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Population Aging, Productivity, and Growth in Living Standards

William Scarth

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SEDAP Research Paper No. 90

January 2003

Note: This paper is cross listed as No. 380 in the McMaster University QSEP Report Series.

Population Aging, Productivity, and Growth in Living Standards

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December 2002

*Without implication, I thank participants at the CSLS-IRPP Workshop in January 2002, and in particular, Marcel Merette, Andrew Sharpe, Daniel Schwanen and Malick Souare for helpful comments. Also, the able research assistance of Krishna Sen Gupta and financial support from the SEDAP research program is gratefully acknowledged. This paper appears in *The Review of Economic Performance and Social Progress: Towards a Social Understanding of Productivity*, Volume 2, December 2002, edited by Andrew Sharpe, France St-Hilaire and Keith Banting.

Abstract

Population aging creates both a problem (higher taxes on a small group of workers to finance higher public pension and health care costs) and automatic adjustments that help to address that problem. The prospect of longer retirement involves an increased incentive to invest in physical capital, and labour scarcity leads to higher pre-tax wages and an increased incentive to invest in human capital. Thus, productivity growth can be favourably affected by aging. The likely empirical magnitude of this beneficial effect is assessed in this paper.

1. Introduction

The productivity challenge is gaining attention among policy makers. One reason for this is that the Finance Minister has “defeated” the deficit and he can now afford to shift his focus to other initiatives that address the same long-run objective – to increase the living standards of Canadians over time. A second reason for this is the warning that has been issued by demographers. For example, Denton and Spencer (1998) note that the rate of growth of per capita *GDP* is certain to fall significantly over coming decades unless either the immigration rate or the productivity growth rate increases rather dramatically. It is the aging of Canada's population that lies behind this concern. The purpose of this paper is to evaluate some of the economic analyses that have attempted to put this concern about aging into perspective. As we shall see, it is *possible* that aging can lead to increases in productivity growth – even if no policy initiative is taken. In other words, population aging may create both a problem and the solution to that problem.

For the remainder of this introductory section, I explain more fully the basis for the concern about aging. Then, in three separate sections, I summarize research that focuses on reasons why it is reasonable to argue that our economy possesses built-in mechanisms that serve to insulate living standards (at least to *some* extent) from the adverse effects of an aging population. In section 2 of the paper, I consider how an aging population affects society's incentive to invest in physical capital accumulation. In section 3, the focus shifts to an open economy setting, where variations in the level of foreign indebtedness play a role that is just as important as changes in the capital stock. Finally, in section 4, I consider how aging affects investment in human capital. Concluding remarks are offered in section 5, and a brief appendix provides a fuller explanation of some of the material in section 4.

Demographers certainly do predict that there will be dramatic growth in Canada's elderly dependency ratio – the number of individuals over 65 years of age divided by the number of individuals aged between 15-64 years. This ratio will essentially double – from 19.2% in 1996 to 38.5% in 2040. The most common reaction to this development is that – with so few workers trying to support so many dependents – it seems obvious that our living standards will have to fall. Indeed, many studies (such as a World Bank Report in 1994) have referred to this development as a "crisis". Other studies (see, for example, Emery and Rongve (1999) and Merette (2002)) reach much more optimistic conclusions, sometimes referring to the aging population phenomenon as "much ado about nothing". How are non-specialists to react when there is such a dispersion of views in the field?

First, it should be noted that Canadians have already experienced an *overall* dependency ratio that was just as high as the level to which the overall dependency will rise in coming decades. In the 1950s, the youth dependency ratio was extremely high – when the baby boom generation was too young to work. But the overall dependency ratio was pulled down by the fact that there were relatively few older Canadians in those years. As time has passed since then – especially given the dramatic drop in birth rates (the so-called baby bust) – things have been in the process of switching. The youth dependency ratio has been falling while the old-age dependency ratio has been rising. The overall dependency ratio fell as baby boomers entered the working years, and now it is rising again as boomers begin to retire. We managed to cope quite well with the high overall dependency ratio before. Optimists presume that we can do so again.

