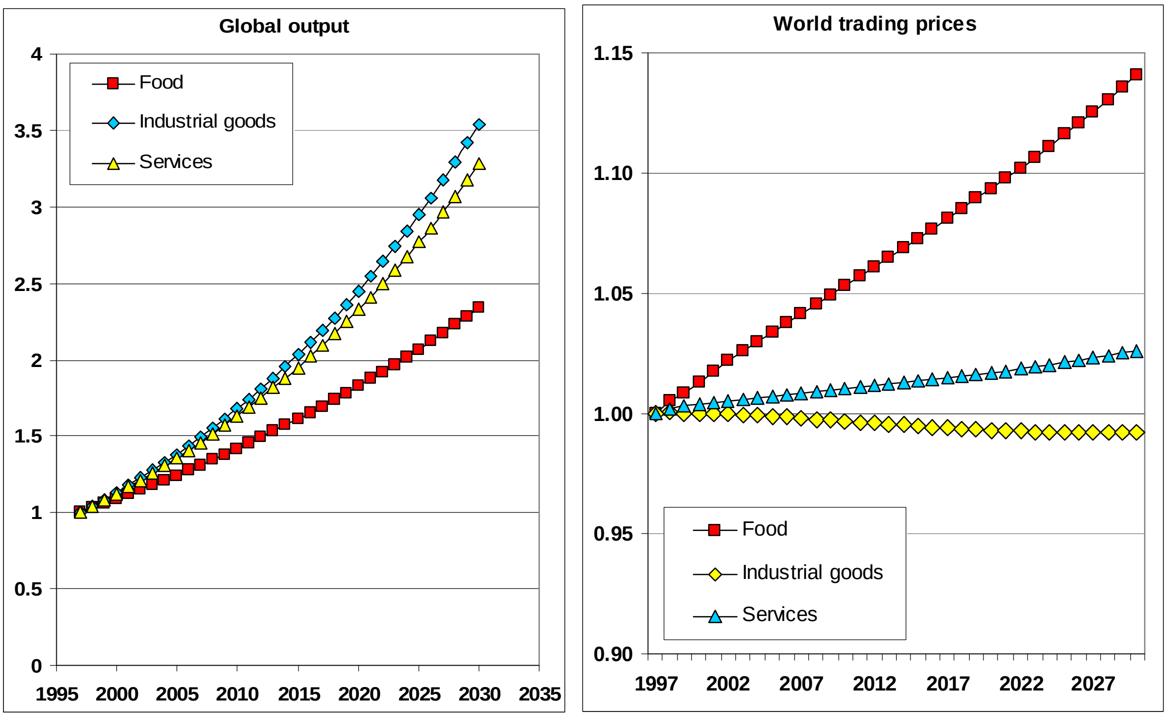


Figure 4: Base Line Global Output and World Trading Product Prices[a]



a World trading prices are relative to a common global numeraire.

Figure 5: "Accelerated Ageing" Labour Force and Average Saving Rate, Departure from Base Line, %

