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The Impacts of Demographic Change in Japan: Some Preliminary Results from the MSG3 model

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Abstract

Demographic shifts may have a profound influence the world economy, directly in the countries experiencing the demographic change and indirectly through changes in global trade, capital markets, and exchange rates. In this paper we apply the approach of Bryant and McKibbin (2001), which extends the approach of Blanchard, Weil, Faruqee, Laxton, and Symansky to modelling consumption and saving behaviour. The analytical approach is applied to a general equilibrium model of the world economy with a focus on Japan (the MSG3 multi-country model). Changes in birth and mortality rates are combined with an approximation of age-earning profiles to allow demographic shifts to influence labour supply, human wealth, consumption, asset accumulation and investment demand in Japan. The results in this draft are preliminary, however they suggest that current and predicted demographic changes in Japan are likely to have an important impact on the Japanese and world economies. Future work will incorporate the impact of global demographic change on the global economy and explore how the global demographic projections will possibly impact on the Japanese economy.

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1. Introduction

Many countries in the world economy are undergoing significant demographic change or are projected to over coming decades. Table 1 illustrates the expected shifts in dependency ratios of a number of countries between 2000 and 2050 as projected by the United Nations. While these shifts are substantial, none is more dramatic than those projected for Japan. What will be the implications of such a large demographic shock to the Japanese economy?

There is already a large and growing literature on the many aspects of demographic change in Japan[1] although few of these papers focus on the international aspects of Japan's demographic shock. An exception is the recent work by Faruqee (2000a). In this paper we explore the issue of demographic change in Japan using a global modelling framework with a number of important decisions endogenous to the model, such as labour supply, human wealth accumulation, consumption and saving decisions, asset accumulation, investment demand and a full portfolio of asset prices.

The consequences of Japanese demographic change on Japan is however is only part of the story, since global demographic change is likely to also impact on the Japanese economy in the coming decades. A future paper using the techniques applied in this paper will take a more global view, focussing on both the demographic shock in Japan and the demographic changes projected in the rest of the world.

Table 2 presents a more detailed breakdown of the demographic transition in Japan from 1950 to 2050. It is clear from this table that the demographic adjustment in Japan is well under way.

In this paper we embed an analytical technique to modelling demographic change outlined in Bryant and McKibbin (2001), which extends the approach of Blanchard, Weil, Faruqee, Laxton, and Symansky to modelling consumption and saving behaviour. The approach allows the key impacts

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[1] See for example Endo and Katayama (1998), Horioka (1991), Meredith (1995), Ogawa and Retherford (1993), Takayama and Kitamura (1999), Takayama (1998), Takayama, Kitamura and Yoshida (1998), Yashiro and Oishi (1997), Yashiro (1998), Yashiro, Oshio, and Matsuya (1997).

of demographic change on consumption and savings and labour supply as well as capturing the endogenous reactions of a wide range of macroeconomic variables built into the general equilibrium framework used.

Section 2 of this paper summarizes the MSG3 model used for this analysis. Section 3 outlines the analytical approach that is used. It implements the approach outlined in Bryant and McKibbin (2001), which builds on the work on Blanchard as extended by Faruqee (2000a, 2000b). In Section 4 some preliminary results are presented for a Japanese demographic shock of a decline in fertility and an aging of the Japanese population. These results are likely to be revised since taking official projections and converting these into shocks for the model simulations have proven to be very difficult. Indeed the stylised shocks implemented seem rather extreme. A summary and conclusion is presented in section 5.

2. The MSG3 Model

The model used in this paper is a reduced version of the MSG3 multi-country model. We aggregate the world into four regions: Japan; the United States; rest of the OECD and rest of the world. In the model used in Bryant and McKibbin (2001) the countries in the simplified MSG3 model were assumed to be symmetric representations of the US economy with simplified functional forms and full intertemporal optimising agents. In this paper we use the empirically based MSG3 model with the Japanese economy based on the Japanese economy in the MSG3 model and with rigidities in consumption and investment decisions found in the larger model.

In the remainder of this section we present the essence of the MSG3 model. The MSG3 model is based on the G-Cubed model of McKibbin and Wilcoxen (1999). The key difference between the MSG3 model and the G-Cubed model is that we aggregate the 12 sectors in each country to 2 sectors (energy and non-energy). This is very similar to the structure of the MSG2 model of McKibbin and Sachs (1991) except that we use the econometric estimation of the G-Cubed model to parameterise the model. The reader is referred to chapters 2 and 5 of McKibbin and Wilcoxen (2001) for greater detail on the analytical basis of the model.

The MSG3 model captures the behaviour of several economic agents: households, the government, the financial sector and 2 firms, one each in the 2 production sectors in each economy. The two sectors of production are energy and non-energy (this is much like the aggregate structure of the MSG2 model). The following gives an overview of the theoretical structure of the model by describing the decisions facing these agents in one of these countries. Throughout the discussion all quantity variables will be normalized by the economy's endowment of effective labour units. Thus, the model's long run steady state will represent an economy in a balanced-growth equilibrium.

1.1 Firms

We assume that each of the two sectors can be represented by a price-taking firm that chooses variable inputs and its level of investment in order to maximize its stock market value. Each firm's production technology is represented by a constant elasticity of substitution (CES) function. Output is a function of capital, labor, energy and materials:

(1) $$Q_i = A_i^o \left(\sum_{j=k,l,e,m} \left(\delta_{ij}^o\right)^{1/\sigma_i^o} x_{ij}^{(\sigma_i^o - 1)/\sigma_i^o} \right)^{\sigma_i^o/(\sigma_i^o - 1)}$$

where Q_i is the output of industry i, x_{ij} is industry i's use of input j, and A_i^o, δ_{ij}^o, and σ_i^o are parameters. A_i^o reflects the level of technology, σ_i^o is the elasticity of substitution, and the δ_{ij}^o parameters reflect the weights of different inputs in production; the superscript o indicates that the parameters apply to the top, or "output", tier. Without loss of generality, we constrain the δ_{ij}^o's to sum to one.

The goods and services purchased by firms are, in turn, aggregates of imported and domestic commodities, which are taken to be imperfect substitutes. We assume that all agents in the economy have identical preferences over foreign and domestic varieties of each commodity. We represent these preferences by defining composite commodities that are produced from imported and domestic goods. Each of these commodities, Y_i, is a CES function of inputs domestic output, Q_i, and an aggregate of goods imported from all of the country's trading partners, M_i:

(2) $$y_i = A_i^{fd} \left(\left(\delta_{id}^{fd}\right)^{1/\sigma_i^{fd}} Q_i^{(\sigma_i^{fd}-1)/\sigma_i^{fd}} + \left(\delta_{if}^{fd}\right)^{1/\sigma_i^{fd}} M_i^{(\sigma_i^{fd}-1)/\sigma_i^{fd}} \right)^{\sigma_i^{fd}/(\sigma_i^{fd}-1)}$$

where σ_i^{fd} is the elasticity of substitution between domestic and foreign goods.[2] For example, the energy product purchased by agents in the model are a composite of imported and domestic energy. The aggregate imported good, M_i, is itself a CES composite of imports from individual countries, M_{ic}, where c is an index indicating the country of origin:

(3) $$M_i = A_i^{ff} \left(\sum_{c=1}^{7} \left(\delta_{ic}^{ff}\right)^{1/\sigma_i^{ff}} M_{ic}^{(\sigma_i^{ff}-1)/\sigma_i^{fd}} \right)^{\sigma_i^{ff}/(\sigma_i^{ff}-1)}$$

The elasticity of substitution between imports from different countries is σ_i^{ff}.

By constraining all agents in the model to have the same preferences over the origin of goods we require that, for example, the agricultural and service sectors have the identical preferences over domestic oil and imported oil.[3] This accords with the input-output data we use and allows a very convenient nesting of production, investment and consumption decisions.

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[2] This approach follows Armington (1969).

[3] This does not require that both sectors purchase the same amount of oil, or even that they purchase oil at all; only that they both feel the same way about the origins of oil they buy.

In each sector the capital stock changes according to the rate of fixed capital formation (J_i) and the rate of geometric depreciation (δ_i):

(4) $$\dot{k}_i = J_i - \delta_i k_i$$

Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa's approach by assuming that in order to install *J* units of capital a firm must buy a larger quantity, *I*, that depends on its rate of investment (*J*/*k*):

(5) $$I_i = \left(1 + \frac{\phi_i}{2}\frac{J_i}{k_i}\right) J_i$$

where ϕ_i is a non-negative parameter. The difference between *J* and *I* may be interpreted various ways; we will view it as installation services provided by the capital-goods vendor. Differences in the sector-specificity of capital in different industries will lead to differences in the value of ϕ_i.