Less optimistic individuals stress the fact that it costs a lot more to provide health care to the elderly than it does to provide education for the young. Numerous studies (such as the Auditor-General (1998) and Robson (2001)) have estimated that Canadian governments may need another 3 percentage points of *GDP* in revenue to finance existing programs for the elderly – despite some savings on other programs – when baby boomers have retired. Since adequate health is needed for individuals to enjoy consumption goods, and since an aging population involves shifting resources away from the production of consumption goods into the health sector, it seems that there may well be grounds for concern about average living standards.

Despite these estimates, optimists draw attention to several factors. First, with increased life expectancy, and growing acceptance of flexible working arrangements (such as job sharing) baby boomers may choose to participate in the work force until a later age than have their predecessors. In addition, Canadian immigration rates may rise. Both these developments may limit the predicted labour shortage. Second, even if these developments do not occur, and labour does become scarce, that scarcity of labour should cause its price to rise. After all, with each scarce worker having more capital to work with, her productivity will be higher. The resulting increase in pre-tax wages may make it possible for governments to tax the generation that follows the baby boomers more (to afford the extra health and pension costs for the boomers) and still leave the young better off. The next section of the paper explains how economists evaluate this possibility.

2. Aging, Relative Factor Prices, and Investment in Capital

Economists use models of overlapping generations to estimate the effects of demographic changes on living standards. The simplest framework (Diamond (1965)) involves just two generations living at any point in time – the "young" and the "old". The young work with the existing stock of capital to produce output, and they decide how much of their income to consume that period (and how much to save so that they can supplement the public pension benefits they will receive during their old age). Saving takes the form of capital accumulation, and the decision to save is affected by the after-tax return that can be expected when the capital is employed during the individual's retirement period.

To derive numerical predictions from a model of this sort, economists need to specify how individuals make their consumption-savings choice, and how firms make their labour-capital choice when producing goods. The household decision depend on how impatient people are, how constrained they are in their attempts to borrow, how accurately they can predict future wages and interest rates (the yield on capital). The decisions made by firms depend on how easily labour can be substituted for capital in production processes, how rapidly capital depreciates, and the degree of competition among firms. Standard practice involves consulting the empirical studies concerning all these issues, and with those results as a guide, selecting representative parameter values for the model economy. The model economy is then used to simulate various developments, and numerical estimates of what can be expected to occur are calculated.

Many economists have constructed model economies of this sort and reported simulation results. I summarize the results of one such study here – that by Scarth and Souare (2002). Their study is the easiest to understand since it involves the simplest, baseline version of the overlapping model to study the aging phenomenon. Fortunately, their results are representative of many of the more involved studies. To simulate the aging population, we need a base for comparison. Initially, therefore, the model economy is in equilibrium with each generation the same size as all the others. Then, a bigger baby-boom cohort arrives, so that the economy involves more young than old for an entire generation. The post-baby-boom cohort is the same size as the pre-baby-boom cohorts, so when the baby boomers become the old generation, the model economy goes through conditions that are designed to be representative of what Canadians will confront in the next few decades. What are the results?

When the baby boomers are young, their large numbers push both pre-tax wages and the tax rates faced by each individual down. In most simulations, the former effect dominates the latter, so living standards for this cohort fall somewhat. The pre-baby-boom generation is better off, however. Since they own the capital that has become relatively scarce when they are old, and since they also benefit from lower tax rates, their incomes and living standards rise. Overall, consumption of the *average* individual rises by close to 2 percent. This analysis is consistent with what we have observed in Canada during the mid-1970s to the mid-1990s period, when baby-boomers flooded the labour market and contributed to very slow growth in wages, and older Canadians enjoyed very high interest income.

When the baby boomers constitute the old generation in the model economy, capital is the relatively abundant factor of production, so interest rates fall and wage rates rise. As a result, the old suffer a drop in their living standards, while the young – the post baby boomers – enjoy an increase in consumption. The model confirms the proposition that the wages of the young rise more than do their taxes, so they should welcome the aging of the generation that has preceded them. Nevertheless, we should not make too much of this result, since – considering both young and old as a group – it turns out that average living standards fall by about 2 percent. Furthermore, when the baby boomers are retired, they constitute the majority of the population. Thus, they have the political power to increase the benefits paid to the old. In this way, part of the drop in their living standards can be passed on to the post baby boom generation. Overall, then, the most important outcome is that average living standards fall by about 2 percent.