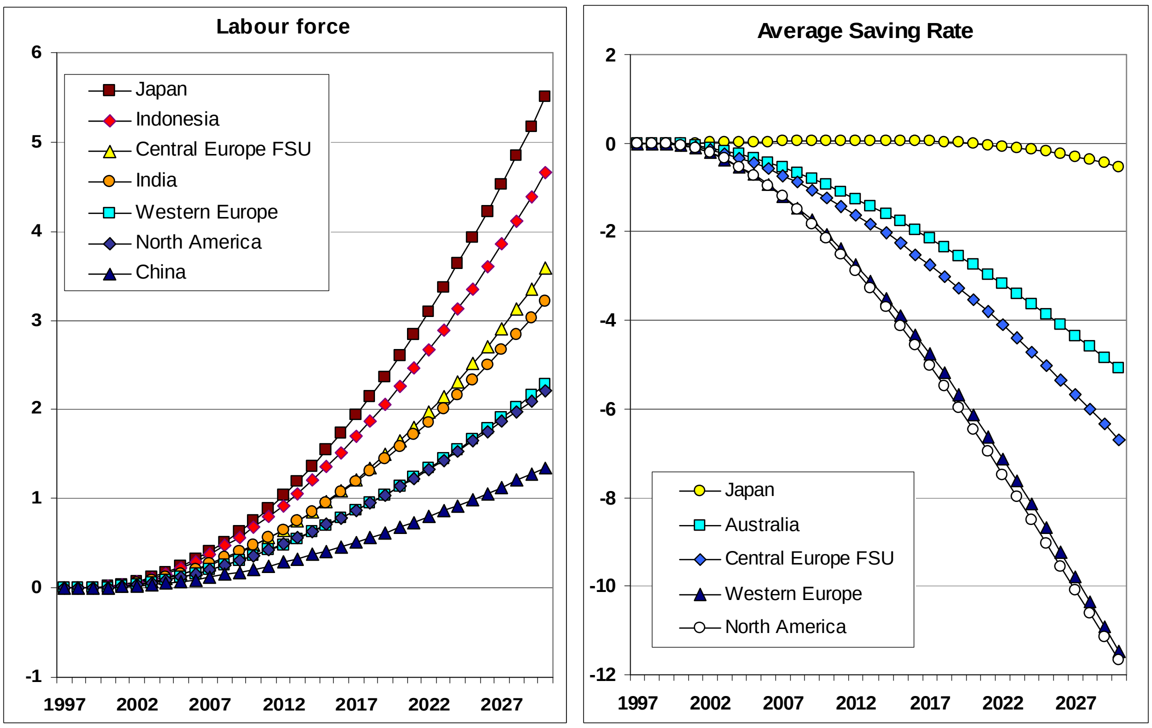


Figure 6: "Accelerated Ageing" Investment and Real GDP, Departure from Base Line, %

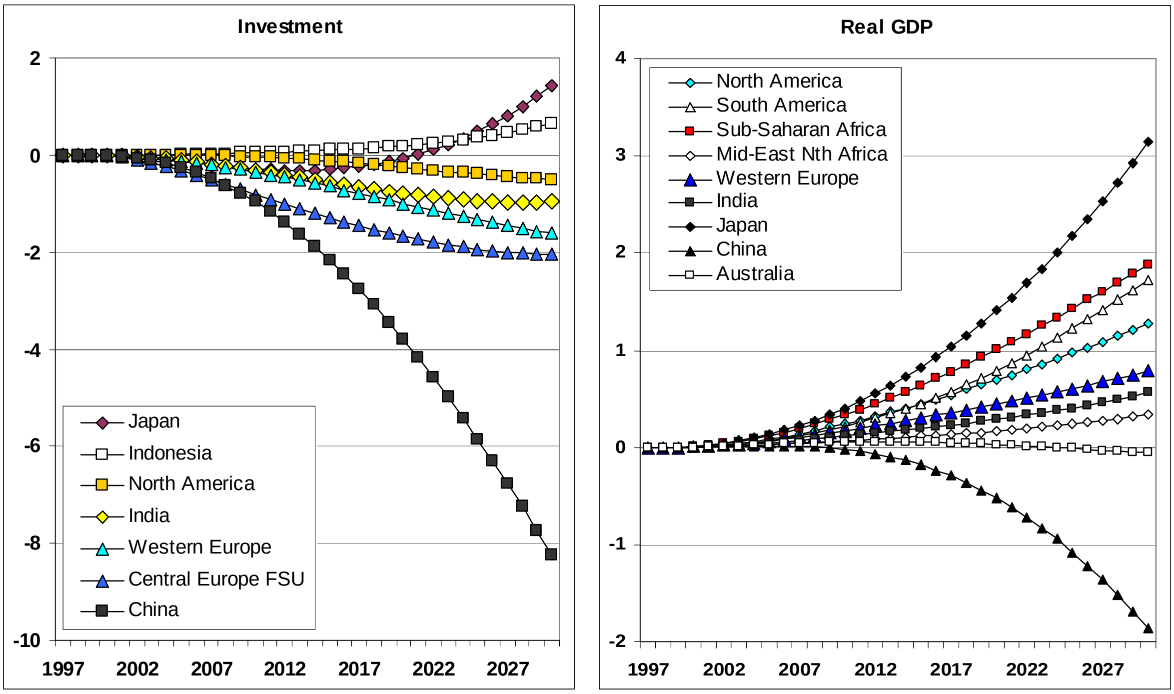


Figure 7: "Accelerated Ageing" Real per capita GNP and Global Product Output, Departures from Base Line, %

