UNIVERSITY OF TARTU

Faculty of Social Sciences and Education

Institute of Government and Politics

Martin Lumiste

Growth modeling: a comparative analysis of main frameworks with regard to the impact of population ageing and decline

Bachelor's thesis

Supervisor: Raul Eamets, PhD

Tartu 2013

Olen koostanud töö iseseisvalt. Kõik töö koostamisel kasutatud teiste autorite tööd, põhimõttelised seisukohad, kirjandusallikatest ja mujalt pärinevad andmed on viidatud.

Olen nõus oma töö avaldamisega Tartu Ülikooli digitaalarhiivis DSpace.

…………………………………..

Martin Lumiste

Table of Contents

Introduction

Sub-replacement fertility levels are a well-known fact in most of the developed world. Amidst the European Union, only Ireland and France have a fertility level near the reproduction rate of populace.[1] Combined with rapid advances in healthcare which have extended the expected life-span, this has led to a situation where various European countries are experiencing population decline and ageing. Countries where this effect is coupled with emigration, the rate of population loss is even higher. This unprecedented long-term demographic phenomenon has numerous implications for the society as a whole.

The purpose of this paper is to analyse the effect of these population changes on economic growth. Intuitively, it would seem that as the population ages and declines, the proportion of dependent people increases while the share of workers diminishes, thus hampering economic growth. This pessimistic view is supported by commentators such as Peter Peterson who has stated that global ageing could trigger a crisis which might threaten the world economy and democracy as a whole (Bloom et al. 2011). This bachelor's thesis suggests the hypothesis that economic theory offers mechanisms which help to avoid the growth slowdown initiated by population ageing and decline. The hypothesis is partly confirmed thanks to a comparative analysis of the main growth modeling frameworks and their extensions which is also the main novelty of this paper.

The applicability of this research is obvious: if there are indeed factors which can promote economic growth in the framework of demographic decline, these can be made use of by economists, legislators and social scientists to minimise the damage done by population ageing. The first chapter explores the various direct and indirect channels through which population changes can alter the economic growth rate. The second part of this thesis presents the most common modeling frameworks. Third chapter compares the four model types in respect to population changes.

---

[1] Eurostat. Fertility statistics.
http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Fertility_statistics 19.04.2013

I Demographic influence on growth
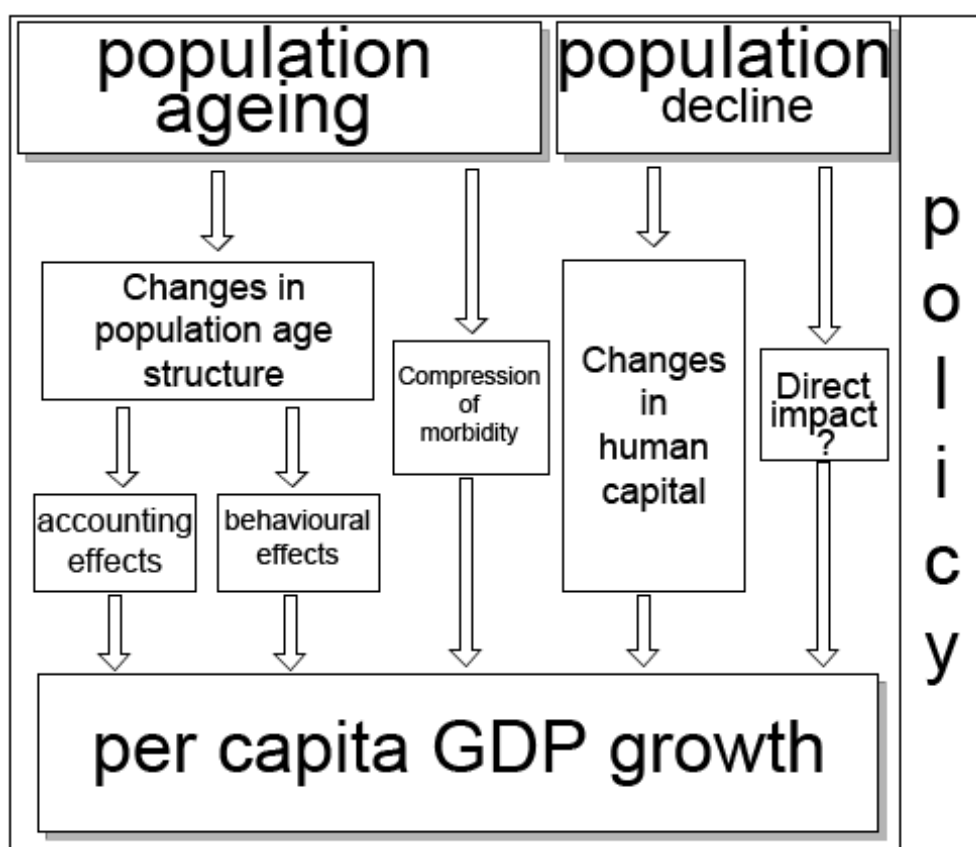
Graph 1.1. Demographic impact on per capita GDP growth

The above chart depicts various channels through which demographic factors can influence economic growth. The demographic variables are somewhat simplistically divided into population ageing and decline. Independent and dependent variables are connected by intermediate mechanisms, which cause the change in GDP per capita growth. For example, population ageing (demographic variable) might cause an increase in savings (intermediate mechanism) which in turn is beneficial for investment and economic growth (dependent variable).