This set of results is surprisingly unaffected when major changes in the model economy are considered: whether households are liquidity constrained, whether individuals within the model accurately anticipate demographic changes and their effects, and whether governments offer favourable tax treatment for household saving. This latter issue has been stressed in the literature (especially by Merette (2002)). As the baby boom generation ages, the RRSP system shifts from being an arrangement that can limit government revenue (when the majority of the population is working and getting tax breaks by contributing to their retirement savings plans) to one that can increase government revenue (when the majority of the population is retired and having to pay tax on the income generated by that savings). But the model economy involves two important features – that both government debt and per-capita government spending are fixed. Thus, when government revenue would otherwise be affected by variations in the proportions of the population that are paying into and receiving payments from their RRSPs, tax rates are adjusted. This is one of the reasons that the model economy's predictions are so unaffected by a major specification change such as the existence (or not) of tax-sheltered savings plans.

3. Aging and Foreign Indebtedness

Other, rather different, versions of overlapping generations models support the general conclusion that has just been reported. In some specifications, there are many generations alive at the same time. Instead of there being just two cohorts, the young and the old, with the period of analysis being an entire generation (roughly 30 years), there are dozens of cohorts coexisting at each point in time (with a new one born every year). Scarth and Jackson (2000) have used this version of model economy to investigate an alternative way for the old-age dependency ratio to increase. Instead of a temporary, but long-lasting, period involving an older population (as discussed above), they consider a permanent reduction in the average retirement age. In this scenario, the aging population occurs because the average person spends a longer portion of her life in retirement. Another important difference in this analysis is that it is designed to represent a small open economy.

The model economy discussed in the previous section involves the assumption that the ratio of the wage rate to the interest rate is determined by the relative scarcity of labour and physical capital. There is no constraint that factor prices bear any relationship to what labour and capital earn elsewhere in the world. For that reason, it is best to apply that model to the entire North American economy. Since the Canadian and American populations are aging at roughly the same rates, this is a natural application of the model.

However, if we want to consider an analysis that is to be applied exclusively to Canada, we must recognize that there are serious limits on how much any one small country's factor prices can depart from what is observed elsewhere. In the modern "globalized" world, capital is very mobile internationally. Indeed, many studies assume that the option of moving capital elsewhere makes it impossible for domestic interest rates to depart, in any lasting way, from the yield available in the rest of the world. With the most common specification for the input-output process, the fact that the interest rate is determined in the rest of the world is sufficient to make the level of the domestic economy's wages determined in the rest of the world as well. Within this framework, then, it is possible to decompose the effect of a rising old-age dependency ratio on average living standards into two components – one that occurs because the domestic population is aging, and the other that occurs because the population in the rest of the world is aging. Only the second of these developments changes relative factor prices in the domestic economy.

An older population continues to bring lower living standards, but – as with the simpler closed-economy overlapping generations specification discussed in the previous section of the paper – living standards fall by a smaller percentage than does the labour force. In this setting, the cushion is provided partly by changing factor prices and partly by a change in the economy's foreign indebtedness. In simulations involving Scarth and Jackson's specification, living standards are reduced by a little over 4 percent if the retirement age falls by an amount that increases the dependency ratio by what we expect to observe for several decades following 2030. Faced with a longer expected retirement, individuals save more. As a result, the country pays off some of its pre-existing foreign debt. Since higher saving means less consumption for a while, there is "short-term pain". But, eventually, with smaller interest payment obligations to foreigners, domestic individuals can consume more, and there is "long-term gain". This gain counteracts – at least partially – the drop in living standards that occurs when there is less labour available to produce consumption goods. Living standards fall by 3 percent if only the domestic economy involves an aging population. The additional 1 percentage point drop in living standards occurs if there is an equivalent increase in the dependency ratio in the rest of the world (an event that causes the domestic interest rate to fall). Some readers may find this last outcome surprising, since it usually assumed that lower interest rates are "good" for the economy.