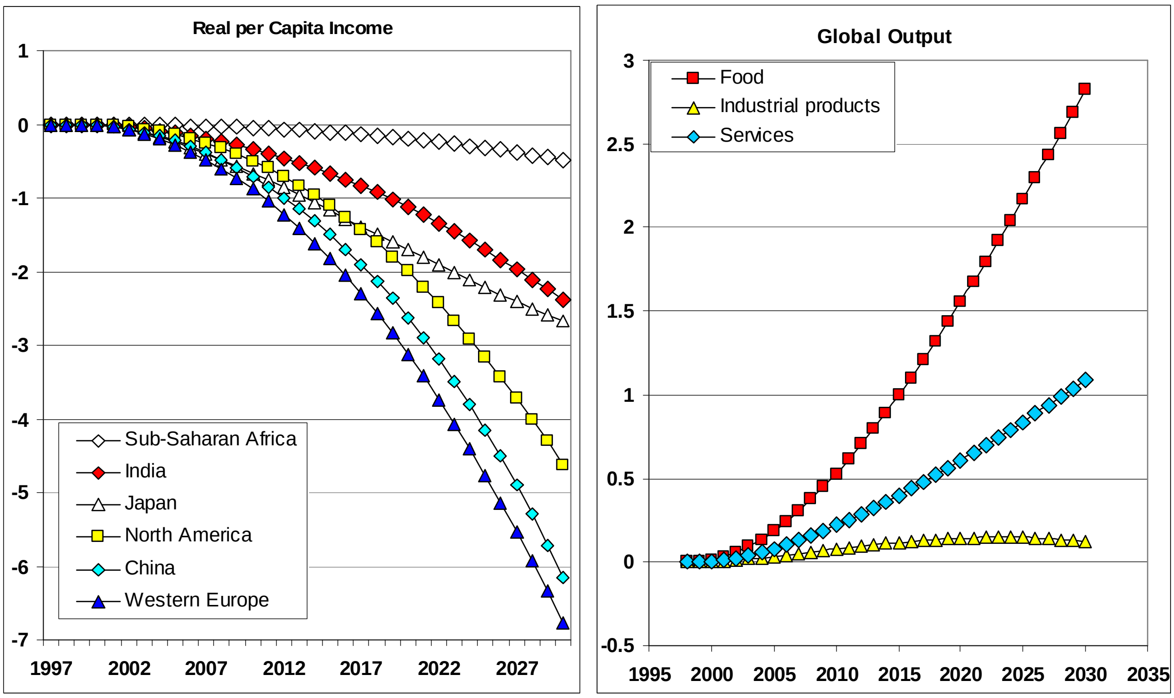


Table 1: Birth Rates and the Sex Ratio at Birth

	Sex ratio at birth	Fertility			
	male/female	Birth: births/ 1000 women aged 15-39 [a] (1997)	Total completed fertility: children per woman (1997)	Birth: births/ 1000 women aged 15-39 [a] (2030)	Total completed fertility: children per woman(2030)
Australia	1.05	72	1.8	70	1.7
North America	1.05	88	2.2	85	2.1
Western Europe	1.06	61	1.5	53	1.3
Central Europe, FSU	1.06	51	1.3	51	1.3
Japan	1.06	57	1.4	57	1.4
China	1.10	76	1.9	58	1.4
Indonesia	1.05	104	2.6	91	2.3
Other East Asia	1.06	99	2.5	90	2.3
India	1.05	139	3.5	115	2.9
Other South Asia	1.05	160	4.0	144	3.6
South America	1.05	105	2.6	101	2.5
Mid East Nth Africa	1.05	137	3.4	130	3.3
Sub-Saharan Africa	1.03	180	4.5	178	4.5
Rest of World	1.05	128	3.2	102	2.6

a Birth rates are based on UN estimates and projections as represented by the US Bureau of the Census. The latter representation has annual changes in rates while the UN model has them stepped every five years. Aggregation is by population weighted average. Initial birth rates are obtained from the UN model by dividing the number of births per year by the number of females aged 15-39. These rates change through time according to annualised projections by the US Bureau of the Census.

Source: Aggregated from United Nations (2003), US Department of Commerce- U.S. Bureau of the Census "International Data Base".