The key flaw in past analysis of the linkage between growth and demography is that the age structure variable has often been ignored. Most research has been conducted with the total population size in mind. However, it is clear that different cohorts of the population have different effects to labour, savings, consumption *et cetera*. These effects have been divided by some authors into accounting and behavioural effects.

1.1   Accounting effects

Accouting effects consist of changes in the labor supply, savings, and education. These effects are considered *ceteris paribus*, i.e. other factors such as productivity and job market participation do not change. It is apparent that accounting effects mainly have a negative impact on growth.

To analyse this further, the concept of a demographic dividend is essential. When societies undertake demographic transition, it is common for the child mortality rate to drop, followed by a decrease in fertility, because parents need to have fewer children to reach their desired number of offspring. However, the fertility drop lags somewhat behind (Bloom et al. 2001:18). This creates an unusally large cohort of people who, initially, are a burden on the society.

Nevertheless, as graph 1.2 shows, they will thereafter enter the labour force and this has a large positive effect on GDP growth. Indeed, empirical findings have proven a robust and important connection between the ratio of working people to total population and growth (Gómez & de Cos 2008). It is important to remember that the relative size, rather than the absolute size, of the working group is important here. Since the young cohort is small due to low fertility, lowering the dependency ratio as well, it is only logical that this effect coupled with increased work participation leads to higher growth rates. Still, this increase can not be perpetual, because this large cohort will eventually retire, which will cause the old age dependency ratio to be disproportionately large.
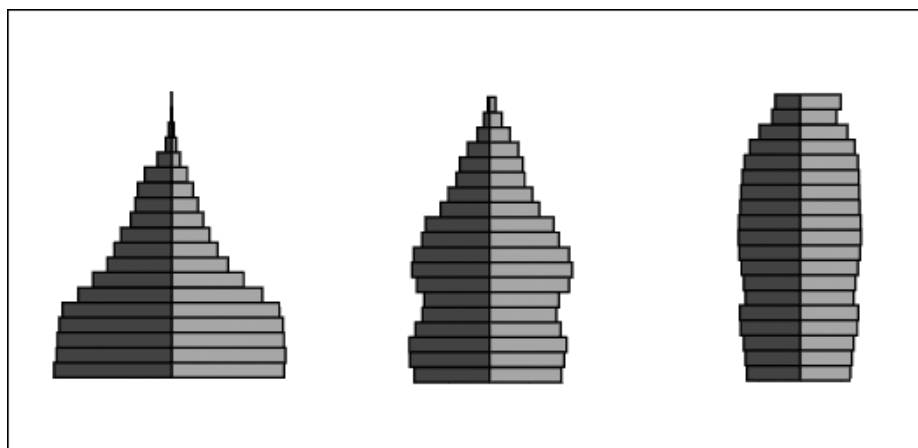
Graph 1.2. The transition of a demographic dividend cohort in the population pyramid.

In addition to the direct effect of age structure to the labour supply, some other factors can influence growth. According to the life cycle theory, individuals have different

habits of saving and consumption in different stages of their life (Bloom et al. 2008:17). For example, it makes a lot of sense that there exists little if any income in years up to adolescence, after which people get jobs which allow for a steady income and savings. This also means higher investment. As people get older and retire, they will have diminished income but steady consumption due to the wealth acquired during the lifetime. Since savings and investment have always been central direct determinants of economic growth, the life cycle concept is important to remember when analysing age structure.

It has also been suggested that individuals have different levels of productivity depending on their age. As they enter the job market, low experience causes low productivity. As they work, productivity rises and eventually reaches peak value, when the ratio of formal education and work experience is optimal, after which people begin to produce less output per capita (Gómez & de Cos 2008:352). Some authors have even suggested that it is the oldest age group of the whole working generation, the people near the retirement age, which works most productively (Lindh & Malmberg 2008:160).

To sum up, it is clear that the demographic dividend creates an opportunity of rapid growth due to increased labour force participation, savings and productivity. A third of the East Asian economic growth miracle has been attributed to these direct demographic changes (Bloom & Sousa-Poza 2010:11). However, this boost in growth cannot be permanent, because the large age cohort eventually retires, creating an abnormally large old age dependency ratio, decreased savings and possibly lower productivity.

1.2   Behavioural effects

The whole accounting effects impact is considered in a situation where other aspects are stationary. However, it is reasonable to believe that as the mean age in a society increases, people will also react differently in order to try to maintain their standard of living. These are called the behavioural effects and while the accounting ones were largely negative in the long run, these are beneficial for economic growth.

Firstly, as longevity and health increase, it is possible for people to work longer. It has been shown that it is optimal for individuals to increase working years and retirement years proportionately in the case of rising life expectancy (Bloom et al. 2008:22). An alternative is to work the same amount of years, but to accumulate higher savings, in order to finance a longer retirement age. Both choices have positive effects on GDP, the

former through increased labour force participation and the latter through higher investment. However, the policy aspect is especially important here.

It has even been suggested that this behavioural effect induced saving increase might constitute a second demographic dividend (Prskawetz et al. 2007:16). As the first, strictly accounting effect related dividend wears off, the labour income of people decreases. Depending on favourable policy and foresight, individuals start saving and investing more, especially in countries which do not use the pay-as-you-go pension system. This increased investment fuels the growth of output per worker.