It is true that lower borrowing costs make it profitable for firms to hire more capital, and more capital to work with makes labour more productive. But this favourable effect on domestic incomes competes with an unfavourable effect. With lower interest rates, individuals choose to save less. As a result, foreign debt (and the associated level of interest payment obligations) is higher. In short, *GDP* is larger, but the ratio of *GNP* to *GDP* is lower. Since domestic income is *GNP*, not *GDP*, this unfavourable effect cannot be ignored. As just noted, it turns out that the unfavourable effect *dominates*.

Before ending this section of the paper, we touch on two issues: first, that aging will affect the economy in ways other than by raising the dependency ratio, and second, that other important developments – such as government debt reduction - will likely continue as aging proceeds. Also, we indicate how estimates of *one-time* effects on the *level* of living standards can be converted to equivalent changes in the productivity *growth rate*.

One of the reasons for the aging population is rising life expectancy. The models that we have discussed have been used to examine this aspect of aging, and have found that favourable effects emerge. People who live longer have an increased incentive to save. Individuals acquire more capital and they achieve lower foreign indebtedness as a result, and (other things equal) these developments raise living standards.

A second aspect of an aging population is a falling birth rate, since a population with many old people has a smaller proportion of individuals in the child-bearing phase of life. As a result, Canada's population growth rate is expected to fall.

According to standard growth theory, low population growth is associated with higher living standards – since less of each year's output must be withheld from consumption and used to provide each worker with an adequate supply of capital. There is tension between this proposition and recent discussions of our aging population. For example, the Auditor General (1998) predicts a large drop in government revenue (and therefore in living standards for those dependent on government transfers) when lower population growth makes *GDP* growth fall. Scarth (2001) uses a small open-economy version of a standard growth model – with overlapping generations, life-cycle features, and both forward-looking and liquidity-constrained consumers – to examine these competing effects. It is found that the "rich" are better off with lower population growth (just as standard theory predicts), while the "poor" are worse off (as predicted by analysts such as the Auditor General). The model permits us calculate the present value of all gains and losses. The conclusion is that the rich gain by much more than the poor lose, so – as long as the rich and poor are given equal weight, and the economist's standard rule for evaluating alternatives, the hypothetical compensation criterion is applied – the analysis supports the proposition that lower population growth is "good".

So the lower population growth dimension of the aging population is cause for more optimism regarding how *average* living standards will fare as the population ages. Nevertheless, the incomes of individuals who are dependent on government transfers will be squeezed slightly, and income redistribution may become increasingly difficult in a global economy where mobile "rich" individuals can escape taxes that exceed international norms. Furthermore, since skilled biased technical change will likely continue to increase the inequality of pre-tax-and-transfer incomes, it would be imprudent to put too much weight on this consideration. In short, in the face of rising demands for governments to address growing inequality, both within Canada and throughout the world, policy makers may feel constrained to increase immigration rates by enough to avoid a significant drop in overall population growth.

One important difference between the model-economy simulations that have been discussed and Canada's future is that the simulations have assumed that the aging population is the only shock to hit the economy, while other important developments will very likely be occurring simultaneously as Canada's population ages. One such development is government debt reduction. Many studies (such as Scarth and Jackson) have indicated that if the federal debt-to-*GDP* ratio continues its downward trend and reaches its previous post-war low of about 20 percent, we can expect average living standards to increase by about 3 percent. This is roughly just what is needed to allow Canadians to shift resources from the production of consumer goods to the provision of health care for the elderly – a requirement that was excluded in the simulations that were reported above. Thus, the two excluded considerations essentially "cancel off" one another. Debt reduction can give governments just the new room needed in their budgets to cope with the rising health care cost problem.