Table 2: Age and Gender Specific Death Rates[a]

(Deaths per year per thousand in each age and gender group)

	0-14				15-39				40-59			
	Males		**Females**		**Males**		**Females**		**Males**		**Females**	
	1997	2030	1997	2030	1997	2030	1997	2030	1997	2030	1997	2030
Australia	1.6	0.6	1.3	0.5	1.3	1.1	0.5	0.4	3.2	2.8	2	1.5
North America	2.2	0.6	1.8	0.6	1.7	0.8	0.7	0.5	4.5	3.6	2.7	2.2
Western Europe	1.8	0.6	1.4	0.6	1.2	1.1	1.1	1.0	4.4	3.2	2.7	2.0
Central Europe, FSU	2.0	0.8	1.8	0.6	2.1	1.6	0.9	0.7	8.0	6.1	3.3	2.5
Japan	1.2	0.7	1.0	0.7	0.7	0.6	0.4	0.3	3.5	2.6	2.0	1.4
China	1.1	0.5	0.9	0.5	0.8	0.6	0.3	0.2	3.9	2.8	2.0	1.8
Indonesia	1.4	1.1	1.1	0.9	2.3	2.0	2.0	1.6	7.9	6.3	3.9	2.7
Other East Asia	1.4	0.7	1.1	0.6	2.3	2.0	1.0	1.0	7.6	3.9	3.4	2.3
India	8.2	3.8	9.4	4.5	1.3	1.1	2.4	2.1	12.3	7.6	8.5	5.7
Other South Asia	8.2	3.6	9.4	4.2	1.3	1.4	3.1	3.1	10.8	9.9	10.3	9.5
South America	1.8	1.4	1.4	1.0	1.3	1.1	0.7	0.4	4.3	3.0	2.3	2.0
Mid East Nth Africa	6.7	1.5	6.5	1.9	1.3	0.9	1.5	1.5	8.3	8.0	5.0	3.6
Sub-Saharan Africa	10.1	14.8	7.7	11.4	1.3	1.7	1.3	1.3	30.0	29.6	30.0	28.4
Rest of World	1.7	0.7	1.4	0.6	1.3	0.8	0.7	0.5	5.4	3.6	2.8	1.9

a Aggregation is by population weighted average. Projections of these parameters to 2020 assume convergence on target rates observed in comparatively “advanced” countries, as explained in the text. Only the end point values are shown here but the model uses values that change with time along the path to convergence.
Source: Aggregated from United Nations (2000) and WHO (2003).

Table 3: Base Line Life Expectancy at 60

Years	Male		Female	
	Initial	**2030**	**Initial**	**2030**
Australia	17	21	21	26
North America	19	21	23	25
Western Europe	19	21	23	25
Central Europe, FSU	15	15	20	21
Japan	22	27	26	33
China	16	17	18	21
Indonesia	14	14	15	15
Other East Asia	17	18	19	19
India	15	16	18	19
Other South Asia	15	16	15	17
South America	17	19	20	21
Mid East Nth Africa	16	17	18	19
Sub-Saharan Africa	10	10	13	13
Rest of World	18	22	23	28

a Aggregation is by population weighted average. Projections of these parameters to 2020 assume convergence on target rates observed in comparatively "advanced" countries, as explained in the text. Only the end point values are shown here but the model uses values that change with time along the path to convergence.
Source: Aggregated from United Nations (2000b) as presented in Chan and Tyers (2005).

Table 4: Income Weights, $W_{a,g,r}$, by Age-Gender Group

	0-14		15-39		40-59		60+	
	Male	Female	Male	Female	Male	Female	Male	Female
Australia	0.60	0.60	1.00	1.00	0.86	0.86	0.67	0.67
North America	0.40	0.40	1.00	1.00	1.10	1.10	0.60	0.60
Western Europe	0.50	0.50	1.00	1.00	1.00	1.00	0.70	0.70
Central Europe, FSU	0.50	0.50	1.00	1.00	1.00	1.00	0.70	0.70
Japan	0.60	0.60	1.00	1.00	1.60	1.60	0.94	0.94
China	0.60	0.60	1.00	1.00	1.60	1.60	0.94	0.94
Indonesia	0.50	0.50	1.00	1.00	1.40	1.40	0.90	0.90
Other East Asia	0.60	0.60	1.00	1.00	1.60	1.60	0.94	0.94
India	0.50	0.50	1.00	1.00	1.40	1.40	0.90	0.90
Other South Asia	0.50	0.50	1.00	1.00	1.40	1.40	0.90	0.90
South America	0.40	0.40	1.00	1.00	1.05	1.05	1.10	1.10
Mid East Nth Africa	0.50	0.50	1.00	1.00	1.40	1.40	0.90	0.90
Sub-Saharan Africa	0.50	0.50	1.00	1.00	1.40	1.40	0.90	0.90
Rest of World	0.60	0.60	1.00	1.00	0.86	0.86	0.67	0.67