Another behavioural mechanism is increased labour force participation of women. It is both theoretically reasonable and empirically proven that as fertility decreases, more women will have careers (Bloom & Sousa-Poza 2010:14). This can be highly beneficial, but an important thing to consider is that many women are already doing jobs which are not reflected in the gross domestic product. In addition, countries which already employ a large share of the females, have a smaller potential growth reserve from this resource.

1.3   Compression of morbidity

First suggested by James Fries, a professor of medicine, the compression of morbidity theory claims that the burden of old-age illness can be compressed into a briefer period of time before death (Gordo 2006:23). This means that as societies age, it does not necessarily mean that the general health of the populace decreases. The number of increased years spent in illness is relatively less than the number of increased years spent in health, due to modern medicine and hygiene. This has important implications if we take into account the previous paragraphs.

 As the longevity increases, people can opt to work for more years. Since their health can be preserved better, it means their productivity will not drop dramatically. On the contrary, since older age groups have been shown to be quite productive by some studies as mentioned before, this means that if policy makers enable old age participation, this allows the society to utilise an important part of the population.

1.4   Changes in human capital

By far the most interesting mechanism connecting demography and economic growth is human capital. This is because it is the only theoretical long-run possibility which can reverse the growth slowdown caused by demographic changes. The aforementioned

intermediate mechanisms are either only short-term solutions or softening factors, however, human capital returns and techonological advances initiated by them have more potential as a viable solution to the demographic problem in Europe.

Elgin and Tumen have proposed that as the degree of increasing returns to human capital falls in traditional production technologies, economies switch from labour-oriented technologies to human capital oriented technologies which support an ageing population (Elgin & Tumen 2010:4). This is thanks to the „efficiency-augmenting mechanism", of which good examples are the automation of Japanese production or the evolution of the banking sector thanks to technological advances. Various authors have also suggested that population ageing makes investment into human capital more profitable (Fougère et al. 2009:1).

On an aggregate level, as the increasing returns to human capital fall in traditional techologies, the population growth rates start declining and the growth rates of per capita income display a U-shaped pattern. Using a time-series sample of 50 countries, the authors show that the degree of increasing returns to human capital has been falling. This supports the claim that human capital returns and population growth are positively related. However, the proposed long-term growth rates of income are U-shaped, therefore allowing negative population growth and positive growth in per capita income to coexist (Elgin & Tumen 2010:3).

Another human capital related growth mechanism called „capital-specific techonological change" has been proposed by Fernandez-Villaverde (Fernandez-Villaverde 2001:18). If economic growth raises the return to human capital investments, parents have an incentive to prefer fewer highly educated children to many less schooled ones. This is known as the quantity-quality tradeoff and was originally proposed by Becker (Becker 1974). Therefore, the per capita human capital increases, subsequently boosting economic growth.

It is a direct ramification of the long-run empirically proven decrease in the relative price of capital. If physical capital and unskilled labour are assumed to be substitutes and physical capital and skilled labour complementery inputs, then the lower price of capital raises the skill-premium attached with higher human capital and gives an incentive to automate the production process (Fernandez-Villaverde 2001:3). This helps to explain a large proportion of the fertility drop in Western nations as well as the per

capita income increase. These findings are empirically robust within the neoclassical growth model (Fernandez-Villaverde 2001:27).

1.5   Direct impact of population increase/decline

Thomas Malthus was, if not the first, then the most famous classical advocate of the importance of demography in economic analysis. In his main paper, he reached a conclusion that when left uncontrolled, population would increase geometrically, while the food supply only arithmetically (Malthus 1798:6). Therefore, living standards could only improve in the short term: any increments of capital per person are quickly nullified by the increasing population. Alternatively, if the population level soars, inadequate food supply increases mortality and equilibrium is reached once again.

This model of economic constancy is known as the Malthusian trap. Although outdated now, this line of reasoning is entirely logical when seen from Malthus' perspective. Land, a fairly constant entity, was the main factor of production. As population increased, the marginal productivity of each economic agent decreased because a larger population could not produce proportionally more goods. In addition to the increased demand on fixed resources, there is a potentially negative impact of population growth on capital intensity. More people require more infrastructure investments to provide for their needs (Crenshaw & Robison 2010:2219). For the better part of history, per capita income and population have stayed relatively stable, only after the Industrial Revolution did both of these soar. Early economic „big push" models that called for concerted investment in order to escape the poverty trap are closely related to the Malthusian concept (Baldwin 1966:49).

Concurrently with the works of population pessimists, authors like Kuznets Simon and various urban economists proposed that larger economies can more easily expand the knowledge stock that they have. As resources deplete, the added scarcity pressure is enough to stimulate human ingenuity to provide more efficient solutions and alternative techologies. Finally, the increased production volume associated with large economies helps to exploit the learning-by-doing concept. Boserup has followed up on this line of thought by suggesting that slash-burn-cultivate agriculture, multi-annual cropping and the Green Revolution are all ramifications of increasing human ingenuity during resource scarcity (Bloom et al. 2001:11).

Thanks to empirical evidence, the population optimistic movement eventually shifted towards neutralism. As the name suggests, this view suggests that absolute population size does not significantly affect economic growth rates. Neutralism has become the dominant view of population effects. Kelley brings forth three reasons for this: the exhaustion of natural resources was found to be less affected by population growth and more by advances in technology, conservation, and market allocation, a negative impact on savings rate was not empirically confirmed, and the fear of investments wasted on non-productive projects did not materialise (Bloom et al. 2001:13).