Nevertheless, it is still the case that the built-in mechanisms that insulate living standards from the aging phenomenon are incomplete. We are left with something like a 3 percentage point reduction in average living standards (since this is the average of the 2%

estimate discussed in section 2 of the paper and the 4% estimate discussed in this section of the paper, and since all these simulations exclude the two effects which cancel off).

We close this section of the paper by indicating how one-time *level* effects on the standard of living can be converted to equivalent *rate of growth* effects. The following illustrative calculation can put the 3 percent one-time reduction finding into a productivity-growth-rate perspective. Growth in real per-capita income of 2.1 percent per year for 30 years results in living standards rising by a factor of 1.865. Growth at one tenth of one percentage point less (that is by 2 percent per year) for the same period results in living standards that are higher by a factor of 1.811 – an outcome that is 3 percent lower than what is achieved with the higher growth rate. Thus, one way of summarizing the simulation results is by saying that the aging population can be expected to reduce the annual growth rate in Canadian living standards by about one tenth of one percentage point. Many Canadians may regard this loss as fairly modest, especially when it is realized that an even smaller estimated loss is warranted if it is not assumed that immigration rates will be increased.

4. Aging and Investment in Human Capital

The economic analyses that have been reported in earlier sections of the paper involve one particularly limiting feature. They involve the assumption that labour productivity can be increased only if labour has more physical capital with which to work. But recent advances in growth theory have stressed the fact that individuals can and do invest in education and training, so that their productivity is higher – even if they work with no additional amount of physical capital. If labour is expected to be the relatively scarce input as the population ages, we can expect that the return to investment in human capital will rise. Thus, by excluding this option for increasing labour productivity, the simulations that have been reported in the previous section have *overestimated* the threat to our living standards that is posed by aging. The purpose of this section is to explain how economists have tried to estimate the magnitude of this overestimate.

Unfortunately, the studies that focus on aging and human capital investment involve model economies that are more complicated than those reported in earlier sections. No study has applied the simplest version of the human-capital, endogenous productivity growth rate model (that is available in the textbooks) to the aging population question. Thus, in the appendix to this paper, I report how this can be done. Only the essence of the approach, and the results, are explained here in the main body of the paper.

The analysis is an extension of the many overlapping generations framework. Households continue to save for their retirement; the main difference is that they have two options for investing their savings - in physical capital and human capital. There are two sectors in the economy – the goods-producing sector which produces both consumption goods and physical capital as before, and the education sector which produces knowledge (human capital – which raises each individual's productivity). The education sector uses human capital more intensively in the production of knowledge than does the manufacturing sector in the production of goods. In the simplest version of the analysis, physical capital is not needed at all in the training sector, so it is employed only in the manufacturing sector. It is the fact that knowledge is a man-made input in the production process in this extended analysis that makes the nation's productivity *growth rate* dependent upon both demographic events and government policy.

The details concerning the structure and empirical calibration of this model economy are given in the appendix. Since we continue to assume that government debt reduction will make room in government budgets for rising health-care expenditure, we limit the reported experiments to the following three:

<u>(i) An increase in the old-age dependency ratio</u> Since individuals plan to spend longer in retirement, this development induces each individual to save more and to re-evaluate how much of her time she spends in training. These responses at the individual level have a positive effect on the growth of living standards. However, there is a reduction in aggregate human capital, since more individuals are retired, and this has a negative effect. The simulations show that these competing influences almost exactly cancel off. The net effect on the growth rate of per capita consumption is positive, but it is too small to be relevant.

<u>(ii) An increase in life expectancy</u> This development induces competing effects as well, but the specifics are different. The incentive for increased saving is more pronounced, so there is, on balance, a noticeable increase in the annual productivity growth rate – roughly an additional one tenth of one percentage point in the annual growth rate for an increase in life expectancy of 4 years.

<u>(iii) A decrease in the population growth rate</u> Just as favourable income-*level* effects accompany this dimension of aging in the models that abstract from human capital, favourable productivity *growth rate* effects accompany this same development when human capital investment is highlighted. A drop in annual population growth of one percentage point yields an increase in the annual productivity growth rate of about one-third of one percentage point.