The goal of each firm is to choose its investment and inputs of labour, materials and energy to maximize intertemporal net-of-tax profits. For analytical tractability, we assume that this problem is deterministic (equivalently, the firm could be assumed to believe its estimates of future variables with subjective certainty). Thus, the firm will maximize:[4]

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[4] The rate of growth of the economy's endowment of effective labor units, *n*, appears in the discount factor because the quantity and value variables in the model have been scaled by the number of effective labor units. These variables must be multiplied by exp(nt) to convert them back to their original form.

(6) $$\int_t^{\infty} (\pi_i - (1-\tau_4)\, p^I I_i\,)\, e^{-(R(s)-n)(s-t)}\, ds$$

where all variables are implicitly subscripted by time. The firm's profits, π, are given by:

(7) $$\pi_i = (1-\tau_2)(p_i^* Q_i - w_i x_{il} - p_i^e x_{ie} - p_i^m x_{im})$$

where τ_2 is the corporate income tax, τ_4 is an investment tax credit, and p^* is the producer price of the firm's output. $R(s)$ is the long-term interest rate between periods t and s:

(8) $$R(s) = \frac{1}{st}\int_t^s r(v)dv$$

Because all real variables are normalized by the economy's endowment of effective labour units, profits are discounted adjusting for the rate of growth of population plus productivity growth, n. Solving the top tier optimization problem gives the following equations characterizing the firm's behavior:

(9) $$x_{ij} = \delta_{ij}^o \left(A_i^o\right)^{\sigma_i^o - 1} Q_i \left(\frac{p_i^*}{p_j}\right)^{\sigma_i^o} \quad j \in \{l,e,m\}$$

(10) $$\lambda_i = (1+\phi_i \frac{J_i}{k_i})(1-\tau_4)\, p^I$$

(11) $$\frac{d\lambda_i}{ds} = (r+\delta_i)\,\lambda_i - (1-\tau_2)\, p_i^* \frac{dQ_i}{dk_i} - (1-\tau_4)\, p^I\, \frac{\phi_i}{2}\left(\frac{J_i}{k_i}\right)^2$$

where λ_i is the shadow value of an additional unit of investment in industry i.

Equation (9) gives the firm's factor demands for labour, energy and materials and equations (10) and (11) describe the optimal evolution of the capital stock. Integrating (11) along the optimum trajectory of investment and capital accumulation, $(\hat{J}(t), \hat{k}(t))$, gives the following expression for λ_i:

(12)
$$\lambda_i(t) = \int_t^\infty \left((1-\tau_2) p_i^* \left. \frac{dQ_i}{dk_i} \right|_{\hat{J},\hat{k}} + (1-\tau_4) p^I \frac{\phi_i}{2} \left(\frac{\hat{J}_i}{\hat{k}_i} \right)^2 \right) e^{-(R(s)+\delta)(s-t)} ds$$

Thus, λ_i is equal to the present value of the after-tax marginal product of capital in production (the first term in the integral) plus the savings in subsequent adjustment costs it generates. It is related to q, the after-tax marginal version of Tobin's Q (Abel, 1979), as follows:

(13)
$$q_i = \frac{\lambda_i}{(1-\tau_4) p^I}$$

Thus we can rewrite (10) as:

(14)
$$\frac{J_i}{k_i} = \frac{1}{\phi_i} (q_i - 1)$$

Inserting this into (5) gives total purchases of new capital goods:

(15)
$$I_i = \frac{1}{2\phi_i} (q_i^2 - 1) k_i$$

Based on Hayashi (1979), who showed that actual investment seems to be party driven by cash flows, we modify (15) by writing I_i as a function not only of q, but also of the firm's current cash flow at time t, π_i, adjusted for the investment tax credit:

(16) $$I_i = \alpha_2 \frac{1}{2\phi_i}\left(q_i^2 - 1\right)k_i + \left(1-\alpha_2\right)\frac{\pi_i}{\left(1-\tau_4\right)p^I}$$

This improves the model's ability to mimic historical data and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings.

So far we have described the demand for investment goods by each sector. Investment goods are supplied, in turn, by a third industry that combines labour and the outputs of other industries to produce raw capital goods. We assume that this firm faces an optimization problem identical to those of the other two industries: it has a nested CES production function, uses inputs of capital, labour, energy and materials in the top tier, incurs adjustment costs when changing its capital stock, and earns zero profits. The key difference between it and the other sectors is that we use the investment column of the input-output table to estimate its production parameters.

1.2 Households

We first describe the behaviour of households in the MSG3 model. How this is modified to incorporate demographic change in outlined in the following section. Households have three distinct activities in the model: they supply labour, they save, and they consume goods and services. Within each region we assume household behaviour can be modelled by a representative agent with an intertemporal utility function of the form:

(17) $$U_t = \int_t^{\infty} (\ln c(s) + \ln g(s))\, e^{-\theta(s-t)}\, ds$$

where $c(s)$ is the household's aggregate consumption of goods and services at time s, $g(s)$ is government consumption at s, which we take to be a measure of public goods provided, and θ is the rate of time preference.[5] The household maximizes (17) subject to the constraint that the present value of consumption be equal to the sum of human wealth, *H*, and initial financial assets, *F*:[6]

(18)
$$\int_t^{\infty} p^c(s)c(s)e^{-(R(s)-n)(s-t)} = H_t + F_t$$

Human wealth is defined as the expected present value of the future stream of after-tax labour income plus transfers:

(19)
$$H_t = \int_t^{\infty} (1-\tau_1)(W(L^G + L^C + L^I + \sum_{i=1}^{12} L^i) + TR)e^{-(R(s)-n)(s-t)}ds$$

where τ_1 is the tax rate on labour income, *TR* is the level of government transfers, L^C is the quantity of labour used directly in final consumption, L^I is labour used in producing the investment good, L^G is government employment, and L^i is employment in sector *i*. Financial wealth is the sum of real money balances, *MON*/*P*, real government bonds in the hand of the public, *B*, net holding of claims against foreign residents, *A*, the value of capital in each sector:

(20)
$$F = \frac{MON}{p} + B + A + q^I k^I + q^c k^c + \sum_{i=1}^{12} q^i k^i$$

Solving this maximization problem gives the familiar result that aggregate consumption spending is equal to a constant proportion of private wealth, where private wealth is defined as financial wealth plus human wealth:

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5 This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable.

6 As before, *n* appears in (18) because the model's scaled variables must be converted back to their original basis.

(21) $$p^c c = \theta(F + H)$$

However, based on the evidence cited by Campbell and Mankiw (1990) and Hayashi (1982) we assume some consumers are liquidity-constrained and consume a fixed fraction γ of their after-tax income (*INC*).[7] Denoting the share of consumers who are not constrained and choose consumption in accordance with (21) by α_8, total consumption expenditure is given by:

(22) $$p^c c = \alpha_8 \theta(F_t + H_t) + (1 - \alpha_8)\gamma INC$$

The share of households consuming a fixed fraction of their income could also be interpreted as permanent income behaviour in which household expectations about income are myopic.