1.6   Policy

The effect of policy on the *long-term* growth has caused a lot of debate. On the one hand, it is clear that direct interference can alter saving and investment rates of an economy. Not many economists would argue that increased investment boosts growth rates. However, as analysis in the modeling chapter later demonstrates, the controversy is caused by the length of this effect. Some authors claim that policy can only induce short-term growth boosts and that in the long run the growth rate converges to its natural speed. This schism is not alleviated by the fact that long-term natural levels of growth *per se* are difficult values to find out. However, from a normative perspective, it is highly desirable for policy to have a long-term positive influence on economic performance.

Regardless of the length of policy effects, it is reasonable to believe that at least some effect exists. Thus policy becomes an important tool in influencing all of the intermediate mechanisms. Bloom et al. have pointed out that European law-makers have done little to maximise the gains of beneficial policy. In the light of increasing longevity and deficit of working age individuals, many European countries do not encourage old age participation. The average life expectancy rose by around 9 years in the period 1965-2005, the average legal retirement age only by less than half a year (Bloom et al. 2011:10). In some countries, retirement is made compulsory in order to receive benefits, or additional years of work are disregarded in pensions (Bloom et al. 2011:20).

II Growth modeling

There are two main reasons to include mathematical analysis of growth theory in this paper. Firstly, mathematical models allow us to formulate definitive connections between variables and the analysis of these can lead to the discovery of indirect effects which could be missed intuitevely. This can be the case when complex interconnected effects exist. The demographic effect on growth with its many intermediate mechanisms is a good example of this. Perhaps more importantly, mathematical models enable empirical testing which is the main indicator of whether a theoretical approach is valid or not.

2.1 The neoclassical model

Developed independently by Robert Solow and Trevor W. Swan in 1956, it is also called the exogenous growth model because the long-run rate of economic growth is determined by an exogenous variable - technological progress. The model is a very simple one and is built around two equations, a production function and a capital accumulation equation (Jones 2002:38).

The production function at time t is given in Cobb-Douglas form by

$$Y(t) = F(K, L) = K(t)^{\propto} (A(t)L(t))^{1-\propto} \qquad 1.1$$

where Y is overall output, K is capital L is labor and A is technology and α is a constant which predicts the factor's share of GDP income, thus being a number between 0 and 1. Since factor shares equal to one, we assume the equation to have constant returns to scale. This means that increasing all production inputs twofold also doubles the value of Y.

Capital is accumulated through the net capital accumulation equation.

$$\dot{K} = sY - Kd \qquad 1.2$$

where s is the constant exogenous savings rate, d is the constant depreciation rate and $\dot{K}$ marks the change in capital.

Labour grows at an exogenous rate and as aforementioned, so does techology. Therefore:

$$L(t) = L(0)e^{nt} \qquad 1.3$$

$$A(t) = A(0)e^{gt} \qquad\qquad 1.4$$

To solve the model for a steady-state solution, it is useful to rewrite y = Y/AL and k = K/AL as output and capital per effective unit of labor (since A is labor-augmenting). Then the production function equals

$$y = k^{\propto} \qquad\qquad 1.5$$

k = K/AL can be rewritten using logarithms and differentiating as

log k = log K − log A − log L and $\frac{\dot{k}}{k} = \frac{\dot{K}}{K} - \frac{\dot{A}}{A} - \frac{\dot{L}}{L}$. Since the growth rate of L and A are n and g from equations 1.3 and 1.4 respectively, and we know the growth rate of K from equation 1.2, all of this can be rewritten into the capital accumulation growth rate equation.

$$\frac{\dot{k}}{k} = (s\frac{y}{k} - (d + g + n)) \qquad\qquad 1.6$$

In the steady state $\dot{k}$ = 0, therefore multiplying equation 1.6 by k and solving for k*, we get

$$k^* = (\frac{s}{n + g + d})^{1/(1-\propto)} \qquad\qquad 1.7$$

and entering this into the production function and multiplying with the technology factor

$$y^*(t) = A(t) (\frac{s}{n + g + d})^{\propto/(1-\propto)} \qquad\qquad 1.8$$

The steady-state balanced growth rate then becomes equal to the technological progress rate.

$$g_y = \frac{\dot{A}}{A} \qquad\qquad 1.9$$

2.2 Extended exogenous models

The easiest way to include ageing is to employ a dependency ratio $D = \frac{N-L}{L}$ in the manner of Gruescu (Prettner & Prskawetz 2010:3). It can be shown that equation 1.8 then changes into

$$g_y = g_A - (1-\alpha)g_{1+D} \qquad\qquad 1.10$$

However, this does not eliminate the assumption that the whole economy consists of one representative individual, which is inherent in the Solow model. Li and Tuljapurkar avoid this by using an overlapping generations models (see (Horvath 2007) for an excellent overview of overlapping generations models) and introducing age-dependent mortality and variance of the death age. Population ageing is found to have a positive effect due to older people having a larger degree of accumulated wealth (Li & Tuljapurkar 2004:10).

Prettner and Prskawetz endogenise the human capital accumulation using the quanitity-quality trade-off effect. This results in the population and economic growth rates being negatively connected (Prettner & Prskawetz 2010:18). Fernandez-Villaverde employs a modified neoclassical model with quanity-quality trade-off, endogenous fertility, mortality and education. He finds that population and economic growth rates can move either together or separately depending on the relative price of capital (Fernandez-Villaverde 2001:27).