Do these results call for a modification of the conclusions reached in the previous sections of the paper? In one sense, no modification is required. There is additional support for the proposition that the falling population growth rate dimension of an aging population is "good news" for *average* living standards. Nevertheless, there is still the concern that there will likely be a rising demand for income redistribution by governments in a global setting that may make it difficult for governments to meet this demand. Since lower population growth hurts those dependent on government transfers – even though it raises the average income level rather dramatically – governments may want to override the falling population growth rate dimension of the aging population – by allowing increased immigration quotas. Thus, as argued in the previous section of the paper, I think it is prudent to identify, but not to count on, this good-news dimension of an aging population.

Nevertheless, there is one reason why a modified conclusion *is* called for. In this analysis of human capital, we have found that rising life expectancy can be expected to have a positive effect on the productivity growth rate that is small, but big enough to compensate for the unfavourable one-time level effect of aging that was found in the previous sections of the paper. Overall, then, a rather benign view about aging is supported. If it is assumed that policy-makers will adjust immigration rates to keep population growth roughly constant, there are likely to be neither large negative nor large positive effects on either productivity growth or the growth in average living standards. If it is assumed that population growth will fall, we will enjoy an increase in the growth rate of living standards.

Before concluding this section of the paper, it is worth considering how we might develop some confidence concerning the finding that a focus on human capital investment does not affect the results dramatically. This is particularly worthwhile since there is disagreement on this finding in the literature. On the one hand, Devereux and Love's (1994) simulation results concerning tax changes are consistent with the small effects reported here for changes in the dependency ratio. However, Fougere and Merette's (2000)) simulations involve large effects accompanying both demographic and tax changes. A full evaluation of these alternative specifications of training and education is beyond this paper. Thus, I provide perspective in another way – by considering the following "back of the envelope" calculations (which are explained in more detail in Scarth (2000, p. 259)).

Consider shifting resources away from current consumption and into education. Assume that the rate of return on education is 10 percent. A shift of 1 percent of *GDP* would lower annual consumption by this much? What would be the pay-off? This reallocation is equivalent to society buying an equity every year that pays a dividend of 10 percent. If the initial year's *GDP* value is unity, the present value of the first "equity purchase" is $(.01)(.10)(1/(r-n))$, where r and n denote the discount rate and the *GDP* growth rate, respectively. Since this permanent shift of resources involves the equivalent of buying such an equity every year, the total benefit is $(.01)(.10)(1/(r-n)^2)$. The present value of the cost is $(.01)(1/(r-n))$, so the net one-time percentage increase in living standards is $(.01)[(.10/(r-n))-1]$, which equals 0.04 if r = .04 and n = .02.

Public expenditure on education is about 5 percent of *GDP* in Canada, so an increase of one percentage point is a significant initiative. Roughly speaking, the reasoning in the last paragraph suggests that the net benefit is equivalent to a one-time increase in consumption of 4 percent. What increase in the annual growth rate brings the same one-time equivalent benefit? If the interest rate is 4 percent, the answer is an increase in n from 0,02 to 0.02078. We can conclude that a significant investment in education can be expected to generate an increase in the economy's growth rate of about one-thirteenth of one percentage point. It would seem that skepticism is warranted whenever formal growth models show more than a modest growth-rate effect following from variations in the size of the education sector.

5. Conclusions

In this paper, I have summarized several approaches used by economists to analyze how an aging population might affect the growth rate of per-capita consumption. I have focused on *basic* versions of each approach so that non-specialists can better appreciate why there are competing effects. A second reason for highlighting the simulation results from several simple model economies is so that our comparison of the numerical results can be interpreted as bold tests of how robust some conclusions are. Viewed in this way, it is noteworthy that a fairly general conclusion has emerged. It appears that the aging population will probably lead to only rather modest changes in the growth rate of our living standards, and that the net effect could even be a favourable one.