Once the level of overall consumption has been determined, spending is allocated among goods and services according to a CES utility function.[8] The demand equations for capital, labour, energy and materials can be shown to be:

(23) $$p_i x_i^c = \delta_i^c y \left(\frac{p^c}{p_i} \right)^{\sigma_c^o - 1}, i \in \{k, l, e, m\}$$

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[7] There has been considerable debate about the empirical validity of the permanent income hypothesis. In addition the work of Campbell , Mankiw and Hayashi, other key papers include Hall (1978), and Flavin (1981). One side effect of this specification is that it prevents us from computing equivalent variation. Since the behavior of some of the households is inconsistent with (21), either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

[8] The use of the CES function has the undesirable effect of imposing unitary income elasticities, a restriction usually rejected by data. An alternative would be to replace this specification with one derived from the linear expenditure system.

where y is total expenditure, x_i^c is household demand for good i, σ_c^o is the top-tier elasticity of substitution and the δ_i^c are the input-specific parameters of the utility function. The price index for consumption, p^c, is given by:

(24) $$p^c = \left(\sum_{j=k,l,e,m} \delta_j^c p_j^{\sigma_c^o - 1} \right)^{\frac{1}{\sigma_c^o - 1}}$$

Household capital services consist of the service flows of consumer durables plus residential housing. The supply of household capital services is determined by consumers themselves who invest in household capital, k^c, in order to generate a desired flow of capital services, c^k, according to the following production function:

(25) $$c^k = \alpha k^c$$

where α is a constant. Accumulation of household capital is subject to the condition:

(26) $$\dot{k}^c = J^c - \delta^c k^c$$

We assume that changing the household capital stock is subject to adjustment costs so household spending on investment, I^c, is related to J^c by:

(27) $$I^c = \left(1 + \frac{\phi^c}{2} \frac{J^c}{k^c} \right) J^c$$

Thus the household's investment decision is to choose I^C to maximize:

(28) $$\int_t^{\infty}(p^{ck}\alpha k^c - p^I I^c)e^{-(R(s)-n)(s-t)}ds$$

where p^{ck} is the imputed rental price of household capital. This problem is nearly identical to the investment problem faced by firms and the results are very similar. The only important differences are that no variable factors are used in producing household capital services and there is no investment tax credit for household capital. Given these differences, the marginal value of a unit of household capital, λ_C, can be shown to be:

(29) $$\lambda_c(t) = \int_t^{\infty}\left(p^{ck}\alpha + p^I \frac{\phi_c}{2}\left(\frac{\hat{J}_c}{\hat{k}_c}\right)^2\right)e^{-(R(s)+\delta)(s-t)}ds$$

where the integration is done along the optimal path of investment and capital accumulation, $(\hat{J}_c(t), \hat{k}_c(t))$. Marginal q is:

(30) $$q_c = \frac{\lambda_c}{p^I}$$

and investment is given by:

(31) $$\frac{J_c}{k_c} = \frac{1}{\phi_c}\left(q_c - 1\right)$$

1.3 The Labour Market

We assume that labour is perfectly mobile among sectors within each region but is immobile between regions. Thus, wages will be equal across sectors within each region, but will generally not be equal between regions. In the long run, labour supply is completely inelastic and is determined by the exogenous rate of population growth. Long run wages adjust to move each region to full employment. In the short run, however, nominal wages are assumed to adjust slowly according to an overlapping contracts model where wages are set based on current and expected inflation and on labour demand relative to labour supply. The equation below shows how wages in the next period depend on current wages; the current, lagged and expected values of the consumer price level; and the ratio of current employment to full employment:

(32) $$w_{t+1} = w_t \left(\frac{p_{t+1}^c}{p_t^c} \right)^{\alpha_5} \left(\frac{p_t^c}{p_{t-1}^c} \right)^{1-\alpha_5} \left(\frac{L_t}{\overline{L}} \right)^{\alpha_6}$$

The weight that wage contracts attach to expected changes in the price level is α_5 while the weight assigned to departures from full employment ($\overline{L}$) is α_6. Equation (32) can lead to short-run unemployment if unexpected shocks cause the real wage to be too high to clear the labour market. At the same time, employment can temporarily exceed its long run level if unexpected events cause the real wage to be below its long run equilibrium.

1.4 The Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among inputs in fixed proportions, which we set to 1996 values. Total government outlays include purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales taxes, corporate and personal income taxes, and from sales of new government bonds. In addition, there can be taxes on externalities such as carbon dioxide emissions. The government budget constraint may be written in terms of the accumulation of public debt as follows:

(33) $$\dot{B}_t = D_t = r_t B_t + G_t + TR_t - T_t$$

where B is the stock of debt, D is the budget deficit, G is total government spending on goods and services, TR is transfer payments to households, and T is total tax revenue net of any investment tax credit.

We assume that agents will not hold government bonds unless they expect the bonds to be paid off eventually and accordingly impose the following transversality condition:

(34) $$\lim_{s \to \infty} B(s)\, e^{-(R(s)-n)s} = 0$$

This prevents per capita government debt from growing faster than the interest rate forever. If the government is fully leveraged at all times, (34) allows (33) to be integrated to give:

(35) $$B_t = \int_t^{\infty} (T - G - TR)\, e^{-(R(s)-n)(s-t)} ds$$

Thus, the current level of debt will always be exactly equal to the present value of future budget surpluses.[9]

The implication of (35) is that a government running a budget deficit today must run an appropriate budget surplus as some point in the future. Otherwise, the government would be unable to pay interest on the debt and agents would not be willing to hold it. To ensure that (35) holds at all points in time we assume that the government levies a lump sum tax in each period equal to the

[9] Strictly speaking, public debt must be less than or equal to the present value of future budget surpluses. For tractability we assume that the government is initially fully leveraged so that this constraint holds with equality.

value of interest payments on the outstanding debt.[10] In effect, therefore, any increase in government debt is financed by consols, and future taxes are raised enough to accommodate the increased interest costs. Other fiscal closure rules are possible, such as requiring the ratio of government debt to GDP to be unchanged in the long run. These closures have interesting implications but are beyond the scope of this paper.

1.5 Financial Markets and the Balance of Payments

The eight regions in the model are linked by flows of goods and assets. Flows of goods are determined by the import demands described above. These demands can be summarized in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries.

Trade imbalances are financed by flows of assets between countries. Each region with a current account deficit will have a matching capital account surplus, and vice versa.[11] We assume asset markets are perfectly integrated across regions.[12] With free mobility of capital, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

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[10] In the model the tax is actually levied on the difference between interest payments on the debt and what interest payments would have been if the debt had remained at its base case level. The remainder, interest payments on the base case debt, is financed by ordinary taxes.

[11] Global net flows of private capital are constrained to be zero at all times – the total of all funds borrowed exactly equals the total funds lent. As a theoretical matter this may seem obvious, but it is often violated in international financial data.

[12] The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980).

(36) $$i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j}$$

where i_k and i_j are the interest rates in countries k and j, μ_k and μ_j are exogenous risk premiums demanded by investors (calibrated in the baseline to make the model condition hold exactly with actual data), and E_k^j is the exchange rate between the currencies of the two countries.

Capital flows may take the form of portfolio investment or direct investment but we assume these are perfectly substitutable *ex ante,* adjusting to the expected rates of return across economies and across sectors. Within each economy, the expected returns to each type of asset are equated by arbitrage, taking into account the costs of adjusting physical capital stock and allowing for exogenous risk premiums. However, because physical capital is costly to adjust, any inflow of financial capital that is invested in physical capital will also be costly to shift once it is in place. This means that unexpected events can cause windfall gains and losses to owners of physical capital and *ex post* returns can vary substantially across countries and sectors. For example, if a shock lowers profits in a particular industry, the physical capital stock in the sector will initially be unchanged but its financial value will drop immediately.

1.6 Money Demand

Finally, we assume that money enters the model via a constraint on transactions.[13] We use a money demand function in which the demand for real money balances is a function of the value of aggregate output and short-term nominal interest rates:

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[13] Unlike other components of the model we simply assume this rather than deriving it from optimizing behavior. Money demand can be derived from optimization under various assumptions: money gives direct utility; it is a factor of production; or it must be used to conduct transactions. The distinctions are unimportant for our purposes.

$$MON = PY\, i^{\varepsilon} \tag{37}$$

where Y is aggregate output, P is a price index for Y, i is the interest rate, and ε is the interest elasticity of money demand. The supply of money is determined by the balance sheet of the central bank and is exogenous.

1.7 Assessing the Model

All models have strengths and weaknesses and the MSG3 model is no exception. Its most important strength is that it distinguishes between financial and physical capital and includes a fully integrated treatment of intertemporal optimization by households, firms and international portfolio holders. This allows the model to do a rigorous job of determining where physical capital ends up, both across industries and across countries, and of determining who owns the physical capital and in what currency it is valued. Overall, the key feature of the MSG3 model is its treatment of capital, and that is also what most distinguishes it from other models in either the macro, trade or CGE literatures.

The MSG3 model also has other strengths. All budget constraints are satisfied at all times, including both static and intertemporal budget constraints on households, governments and countries. Short-run behaviour captures the effects of slow wage adjustment and liquidity constraints, while long-run behaviour is consistent with full optimization and rational expectations. In addition, wherever possible the model's behavioral parameters are determined by estimation, which is discussed further in Chapter 4 of McKibbin and Wilcoxen (2001).