Using a dynamic overlapping generation CGE model with endogenouns human capital investment decisions, Fougère et al. manage to explain the significant rise of education levels. This is compatible with the theory of increasing returns to human capital and the added incentive of educating the youth. Authors claim that the return on human capital investments is lagged, thus the potential benefits are going to be seen in the future. However, it is emphasised that „accumulation of human capital is a powerful smoothing mechanism: neglecting this is bound to lead to substantial overestimation of the economic costs of ageing" (Fougère et al. 2009:24).

2.3 First generation endogenous growth models

Due to the drawbacks of the neoclassical model, economists were eager to develop one which would explain growth better and allow for effective long-term policy interference. However, perhaps the most prominent reason was that the Solow model

predicted convergence among countries: poorer economies should have higher growth rates than developed ones, given the same parameter values (Aghion & Howitt 1999:17). For the world as a whole, this is not empirically correct. A first version of the new, „endogenous" growth model was popularised by Romer in 1986. This paper presents the macrofoundations of the subsequent Romer 1990 model, without explaining the detailed micromechanisms at work. This does not change the overall conclusions regarding the model.

A main feature of modern growth theory has been the inclusion of ideas and the potential externalities they cause. Since ideas are non-rivalrous in nature, the classical economic laws regarding goods do not apply. In addition, a discovery or scientific breakthrough in one sector can have highly beneficial effects for the economy as a whole. This is a positive externality and also the reason why the production function can have increasing returns to scale. As shown later, this property becomes the main cause of endogenous growth.

Generally speaking, the endogenous models of interest regarding the topic of this paper can be divided into three main types: R&D models, human capital models and fertility choice models (Chol-Won Li 2003:3). Due to techonological progress being most often identified as the primary engine of growth, the first are perhaps the most effective at explaining economic growth and they are mainly featured in this paper. The other model types have their merit and it is shown in this paper that the most effective models actually incorporate various features: e.g. a R&D model which takes fertility choice and human capital mechanisms into account. However, they have one important character in common: they endogenize the technological progress rate. This is a logical reaction to the exogenous model which handles technological progress as a gift sent from heaven rather than a product of economic forces.

It is common to use the AK model to explain the potential of making growth dependent on endogenous variables. It does so by eliminating diminshing returns thanks to using a linear production function instead of the Cobb-Douglas counterpart found in the neoclassical model (Barro & Sala-i-Martin 1999:141). However, the AK model behaves similarly to the Solow-Swan model in relation to population decrease (Ferrara 2011:1242). Therefore, for the sake of exemplifying a different view on the issue, the simplified Romer (1990) endogenous model will be introduced in this chapter. It is built

around the concept of ideas and innovation being the main engine of growth and a balancing factor to diminishing capital returns.

The production function can be assumed to be similar to that of Solow:

$$Y = K^{\propto}(AH_Y)^{1-\propto} \tag{2.1}$$

where H_y is human capital employed in the production sector and A is the stock of ideas in a society. The production function exhibits constant returns to scale in K and H_y, but when A is also recognised as an input, then there are increasing returns. The capital and population accumulation equations remain similar to their neoclassical counterparts.

$$K = s\dot{Y} - Kd \tag{2.2}$$

$$L = L(0)e^{nt} \tag{2.3}$$

The big difference between the two models derives from the next equation (Romer 1990:S83):

$$\dot{A} = \delta H_A{}^{\lambda} A^{\phi} \tag{2.4}$$

Since A symbolises the stock of all knowledge and ideas accumulated in history, then $\dot{A}$ is the number of new ideas produced at any given time. L_A is then the amount of labour in the production process trying to discover new ideas (scientists) and δ is the rate at which new ideas are being discovered. If ϕ is smaller than 0, then the discovery rate becomes smaller as more and more knowledge is produced. This can be explained by the most urgent and obvious ideas being discovered first, so that next ones are increasingly difficult to discover. However, if $\phi > 0$, then the productivity of scientists increases together with the base amount of knowledge, constituting a knowledge spillover effect. λ is a parameter between 0 and 1. It allows to model the chance of duplication in the scientists' work, therefore rendering the effective number of people working on new ideas smaller than L_A.

Equation 2.4 also becomes important in the case of semi-endogenous growth. Indeed, the only difference between the two models is that Romer assumed $\phi = 1$ and Jones, the creator of semi-endogenous models, proposed $\phi < 1$. In the former case, and assuming the duplication parameter to be equal to unity as well, we get the following:

$$\dot{A} = \delta H_A A \tag{2.5}$$

Dividing the knowledge production function by A, we get the knowledge growth rate

$$\frac{\dot{A}}{A} = \delta H_A \qquad\qquad 2.6$$

From equation 2.5 it is apparent that the growth speed of ideas is positively connected with the total amount of ideas. δ is assumed to be proportional to the aggregate amount of ideas and hence the productivity of researchers is growing in time as well. This enables sustained growth of ideas even if H_A is constant. Romer closed his original model with the following balanced growth path (Romer 1990:S92):

$$g_y = \frac{\delta H - \gamma \rho}{\sigma \gamma + 1} \qquad\qquad 2.7$$

where H is aggregate human capital ($H_Y + H_A$), γ is a constant deriving from production function parameters α and β, ρ is the time preference rate of individuals and σ the inverse of intertemporal elasticity of substitution in an individual's utility function (Prettner & Prskawetz 2010:8). Growth rate hence depends on the productivity of researchers, aggregate population size and the patience of individuals.