Source: Compiled from studies of consumption behaviour on particular countries, including US and UK: Attanasio and Banks (1998), Attanasio et al. (1999); Japan: Kitamura et al. (2001: Table 1); Mexico (standard for Latin America and an indicator for some other developing regions): Attanasio and Szekely (1998: Figure 1); New Zealand (standard for Australia and Western Europe): Gibson and Scobie (2001: Figure 1).

Table 5: Initial Saving Rates From Personal Disposable Income by Age Gender Group

Per cent	0-14		15-39		40-59		60+	
	Male	Female	Male	Female	Male	Female	Male	Female
Australia	0	0	7	7	31	31	-5	-5
North America	0	0	14	14	19	19	-30	-30
Western Europe	0	0	10	10	39	39	-20	-20
Central Europe, FSU	0	0	4	4	18	18	-6	-6
Japan	0	0	24	24	28	28	22	22
China	0	0	35	35	40	40	31	31
Indonesia	0	0	23	23	34	34	23	23
Other East Asia	0	0	36	36	40	40	32	32
India	0	0	19	19	28	28	19	19
Other South Asia	0	0	7	7	10	10	7	7
South America	0	0	7	7	17	17	6	6
Mid East Nth Africa	0	0	8	8	19	19	7	7
Sub-Saharan Africa	0	0	2	2	6	6	2	2
Rest of World	0	0	5	5	23	23	-5	-5

Source: Compiled from studies of consumption behaviour on particular countries, including Mexico: Attanasio and Szekely (1998); Japan: Kitamura et al. (2001); New Zealand: Gibson and Scobie (2001); US: Attanasio et al. (1999).