3. A Theoretical Framework for Incorporating Demographic Change in a multi-country model

The theoretical framework used in this paper is that of Bryant and McKibbin (2001) applied to the MSG3 multi-country summarized above. The MSG3 model has been extended to include demographic considerations, such that economic agents in the model now possess finite life-spans, and their incomes vary as they age. This section draw heavily on Faruqee (2000a, 2000b), who extended the Blanchard (1985) model of finitely-lived agents to include aging considerations. The remainder of this section follows Faruqee closely.

1.8 Population and individual cohorts

Abstracting away from the children in a population[14], assume a population comprised entirely of adults, into which a new cohort of adults is born in each period. At any time *s*, the size of the newly born cohort is dependent on the size of the existing population, $N(s)$, and the birth-rate $b(s)$. Following Blanchard, we make the simplifying assumption that at any time *s*, all agents in the economy face the same mortality rate[15], $p(s)$, defined here as the probability of any given agent dying before the next period. Thus, after a cohort is born at time *s*, the number of survivors in the cohort, at a subsequent time *t*, is given by:

$$n(s,t) = b(s)N(s)e^{-\int_s^t p(v)\,dv} \tag{38}$$

The population size, for any time *t*, can then be determined by summing the number of survivors, at time *t*, from all of the cohorts that have ever been born:

$$\begin{aligned} N(t) &= \int_{-\infty}^{t} n(s,t)\; ds \\ &= \int_{-\infty}^{t} b(s)N(s)e^{-\int_s^t p(v)\,dv}\; ds \end{aligned} \tag{39}$$

14. A forthcoming paper (McKibbin and Nguyen (2001)) will address the issue of adding children to the model, the associated theoretical implications, and the effect this will have on simulation results.

15. Blanchard notes that the assumption of a common mortality rate is a reasonable approximation for adults within the ages of 20 to 40. The fact that children and retirees, whose behaviour is of interest in studies of population aging, fall outside of this age bracket certainly indicates that the issue requires further attention.

where $N(t)$ represents the total population size, at time t.

Taking the derivative with respect to time yields an equation governing the evolution of the population size over time:

$$\frac{\dot{N}(t)}{N(t)} = b(t) - p(t) \tag{40}$$

The above equation has a simple interpretation: the population grows at a rate determined by the birth rate less the mortality rate.

1.9 Optimal Consumption

Economic agents attempt to maximise the expected utility derived from their lifetime consumption. Agents must take into account the uncertainty of their life-spans and thus they discount their planned future consumption by the probability that they may not survive through to future periods. Assuming a logarithmic utility function, each agent will maximise the following:

$$max \quad \int_t^{\infty} \ln c(s,v) e^{-\int_t^v [\theta + p(i)] di} \, dv \tag{41}$$

subject to the budget constraint:

$$\dot{w}(s,t) = [r(t) + p(t)] w(s,t) + y(s,t) - c(s,t) \tag{42}$$

where $c(s,t)$ is the consumption, at time t, of an agent who was born at time s, θ is the rate of time preference, $w(s,t)$ is the financial wealth that an agent born at time s holds at time t; and $r(t)$ is the interest rate earned on financial wealth. In addition to interest payments, agents also earn a rate of

$p(t)$ on their holdings of financial wealth, due to the assumption of a life insurance market, as in Blanchard.

The optimal consumption path can be shown to be:

(43) $$c(s,t) = (\theta + p(t))\left[w(s,t) + h(s,t)\right]$$

where $c(s,t)$ is the consumption, at time t, of an agent born at time s, and $h(s,t)$ represents the human wealth of the agent. An agent's human wealth is defined as the present value of the agent's expected income over the remainder of his or her lifetime:

(44) $$h(s,t) = \int_t^{\infty} e^{-\int_t^v r(i)+p(i)\,di} y(s,v)\ dv$$

At any time t, then, the sum of financial wealth and human wealth—$w(s,t)$ and $h(s,t)$—represents an agent's total wealth: the means by which the agent can pay for his or her future consumption. Agents consume a proportion of their total wealth each period, the proportion being determined by their rate of time preference, and their likelihood of perishing before the next period.

Aggregate consumption, financial wealth and human wealth are simply the sums of the individual consumption, financial wealth and human wealth for all agents in the economy:

(45) $$C(t) = \int_{-\infty}^{t} c(s,t)n(s,t)\,ds$$

(46) $$W(t) = \int_{-\infty}^{t} w(s,t)n(s,t)\,ds$$

(47) $$H(t) = \int_{-\infty}^{t} h(s,t)n(s,t)\,ds$$

where $C(t)$ represents aggregate consumption, $W(t)$ is aggregate financial wealth, and $H(t)$ is aggregate human wealth.

The aggregate consumption function can be shown to be given by:

(48) $$C(t) = (\theta + p(t))[W(t) + H(t)]$$

1.10 Labour Supply, and Demographic Considerations

Empirically, one of the key economic characteristics that changes with age is the income that a person receives. We thus introduce age-earnings profiles into the model, such that an agent's income is determined by his or her age. Faruqee (2000a) utilises hump-shaped age-earnings profiles, fitted to Japanese data using non-linear least squares (NLS). Intuitively, the hump-shaped profile of age-earnings reflects the fact that young adults generally have incomes that are increasing as the young individuals age and gain more experience. After a certain age, however, earnings decline, reflecting first the decreasing productivity associated with aging, and then eventually reflecting retirement behaviour.

Individual income is not specified as suddenly dropping to zero, at a given retirement age, for two reasons. Firstly, in practice, people typically retire at various ages, and some retirees continue to earn alternative forms of income even after retirement. Secondly, a discontinuous age-earnings profile introduces complications with respect to implementation in the MSG3 model.

We model the evolution of income over the lifecycle by beginning with the assumption that individuals are paid a wage for each unit of effective labour that they supply. Assume also that effective labour supply is a function of an individual's age and of the current state of technology.

Aside from aging considerations, note that as time passes, the technological progress in the economy has a positive effect on the value of effective labour supplied by all agents.

The effective labour supply, at time *t*, of an individual born at time *s*, is given by:

(49) $$l(s,t) = e^{ut}[a_1 e^{-\alpha_1(t-s)} + a_2 e^{-\alpha_2(t-s)} + (1 - a_1 - a_2)e^{-\alpha_3(t-s)}]$$;(a_i>0, α_i>0 for *i*=1 to 3)

The $e^{\mu t}$ component (where μ is the rate of technological progress) captures productivity increases due to advancements in technology. The remaining terms represent the non-linear functional form used to estimate the hump-shaped profile. The a_i and α_i parameters are estimated, based on empirical data, using NLS[16]. The hump-shaped effective labour supply specification will in turn lead to a hump shaped age-earnings profile.

Individual labour supply can be re-written as:

(50) $$l(s,t) = \sum_{i=1}^{3} l_i(s,t)$$

where:

(51) $$l_i(s,t) = e^{\mu t} a_i e^{-\alpha_i(t-s)};$$ (a_i>0,α_i>0)

and:

(52) $$a_3 = (1 - a_1 - a_2)$$

Thus, the evolution of an agent's labour supply over time is given by:

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[16] Values used in this paper are as estimated by Faraque for Japan: $\alpha_1 = 0.073$, : $\alpha_2 = 0.096$, : $\alpha_3 = 0.085$ and $a_1 = a_2 = 200$.

(53) $$\dot{l}(s,t) = \sum_{i=1}^{3} (\mu - \alpha_i) l_i(s,t)$$

Aggregate effective labour supply in the economy for any time *t*, *L*(*t*), is the sum of the effective labour supplied by all individuals in the economy.

(54) $$\begin{aligned} L(t) &= \int_{-\infty}^{t} n(s,t) l(s,t)\ ds \\ &= \sum_{i=1}^{3} L_i(t) \end{aligned}$$

where:

(55) $$L_i(t) = \int_{-\infty}^{t} n(s,t) l_i(s,t)\ ds$$

It can then be shown that:

(56) $$\dot{L}(t) = (\mu - \alpha_1 - p(t))L_1(t) + (\mu - \alpha_2 - p(t))L_2(t) + (\mu - \alpha_{3i} - p(t))L_3(t) + e^{\mu t} b(t) N(t)$$

The intuition behind the equation above is that the aggregate labour supply of the economy changes as the entire population ages, and also as new agents are born into the labour force.