2.4   Extended Romer model

Futagami et. al introduce longevity into the first generation endogenous model and find that it has no clear implications on the economic growth rate. Increases in longevity *per se* do not increase the potential labour force, which otherwise could be beneficial in the Romer framework. However, a rise in the retirement age does this and the positive effect is large enough to balance the effect of lower aggregate savings also due to the higher retirement age (Prettner & Prskawetz 2010:8). Prettner uses an OLG framework in continuous time and deduces that population ageing fosters long-run growth in the Romer model (Prettner 2011:18).

Bucci succeeds in modeling a Romerian-type framework with endogenous human capital accumulation and quanitity-quality tradeoffs. It is concluded that growth is mostly dependent on the degree of altruism towards future generations (Bucci 2007:16). This is essentially the same main idea as in the previous models: investment into children combined with human capital accumulation can sustain long-run growth.

2.5 Semi-endogenous growth models

The first generation endogenous models were proven invalid by Jones in 1995. In an influential paper he pointed out that time-series evidence does not support the models (Jones 1995:761). If they were true, the increase in R&D financing and participation would cause higher economic growth rates and larger nations would experience improved growth as well. In reality, the opposite was more likely. It is apparent from his analysis that the highly desirable $\phi = 1$ condition has little validity in real life. First-generation models only hold true when $\phi = 1$, however this is a so-called „knife-edge condition". This means that the model requires this parameter value to work but there is no mechanism creating an equilibrium at this value. He proposed a general parameter value of $\phi < 1$ and the family of semi-endogenous growth models was born.

Semi-endogenous models use the L_A rather than the H_A variable, thus from equation 2.5, the technology growth rate in this case can be derived.

$$\frac{\dot{A}}{A} = \delta \frac{L_A{}^\lambda}{A^{1-\phi}} \qquad \text{3.1}$$

The requirement of $\phi < 1$ has changed an important property of the knowledge production function: it now has decreasing returns to scale. In case of a constant population, the relative share of $\delta L_A/A$ decreases over time and the technological growth rate eventually stops because the constant research effort becomes a smaller and smaller part of the aggregate knowledge stock and δ is assumed to be constant.

Along a balanced growth path, the technology growth rate is constant. Therefore, the denominator and numerator on the right side of equation 2.6 have to grow at the same rate. Logarithmical differentation of the equation yields

$$0 = \lambda \frac{\dot{L_A}}{L_A} - (1 - \phi)\frac{\dot{A}}{A} \qquad \text{3.2}$$

Since the long run growth rate of scientists has to equal the labour growth rate n, the balanced growth path for technology is

$$g_A = \frac{\lambda n}{1 - \phi} \qquad \text{3.3}$$

Long-run economic growth is determined by the growth rate of population, the duplication and spillover parameters. As the name suggests, these models are only semi-endogenous because although technological change is explained, the long-run growth rate is determined by an exogenous variable, the population growth rate.

2.6   Extended semi-endogenous models

Prettner uses an OLG framework with a constant risk of death μ which is age independent. The birth rate variable β is assumed to be larger than μ because the Jones model works best with a positive population growth rate. Equation 3.3 then becomes:

$$g_y = \frac{\beta - \mu}{1 - \phi} \qquad \qquad 3.4$$

A decrease in fertility (equivalent of population ageing) lowers economic growth, decreasing mortality (associated with population growth) has the opposite effect (Prettner 2011: 18). Prettner and Trimborn set up a similar model with the exception that the transitional growth path has a level increase in per capita income (Prettner & Trimborn 2012:17).

Dalgaard and Kreiner endogenise human capital accumulation so that the importance of human capital increases as technology gets more complex. This results in a steady state growth path which implies that economic growth negatively depends on the growth rate of the population, which is the exact opposite to the original result of this model framework (Dalgaard & Kreiner 2001:196).

2.7   Second generation endogenous growth models

Sometimes referred to as Schumpeterian growth models, the second generation endogenous growth models have essentially the same purpose as their Romerian precursors: to allow for effective policy interference and to allow for economic growth not entirely dependent on exogenous variables. Schumpeterian models draw on the microfoundations of the economy. Progress is a product of innovation. Innovation, in turn, is caused by self-interested firms who are trying to capitalise on the potential monopoly following a successful invention. However, innovations become obsolete in time and firms which are unable to adapt, are driven out of the market. This is the famous principle of „creative destruction".

There are various ways to model sustained endogenous growth. One approach is to include scale effects as in the Romer model, but to introduce product diversification so

that the increased knowledge is diluted between more and more R&D strains (Barcenilla-Visus et al. 2008). This is in line with the historical data which suggests an increase in the R&D share but relatively stable economic growth rates in the developed countries.

Another way is to model two R&D sectors: vertical and horizontal R&D (Li 2003:35). The first considers innovation to be a fundamental increase in the quality of goods. Horizontal innovation refers to the Romer-like concept of knowledge exponentially growing through time, this essentially means the variety of products. Most contemporary models rely on at least two R&D sectors, but it is possible to model endogenous growth with only horizontal or vertical innovatios. It should be mentioned that semi-endogenous growth can emerge in the two sector version as well.