Table 6: Private Expenditure Shares by Age-Gender Group

		0-14		15-39		40-59		60+	
		Male	Female	Male	Female	Male	Female	Male	Female
Australia	Food	0.18	0.18	0.10	0.10	0.10	0.10	0.18	0.18
	Manufactures	0.07	0.07	0.19	0.19	0.19	0.19	0.05	0.05
	Services	0.74	0.74	0.71	0.71	0.71	0.71	0.77	0.77
North America	Food	0.12	0.12	0.05	0.05	0.06	0.06	0.11	0.11
	Manufactures	0.12	0.12	0.16	0.16	0.16	0.16	0.09	0.09
	Services	0.76	0.76	0.79	0.79	0.78	0.78	0.80	0.80
Western Europe	Food	0.18	0.18	0.09	0.09	0.09	0.09	0.18	0.18
	Manufactures	0.12	0.12	0.30	0.30	0.30	0.30	0.09	0.09
	Services	0.70	0.70	0.61	0.61	0.61	0.61	0.73	0.73
Central Europe, FSU	Food	0.44	0.44	0.26	0.26	0.26	0.26	0.43	0.43
	Manufactures	0.10	0.10	0.27	0.27	0.27	0.27	0.07	0.07
	Services	0.47	0.47	0.47	0.47	0.47	0.47	0.50	0.50
Japan	Food	0.18	0.18	0.10	0.10	0.10	0.10	0.17	0.17
	Manufactures	0.07	0.07	0.18	0.18	0.18	0.18	0.05	0.05
	Services	0.75	0.75	0.72	0.72	0.72	0.72	0.78	0.78
China	Food	0.47	0.47	0.26	0.26	0.26	0.26	0.47	0.47
	Manufactures	0.13	0.13	0.35	0.35	0.35	0.35	0.10	0.10
	Services	0.40	0.40	0.39	0.39	0.39	0.39	0.43	0.43
Indonesia	Food	0.46	0.46	0.30	0.30	0.30	0.30	0.45	0.45
	Manufactures	0.07	0.07	0.26	0.26	0.26	0.26	0.05	0.05
	Services	0.48	0.48	0.44	0.44	0.44	0.44	0.50	0.50
Other East Asia	Food	0.30	0.30	0.17	0.17	0.17	0.17	0.29	0.29
	Manufactures	0.10	0.10	0.35	0.35	0.35	0.35	0.08	0.08
	Services	0.60	0.60	0.47	0.47	0.47	0.47	0.63	0.63
India	Food	0.57	0.57	0.37	0.37	0.37	0.37	0.56	0.56
	Manufactures	0.08	0.08	0.31	0.31	0.31	0.31	0.06	0.06
	Services	0.35	0.35	0.32	0.32	0.32	0.32	0.38	0.38
Other South Asia	Food	0.54	0.54	0.37	0.37	0.37	0.37	0.54	0.54
	Manufactures	0.07	0.07	0.27	0.27	0.27	0.27	0.05	0.05
	Services	0.39	0.39	0.36	0.36	0.36	0.36	0.41	0.41
South America	Food	0.36	0.36	0.21	0.21	0.21	0.21	0.36	0.36
	Manufactures	0.10	0.10	0.36	0.36	0.36	0.36	0.08	0.08
	Services	0.53	0.53	0.43	0.43	0.43	0.43	0.57	0.57
Mid East Nth Africa	Food	0.39	0.39	0.25	0.25	0.25	0.25	0.38	0.38
	Manufactures	0.07	0.07	0.27	0.27	0.27	0.27	0.05	0.05
	Services	0.54	0.54	0.48	0.48	0.48	0.48	0.57	0.57
Sub-Saharan Africa	Food	0.46	0.46	0.30	0.30	0.30	0.30	0.45	0.45
	Manufactures	0.07	0.07	0.28	0.28	0.28	0.28	0.05	0.05
	Services	0.47	0.47	0.42	0.42	0.42	0.42	0.50	0.50
Rest of World	Food	0.36	0.36	0.20	0.20	0.20	0.20	0.35	0.35
	Manufactures	0.10	0.10	0.27	0.27	0.27	0.27	0.07	0.07
	Services	0.54	0.54	0.53	0.53	0.53	0.53	0.58	0.58

Source: Constructed with guidance from the results presented by: Abdel-Ghany and Sharpe (1997), Blisard (2001a and b), Blisard et al. (2003), Case and Deaton (2002), Paulin (2000), Regmi et al. (2001) and Weber et al. (2002). The shares are then modified using a RAS process to conform with aggregate expenditures by product in the *GTAP* database.

Table 7: Base Line Projections of Labour Force Size and Structure

	Labour force[a]		% Female		% 40+	
	Initial	2030	Initial	2030	Initial	2030
Australia	8	10	37	40	42	48
North America	182	250	40	42	42	47
Western Europe	184	165	40	44	47	55
Central Europe	181	148	47	46	44	53
Japan	61	55	37	37	58	65
China	570	592	37	36	34	47
Indonesia	87	130	38	38	40	54
Other East Asia	127	178	41	40	37	51
India	356	594	27	28	36	47
Other South Asia	134	265	28	28	32	44
South America	123	193	38	39	33	48
Mid East Nth Afr	103	176	24	23	30	42
Sub-Saharan Afr	150	349	28	29	29	36
Rest of World	79	131	36	34	38	48

a Measured in full time equivalent workers.
Source: Projection using the demographic model described in the text, as presented in detail by Chan and Tyers (2005).

Table 8: Base Line Non-Working Aged Dependency Ratios

	Non-working aged/working	
	Initial	2030
Australia	0.35	0.54
North America	0.24	0.36
Western Europe	0.42	0.61
Central Europe	0.29	0.42
Japan	0.32	0.48
China	0.19	0.44
Indonesia	0.09	0.16
Other East Asia	0.09	0.23
India	0.12	0.23
Other South Asia	0.09	0.18
South America	0.16	0.29
Mid East Nth Afr	0.15	0.33
Sub-Saharan Afr	0.13	0.15
Rest of World	0.15	0.27

Source: Base period statistics constructed from population statistics from United Nations (2003) and simulation results from the demographic model described in the text.