1.11 Income and Human Wealth

Previously, individual human wealth was defined as the expected present-value of future income over an individual's remaining lifetime. Having defined the profile of labour supply over the lifecycle, we can now be more explicit with respect to income. An individual's income is the after tax labour income, less lump sum taxes, plus government transfers:

(57) $$y(s,t) = [1 - \tau(t)] w(t) l(s,t) + tr(t) - tx(t)$$

where $y(s,t)$ denotes the income, at time t, of an individual born at time s; $l(s,t)$ is the individual effective labour supply; $\tau(t)$ is the marginal tax rate; and $w(t)$ is the wage paid per unit of effective labour. We assume that the distribution of lump sum taxes, *tx*, and government transfers, *tr*, is uniform across the population, thus the year of an individual's birth is not a determinant of either of these two variables.

Taking the time derivative of $h(s,t)$, we obtain:

(58) $$\dot{h}(s,t) = [r(t) + p(t)]h(s,t) - [1-\tau(t)]w(t)l(s,t) - [tr(t) - tx(t)]$$

The intuition for the equation above is that as time passes, future earnings are no longer as distant in time and should therefore be discounted by a lesser magnitude—this explains the $(r + p)$ growth—while at the same time, some income has just been received, and thus can no longer be considered part of human wealth—this explains why the current period's income is subtracted.

We can show that the evolution of aggregate human wealth is governed by the following relationship:

(59) $$\dot{H}(t) = r(t)H(t) - Y(t) + h(t,t)n(t,t)$$

The intuition behind the equation above is that aggregate human wealth changes over time as future income draws nearer, thus H grows at the rate of r; the presence of death, and hence p, does not affect *aggregate* human wealth, because insurance companies redistribute the wealth of the dead. Further, in each period, people receive income, and having been received, it can no longer be considered human wealth. The last term on the right hand side represents the new human wealth that the newly-born cohort brings to the economy, each period.

4. Some Preliminary Results

In this section we present results for a stylised demographic shock in Japan. We commence the simulation in 1990 on the assumption that the demographic shock becomes news in that year. The assumption that the demographic shock is unanticipated until 1990, might be regarded as problematic for a number of reasons. In a model with rational expectations we have little choice than to make that assumption. The main consequence is that the results for 1990 and years around that date are likely to be less accurate than results by the time the model reaches 2000 and beyond. Given we are interested in what is likely to happen from now for the next century this assumption may not be such a problem for the analysis. However, the reader is cautioned to interpret the results from 1990 to 2000 with great care.

A stylised shock that we attempt to replicate is presented in Figure 1. This figure contains projections from the United Nations Population Division World Population Prospects: The 1998 Revision (Medium Variant Projections). These are converted into adult population projections because the analytical modelling approach ignores children. Thus the shock is not realised until the children born in the 1970s and 1980s become adults in 1990. We plan to implement the approach of incorporating children in a future paper following the papers by Bryant and Velculescu (2001) and McKibbin and Nguyen (2001). Nonetheless we must modify the projection for this paper to take into account this rather extreme assumption.

Figure 2 plots the shocks to the birth rate and mortality rates from 1990 to 2100. This shock is characterized as a sharp fall in the rate of emergence of new adults into the population from 1990 to 2050. After 2050, the birth rate (emergence of adults) gradually returns to baseline. Figure 3 shows the impact of the assumptions on the population, shown as percent deviation from what would have been the case without the change in the birth rate. This figure also shows the implications for the effective labour supply. The overshooting of effective labour supply, relative to the population decline, reflects the aging of the population and the movement of the current working population along the age earnings profile with decline effectiveness as they move past the peak earning years of 40-45 year of age. The profile of the effective labour force (relative to the baseline) seems rather large but reflects the size of the estimated coefficients of the age earnings profile. Future drafts of this paper will explore the sensitivity of the results to these parameters.

Figures 4 through 6 shows results for Japan for the shock. These results are expressed as deviation from the baseline (which has the estimated age earnings profiles but no changes in birth rates and death rates) expressed as either percent deviation from baseline or percentage point deviation from baseline as indicated.

The realization that the demographic shock is to occur leads to a rise in private saving (fig 4, top right hand chart). Per capita saving rises even more than aggregate because the population is falling throughout the early years of the shock. An interesting aspect of the shock is that although real GDP growth is expected to decline over time, there is a realization that the capital stock will need to rise in Japan as workers become scarce in the future. The initial rise in investment caused by a desire to gradually increase the capital stock, causes a short term Keynesian style rise in GDP in the early years of the shock. This lasts for a number of decades until the large fall in the number of people in Japan leads to a fall in the capital stock in Japan. The surprising result is contained in figure 6 in which the current account is shown to move towards deficit relative to baseline. This result is due to the combination of the rise in saving more than offset by a rise in private investment. Thus although the saving response is as expected from standard life cycle models, the endogenous investment response dominates. Thus rather than a capital outflow, the rise in private saving finances a period of capital deepening in Japan. Indeed this result would be expected to be ambiguous, and greater sensitivity testing is required before pushing too hard on this result.

The movement in the real exchange rate is consistent with the relative changes in saving and investment. In the long run, the consumption side of the model in which all households in all countries consume a share of Japanese goods in their consumption bundle implies that as less Japanese goods are produced, their relative value will rise. Thus a long run real appreciation of the Yen is expected. In the short run, this effect partly determines the real exchange rate. The real exchange rate is also determined by the allocation of international financial capital. The strong investment response suggests that the capital flow effect of a smaller capital outflow from Japan relative to baseline, implies a real appreciation in the short run as well. Again this result could go either way in the short run, although the long run trend will be tied down by the assumption of global preferences of households in the model.

One inference that the reader might draw from these results is that because the actual response of the Japanese economy from 1990 to 2001 has been quite different, the model must be incorrect. However, an alternative inference is that the malaise in the Japoanese economy in the last decade has overshadowed the underlying process captured by this model. Indeed it is surprising to me how strong private investment has been in Japan during the 1990s despite the economic slowdown. Thus there needs to be an assessment of the range of shocks facing Japan during the 1990s, independently of the demographic shock, before a firm conclusion can be drawn[17].

5. Summary and Conclusion

The preliminary results in this paper suggest some surprising implications of population aging in Japan. They may be specifically driven by key assumptions in the modelling framework used. Future drafts of this paper will include tests of robustness. What the paper shows is that despite the standard view that Japan would be expected to run a current account surplus followed by a deficit as the population ages, this inference only considers the adjustment of consumption and saving in Japan. Allowing investment to also respond to the demographic shock, can lead to the opposite result in the short run as a period of capital deepening in Japan might be expected as capital is used to substitute for increasingly scarce workers. To the extent that foreign goods are more substitutable for Japanese goods in consumption bundles of Japanese households, this effect would be expected to be smaller since investment could be undertaken in foreign economies and the goods reimported at a future date. Nonetheless in this model, Japanese goods are imperfect substitutes for foreign goods and this is likely to be an important source of the results we find of a preference for maintaining output in Japan rather than undertaking large investments in countries outside Japan.

Theses results are preliminary and significantly more work is needed on the modelling the nature of the demographic shock as well as sensitivity analysis on the key determinants of the macroeconomic outcomes. Secondly, Japan is not undergoing a demographic transition in isolation

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[17] See for example Callen and McKibbin (2001).

from the rest of the world and once the foreign demographic changes are incorporated into the analysis the results for Japan could be quite different. Nonetheless this preliminary report suggests that we the approach taken in this paper and related research in the Brookings Insitution Project on demographic change is very promising.