Appendix

To highlight the role of training in the growth process, I follow Uzawa (1965) and Lucas (1988), and focus on a simple model economy with two sectors. I start with the simplified treatment in Barro and Sala-i-Martin (1995) and Turnovsky (1995) and extend it to overlapping generations by using Nielsen's (1994) extension of Blanchard's (1985) analysis of household savings behaviour. As long as household utility depends on private consumption and government-provided goods in a separable fashion, this specification involves private consumption being proportional to broadly defined wealth (the sum of physical and human capital). The factor of proportionality is the sum of each individual's rate of impatience, *m*, and the (constant) probability of death, *p*. More than one newborn appears to replace each individual as she dies, so the overall population grows (at rate *z*).

One sector uses physical capital and labour to produce goods, and these goods can be either consumed by households or used by firms as additional capital in future periods of time. The second sector involves just labour; it is the education sector which produces human capital. Individuals are more productive in the goods sector when they have more human capital. The production processes are a Cobb-Douglas function in the goods sector (with capital's share equal to *a*), and a linear function in the training sector. Net of depreciation, the increase in human capital equals *B* times the amount of human capital, *H*, that is employed in that sector. Parameters *b*, *p*, and *f* are the fraction of non-retired individuals that are employed in the manufacturing sector, the annual death probability faced by each individual, and the retirement age. As a result, the fraction of the population that is working in the training sector is $(1-b)(1-e^{-pf})$.

Long-run equilibrium exists when the growth rate for all per-capita variables is the same; that is when per-capita consumption, per-capita output, per-capita physical capital and per-capita human capital all grow at one rate, *n*, which I use to denote the growth rate in living standards. The model is used to determine how a reduction in the retirement age, *f*, an increase in life expectancy (a fall in *p*), and a reduction in the population growth rate, *z*, affect the growth rate in living standards, *n*.

Parameter *B* indicates the gross yield on human capital, since it indicates how much "output" follows from employing one unit of "input" in the training sector. It is assumed that both physical and human capital wear out with the passage of time at the same depreciation rate, *d*. Thus, the net return on human capital is $r^* = B - d$. Equilibrium requires that the pre-tax return on physical capital, *r*, generate the same net return: $r^* = r(1 - t)$, where *t* is the tax rate. With firms in the manufacturing sector hiring physical capital so that its marginal product is just equal to its rental cost, we have $(Y/K) = (r + d)/a$, where *Y* and *K* denote manufacturing output and physical capital.

The full-equilibrium version of the human capital accumulation identity is:

$$n + z + d = B(1-b)(1-e^{-pf}). \qquad (1)$$

The physical capital accumulation identity, when combined with the resource constraint (that output equals the sum of private consumption, *C*, government programs and investment in physical capital), the government budget constraint (that government spending equals *tY*), and the (*Y*/*K*) expression given above, implies:

$$z + x + n - d(1-t)(1-a)/a = r^*/a \qquad (2)$$

where $x = C/K$. Finally, as derived in Nielsen (1994), the full-equilibrium version of the consumption function is

$$n = r^* - m - [(p+z)(p+m)]/x + q(Y/K)/x \qquad (3)$$

where

$$q = [p(p+m)(1-a)(1-t)(1-e^{-r^*f})]/[r^*(e^{pf}-1)]. \qquad (4)$$

The total differential of these four equations, along with the definitions of *r*, *r** and the expression for (*Y*/*K*) given in the last paragraph are used to determine the changes in *n*, *x*, *r*, *r**, *b*, *q* and *Y*/*K* that result when changes in life expectancy (1/*p*), the population growth rate (*z*), and the retirement age (*f*) are specified.

The model ensures that the discussion of these issues is internally consistent. While it is deliberately simplified, the model can be used to illustrate the quantitative effects of these developments. To do so, representative parameter values that are suitable if each period is interpreted as one year have been selected. The initial values for private consumption, government spending and investment in physical capital (as proportions of measured (manufactured goods) output) are assumed to be 0.55, 0.27, and 0.18. Physical capital's share of output in the manufactured goods sector is 0.33; capital's depreciation rate is 0.04; the net-of-tax yield on capital is 6 percent; and the initial growth rates of the population and per-capita living standards is 0.02 ($n = z = 0.02$). All other parameter values are determined by the equations of the model. The numerical results are reported in the paper.

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