Table 9: Base Line Real Per Capita Income Projection to 2030, Per Cent Change Over 1997

Ranked by performance	
India	369
China	361
Indonesia	356
Other East Asia	341
Central Europe FSU	218
Japan	207
Australia	185
Western Europe	171
Other South Asia	156
South America	142
Rest of World	141
North America	139
Sub-Saharan Africa	125
Mid-East Nth Africa	88

Source: The base line simulation using the augmented GTAP-Dynamic, as described in the text.

Table 10: Demographic Effects in 2030 of "Accelerated Ageing"[a], Per Cent Departures from the Base Line Scenario

per cent	Population		Labour force		Non-working aged dep ratio
	Total	**60+**	**Total**	**60+**	**Aged NW**
Australia	5.7	23.7	1.3	24.6	22.0
North America	5.1	23.6	2.2	24.0	20.9
Western Europe	7.5	25.8	2.3	26.3	22.9
Central Europe	7.8	31.4	3.6	32.5	26.6
Japan	7.4	21.4	5.5	22.1	14.8
China	5.9	27.4	1.4	29.0	25.5
Indonesia	4.5	31.0	4.7	31.2	25.0
Other East Asia	4.4	25.8	3.5	26.1	21.4
India	3.8	26.6	3.2	27.5	22.2
Other South Asia	3.1	26.6	3.0	26.7	22.7
South America	4.1	24.4	3.4	24.6	20.1
Mid East Nth Africa	3.3	25.3	2.3	25.8	22.3
Sub-Saharan Africa	2.4	34.5	2.8	36.2	30.0
Rest of World	3.6	20.1	3.3	21.0	15.8

a Growth in Target Life Expectancies at 60 by 2% per year

Source: Simulation results from the model described in the text.

Table 11: "Accelerated Ageing" - Product and Factor Prices, per cent Departure from the Base Line in 2030

	Labour force	Average saving rate	Real invest-ment	Real GDP	GDP price[a]	Real per capita income	Real produc-tion wage[b]	Land rent[b]	Resource rent[b]	Food output	Manu-factures output	Services output
Australia	1.3	-5.1	-2.7	-0.1	0.3	-5.2	-0.9	2.7	-1.2	1.5	-1.3	0.0
North America	2.2	-11.7	-0.5	1.3	-0.1	-4.6	-0.3	5.4	0.6	2.8	0.7	1.3
Western Europe	2.3	-11.5	-1.6	0.8	0.2	-6.8	-1.0	7.9	-0.6	4.9	-0.3	0.9
Central Eur, FSU	3.6	-6.7	-2.0	0.9	-0.1	-6.6	-1.7	6.6	0.3	3.8	0.4	0.8
Japan	5.5	-0.5	1.4	3.1	0.5	-2.7	-1.4	7.8	0.9	4.6	1.1	3.4
China	1.4	0.3	-8.2	-1.9	-0.5	-6.2	-2.1	2.9	-1.1	2.1	-1.1	-3.1
Indonesia	4.7	-0.2	0.7	1.4	0.0	-2.4	-2.1	4.3	0.5	2.1	0.6	1.8
Other East Asia	3.5	0.1	-1.8	0.8	0.0	-2.1	-1.7	3.6	-0.1	1.8	-0.1	1.1
India	3.2	0.0	-0.9	0.6	0.2	-2.4	-2.1	2.8	-0.1	1.3	0.2	0.6
Other South Asia	3.0	-2.3	-0.7	1.0	-0.1	-1.9	-1.6	3.0	0.6	1.2	0.8	1.0
South America	3.4	-1.1	0.9	1.7	-0.2	-2.4	-1.1	5.3	1.1	2.7	1.3	1.8
Mid East Nth Africa	2.3	-0.1	-2.5	0.3	0.0	-2.1	-1.3	5.4	-0.5	3.2	-0.7	0.5
Sub-Saharan Africa	2.8	0.6	1.0	1.9	-0.2	-0.5	-0.5	6.2	1.0	3.4	0.9	2.1
Rest of World	3.3	-3.3	0.0	1.1	-0.2	-2.6	-1.4	4.3	0.7	2.3	0.7	1.2

a The GDP price is measured relative to the common numeraire in *GTAP-Dynamic*. Note relative values only, indicative of real exchange rate changes.
Source: Simulations of the model described in the text.