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Table 1: Selected Dependency Ratios

	2000	2050
	Selected Old Age Dependency Ratios (60+ to 15-59)	
World	16.7%	36.3%
Australia 1	25.9%	52.2%
China	15.5%	55.5%
China, Hong Kong SAR 2	20.7%	69.9%
Dem. Peoples's Rep. of Korea	15.8%	38.6%
France	33.8%	63.7%
Germany	38.0%	77.0%
Greece	38.0%	88.0%
India	12.9%	34.5%
Indonesia	12.4%	38.7%
Japan	37.4%	93.7%
Malaysia	11.1%	35.0%
Philippines	9.7%	32.4%
Republic of Korea	16.1%	65.8%
Russian Federation	29.1%	75.5%
Singapore	15.6%	68.6%
South Africa	9.4%	21.8%
Spain	34.3%	98.9%
Sri Lanka	14.4%	50.1%
Sweden	37.7%	78.1%
Switzerland	34.3%	80.0%
Thailand	12.4%	48.5%
United Kingdom	34.1%	66.5%
United States of America	26.0%	49.2%
Viet Nam	12.6%	41.6%

Source : United Nations Population Division.
World Population Prospects: The 2000 Revision

Table 2: Demographic Estimates for Japan 1950-2050

A. HISTORICAL ESTIMATES

Indicator	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995
Population (thousands)										
Total	83,625	89,815	94,096	98,881	104,331	111,524	116,807	120,837	123,537	125,472
Males	41,003	44,111	46,176	48,531	51,205	54,880	57,468	59,393	60,658	61,526
Females	42,622	45,704	47,920	50,350	53,126	56,644	59,339	61,444	62,879	63,946
Sex ratio (per 100 females)	962	965	964	964	964	969	968	967	965	962
Age distribution										
Percentage aged 0-4	13.4	10.6	8.5	8.3	8.5	8.9	7.4	6.2	5.3	4.8
Percentage aged 5-14	22.1	23	21.7	17.6	15.5	15.4	16.2	15.4	13.1	11.2
Percentage aged 15-24	19.6	19.1	18.9	20.2	19	15.4	13.8	14.2	15.2	14.7
Percentageaged60orover	7.7	8.1	8.9	9.6	10.7	11.7	12.9	14.8	17.4	20.5
Percentage aged 65 or over	4.9	5.3	5.7	6.2	7.1	7.9	9	10.3	12	14.6
Median age (years)	22.3	23.6	25.5	27.3	29	30.4	32.6	35.2	37.4	39.7

	1950-1955	1955-1960	1960-1965	1965-1970	1970-1975	1975-1980	1980-1985	1985-1990	199Q-1995
Population change per year (thousand	1238	856	957	1090	1439	1057	806	540	387
Births per year (thousands)	2052	1664	1662	1805	2073	1733	1509	1321	1213
Deaths per year (thousands)	812	715	702	697	712	697	730	773	863
Population growth rate (percentage)	1.43	0.93	0.99	1.07	1.33	0.93	0.68	0.44	0.31
Crude birth rate (per 1.000 population)	23.7	18.1	17.2	17.8	19.2	15.2	12.7	10.8	9.7
Crude death rate (per 1.000 populatior	9.4	7.8	7.3	6.9	6.6	6.1	6.1	6.3	6.9
Totalfertilityrate(perwoman)	2.75	2.08	2.02	2	2.07	1.81	1.76	1.66	1.49
Gross reproduction rate (perwoman)	134	1.01	0.98	0.97	1.01	0.88	0.86	0.81	73
Net reproduction rate (perwoman)	1.19	0.95	0.94	0.97	0.98	0.87	0.85	0.8	0.72
Infant mortality rate (per 1.000 births)	51	37	25	16	12	9	7	5	4
Life expectancy at birth (years)									
Both sexes combined	63.9	66.8	69	71.1	73.3	755	76.9	78.3	79.5

B. MEDIUM-VARIANT PROJECTIONS

	1995	2000	2005	2010	2015	2020	2025	2030	2040	2050
Population (thousands)										
Total	125472	126714	127457	127315	126070	123893	121150	118145	111691	104921
Males	61526	62093	62423	62303	61619	60471	59058	57541	54395	51162
Females	63946	64621	65034	65013	64451	63422	62092	60604	57296	53759
Sex ratio (per 100 females)	96.2	96.1	96	95.8	95.6	95.3	95.1	94.9	94.9	95.2
Age distribution										
Percentage aged 0-4	4.8	4.9	5	4.9	4.6	4.3	4.3	4.5	4.6	4.4
Percentage aged 5-14	11.2	9.9	9.6	9.9	10	9.6	9.2	9	9.4	9.4
Percentage aged 15-24	14.7	12.6	11	9.8	9.7	10.2	10.4	10.1	9.5	10
Percentage aged 60 or over	20.5	23.1	25.8	29.3	31.2	32.1	32.9	34.2	37.4	37.6
Percentage aged 65 or over	14.6	17.1	19.2	21.5	24.6	26.2	26.7	27.3	30.3	31.8
Median age (years)	39.7	41.2	42.5	43.8	45.2	46.9	48.4	49.3	49.5	49

	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-2040	2040-2050
Population change per year (thousand	248	149	-28	-249	-435	-549	-601	-645	-677
Birtl'ls per year (thousands)	1254	1288	1246	1154	1080	1054	1061	1041	946
Deaths per year (thousands)	1005	1139	1274	1403	1515	1603	1662	1686	1623
Population growth rate (percentage)	0.2	0.12	-0.02	0.2	-0.35	-0.45	-0.5	-0.56	-0.63
Crudebirtl'lrate (per 1,000 population)	9.9	10.1	9.8	9.1	8.6	8.6	8.9	9.1	8.7
Crude deatl'l rate (per 1,000 populatior	8	9	10	11.1	12.1	13.1	13.9	14.7	15
Total fertility. rate (perwoman)	1.43	1.47	1.54	1.61	1.68	1.73	1.75	1.75	1.75
Gross reproduction rate (perwoman)	0.7	0.71	0.75	0.78	0.82	0.84	0.85	0.85	0.85
Net reproduction rate (per woman)	0.69	0.71	0.74	0.77	0.81	0.84	0.85	0.85	0.85
Infant mortality rate (per 1 ,000 births)	4	4	4	4	4	4	4	4	4
Life expectancy at birth (years)									
Both sexes combined	80	80.3	80.7	81.1	81.5	81.9	82.3	82.8	83.6
Net migration per year (thousands)	0	0	0	0	0	0	0	0	0
Net migration rate (per 10000 populati	0	0	0	0	0	0	0	0	0

Source: Population Division, Department of Economic and Social Affairs of United Nations Secretariat, World Population Prospects: The 1998 Revisionn.

Figure 1: Medium-Variant, Adult Population Projections

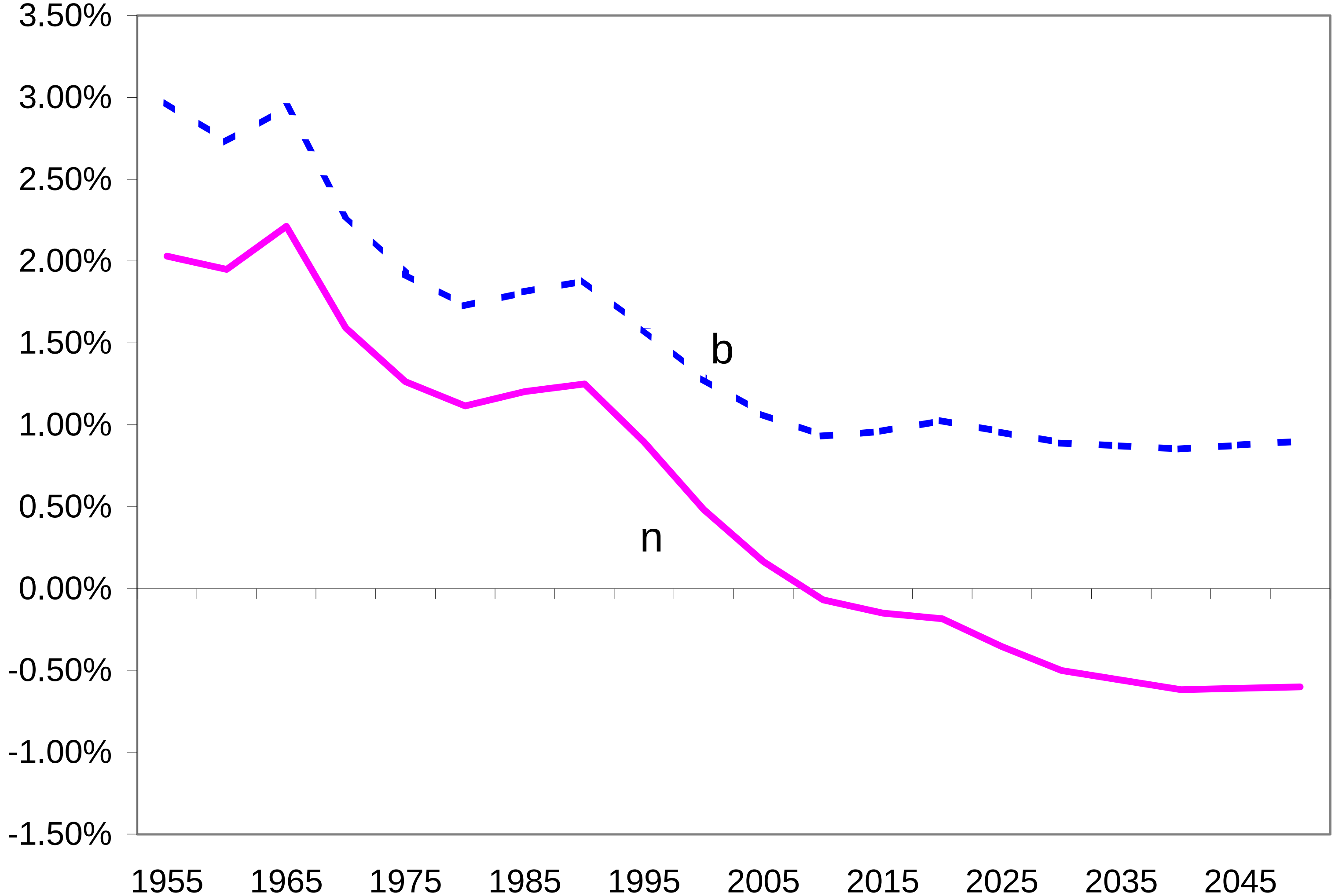

Figure 2
Decline in Japanese Fertility and Mortality:
Birth Rates, Mortality Rates, Population Growth Rates