These models are very complex in character and beyond the scope of this. Nonetheless, below are some steady state growth paths proposed by various authors of endogenous models.

Peretto's 1998 scale invariant model combines horizontal and vertical innovations and derives the following steady state path (Prettner & Prskawetz 2010:14):

$$g_y = \frac{\varepsilon n}{\varepsilon - 1} + g_v \qquad\qquad 4.1$$

where ε is a behavioural parameter and V is productivity.

Li also eliminates scale effects and combines the two versions of innovations and reaches a similar long-run rate of growth (Li 2003:38):

$$g_y = \frac{1 - \alpha}{\alpha} n + \delta b \frac{(1 - a)}{a} n \qquad\qquad 4.2$$

where α is the typical production function parametre but a and b are endogenously determined parameters determining the relative share of workers in the two R&D sectors. From equation 2.11, it is apparent that the first summand is proportional to the population growth rate because α is the usual production function parameter. However, the second part is different because a and b are endogenous parameters (shares of workers employed in the two R&D sectors). In this sense, the growth is not entirely dependent on the population growth rate, but is affected by it nonetheless

These solutions are similar and indeed, Dinopoulos and Sener have proposed the general form solution of the endogenous model with horizontal and vertical innovatinos is (Dinopoulos & Sener 2007:9):

$$g_y = l_a + (\rho - 1)n \qquad\qquad 4.3$$

In this case, l_a is the relative number of scientists in a typical industry, which is endogenously determined. A common feature of these models is that the balanced growth path solution consists of an exogenous and endogenous component. Dinopoulos and Syropoulus have proposed a model based on Rent Protection Activities, which arrives at the same conclusion: long-run growth is positively dependent on the population growth rate, but it is not fully determined by it (Dinopoulos & Syropoulos 2006:326).

2.8   Extended endogenous models

Connolly and Peretto endogenise the fertility rate in the Schumpeterian framework and leave the mortality rate exogenous. This gives the steady state growth path (Prettner & Prskawetz 2010:15):

$$g_y = (\phi - 1)n + \theta z \qquad\qquad 4.4$$

where ϕ denominates research spillover from horizontal innovations as in the Romer and Jones models. θ is the elasticity of the production function with respect to quality improvement, which itself is z. Strulik employs a model with two R&D sectors and endogenous educational decisions and finds that population growth also has ambiguous effects as in equation 2.13 (Prettner & Prskawetz 2010:15).

Elgin and Tumen endogenise the fertility rate in an endogenous overlapping generations model with increasing returns to aggregate human capital (Elgin & Tumen 2010:11). As such, the model takes into account the age structure, population decline and the quanitity-quality trade-off. Their main findings are that labour acts in a similar manner to other resources: when scarce, more efficient ways of use and alternatives are developed. Increased education makes labour more productive and this increase is enough to offset the negative impacts of demographic change.

Tournemaine endogenises technical progress, human capital and population dynamics. It is found that population growth is not essential for economic growth. Human capital accumulation instigated by the quanity-quality trade-off due to fewer children proves to be the long-run growth sustaining factor again (Tournemaine 2007:6).

III Comparative model analysis

The purpose of this chapter is to compare the main modeling frameworks presented in this paper in consideration of their long-term balanced growth paths, the dependence of those paths on demographic variables, the effect of policy on long-term growth, whether public policy and demographic variables cause temporary or permanent growth effects and the general strengths and weaknesses of each model. Population decline dynamics in each framework will be presented.

### 3.1　Exogenous growth model

The first most apparent property of the Solow model regarding demography is that the solution includes only one related variable, the population growth rate. The effect of population dynamics becomes apparent when equation 1.6 is multiplied by k. The steady state value of $\dot{k}$ has to be 0, therefore $sy - (n+d)k = 0$. This is exemplified by the graph 4.1. If the population growth rate n decreases, the whole $(n+d)k$ curve moves to the right and the optimum value of capital per worker increases. This is a logical result in the Solow framework, because if the labour force increases, capital is diluted between more individuals.
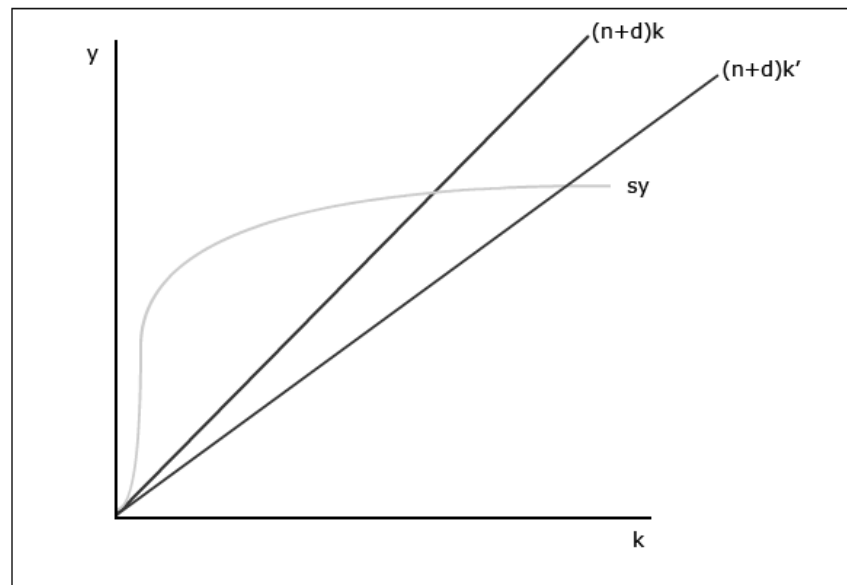
Graph 4.1. A change in population growth rate