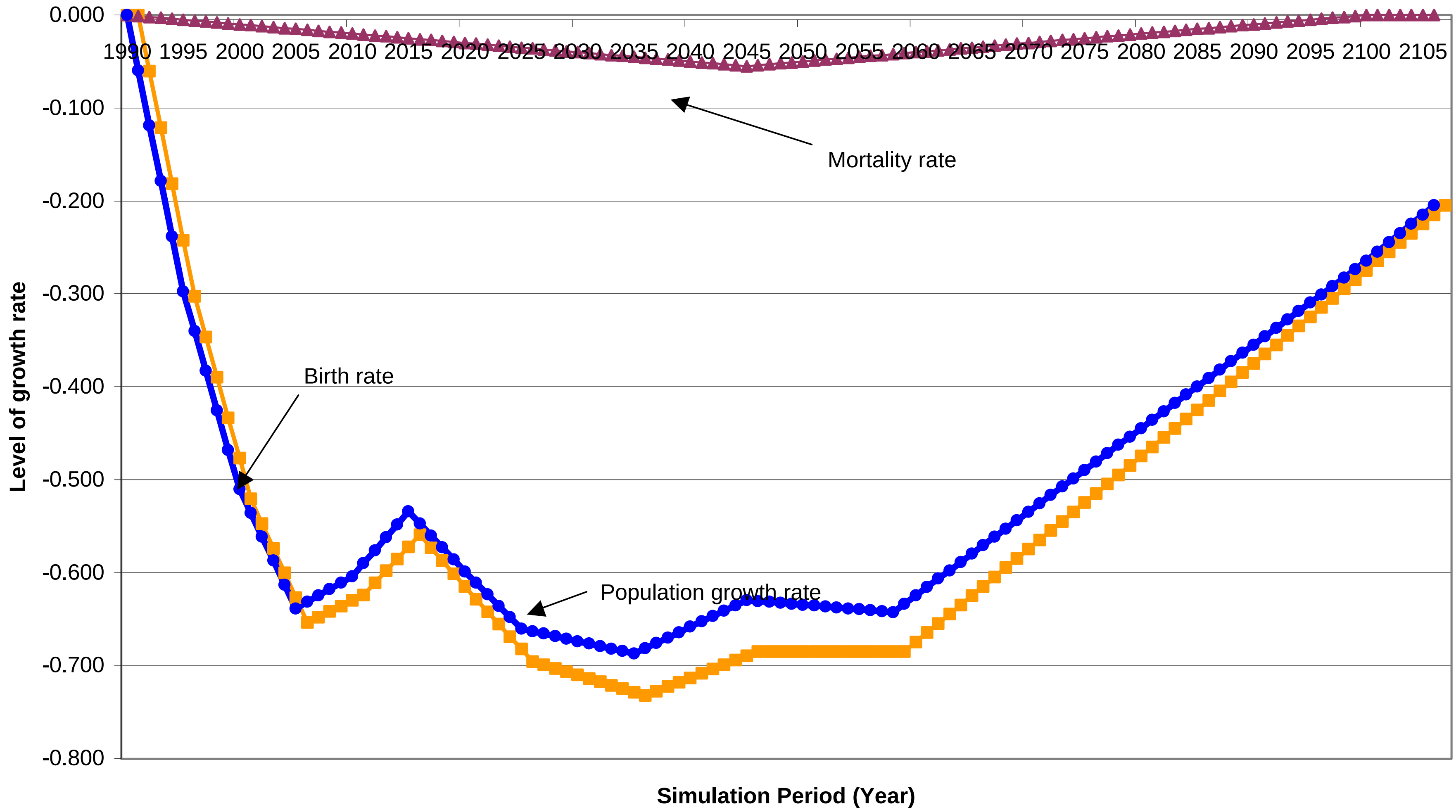

Figure 3
Effective Labor supply and population profiles for a decline in Japanese Fertility and Mortality

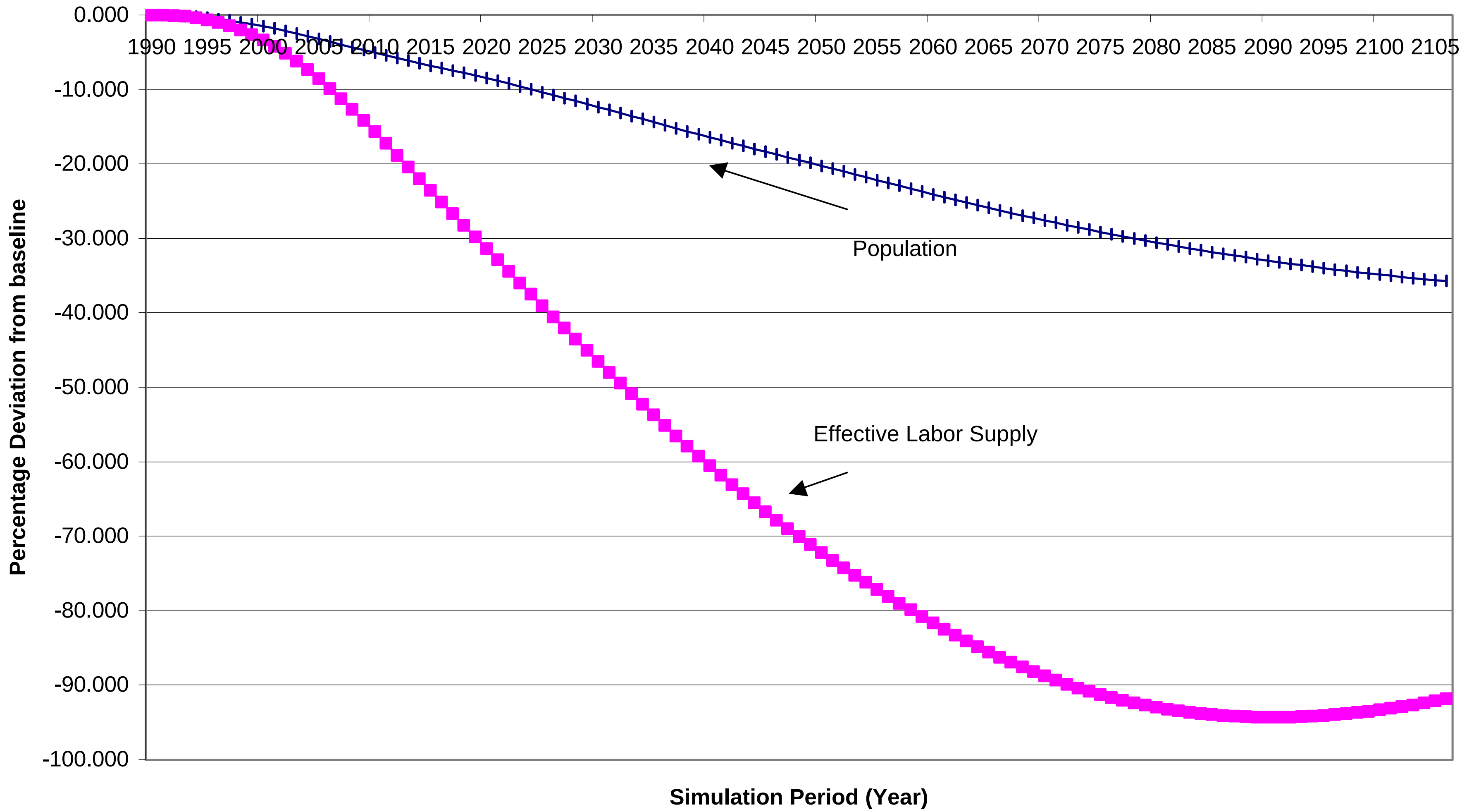

Figure 4: Real Implications of a Decline in Fertility and mortality in Japan - MSG3 Model

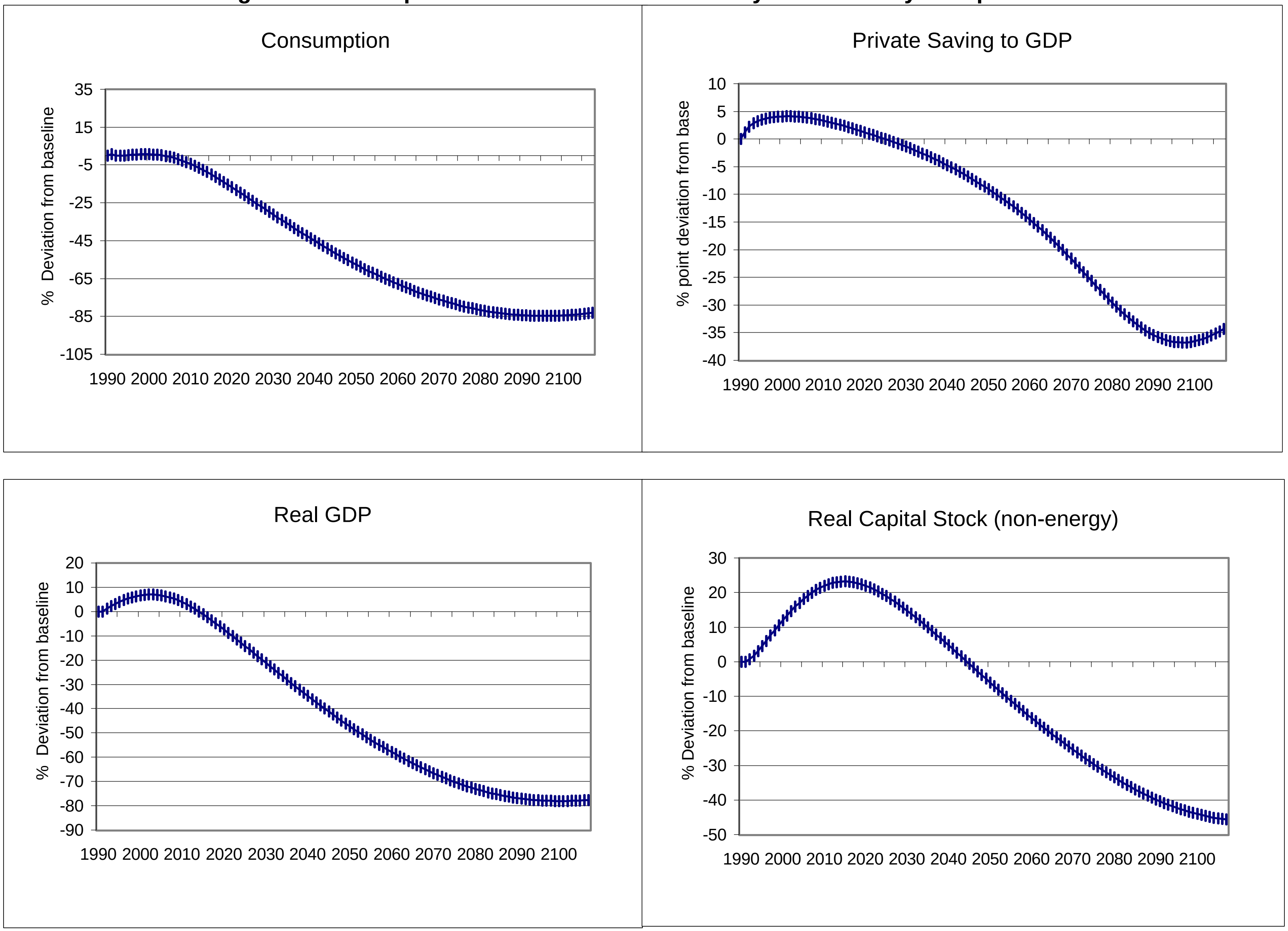

Figure 5: Financial Implications of a decline in Fertility in Japan - MSG3 Model

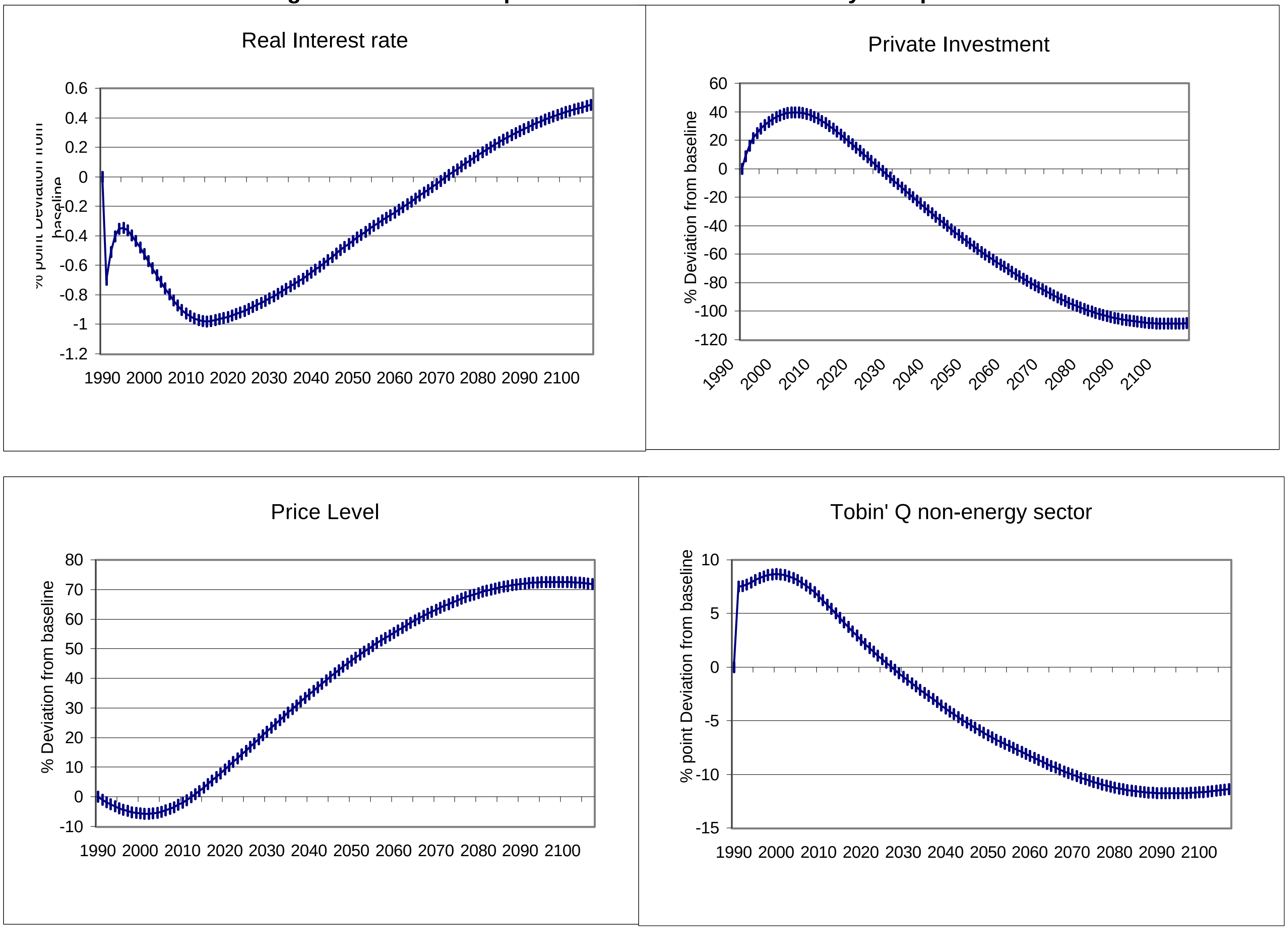

Figure 6: International Implications of a decline in fertility and mortality in Japan - MSG3 Model