However, population change does not affect the long-term economic growth rate because in equation 1.7 only A is dependent on the time variable t. A decrease in the

23

population growth rate induces level effects rather than growth effects, i.e. the long-term growth rate itself remains similar regardless of the temporary boost. Graph indicates this by simulating equation 1.7 with constant parameter values and arithmetically increasing technologic progress. A population growth rate decrease from 0,05 to -0,2 at period t* has strong transitional effects but the long term growth rate remains unchanged.
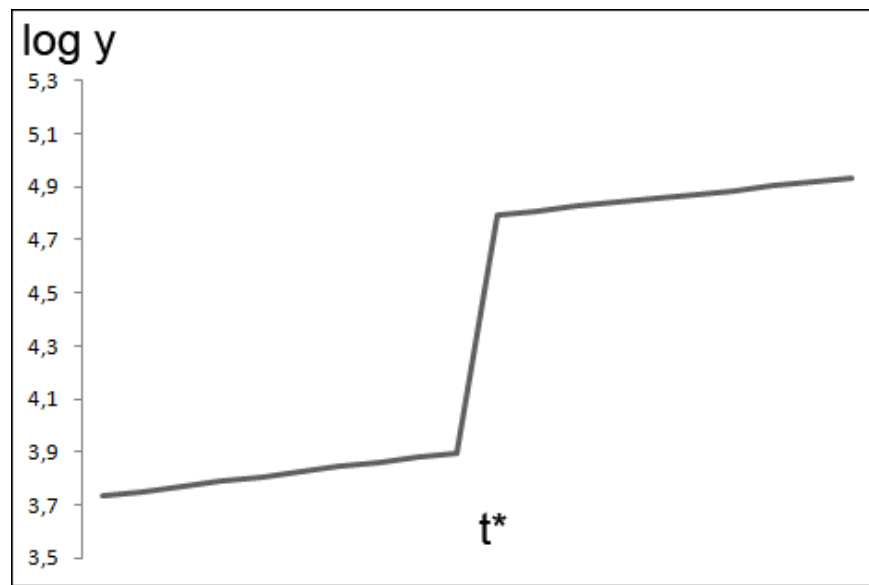
Graph 4.2. The level effect of a decrease in population growth.

Since technological progress is exogenously determined in a „black box"-like manner, it is not affected by population changes. Therefore, the only conclusion regarding demography in this simple Solow framework is that population decline will cause capital deepening and the level of income per worker to temporarily change, unaffecting the long-term growth rate but raising the level of output.
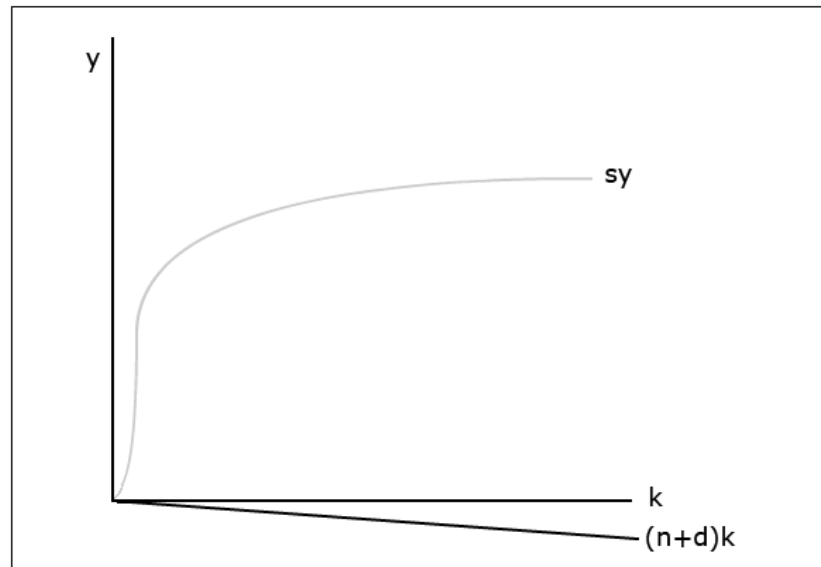
Graph 4.3. Disequilibrium in the neoclassical model.

It is interesting to consider what happens to the Solow solution in case of sufficiently negative population decline rates. Apparent from graph 4.3. is that if the (n+d)k curve is too low, i.e. n+d ≤ 0, then it does not intersect with the sy curve in the first quadrant. Therefore, positive values of steady state k are only possible if the savings rate s is also negative. Otherwise, the capital per worker increases to infinity.

Using the functional form of the production function from equation 1.1, it is possible to derive the following balanced path growth rate:

$$Y = K^\alpha (AL)^{1-\alpha}$$
$$y = k^\alpha A^{1-\alpha}$$
$$g_y = \alpha \frac{\dot{k}}{k} + (1 - \alpha)\frac{\dot{A}}{A}$$

$$g_y = \alpha \left(s\frac{y}{k} - n - d \right) + (1 - \alpha)g$$

$$g_y = \alpha s k^{\alpha-1} A^{1-\alpha} - \alpha n - \alpha d + (1 - \alpha)g$$

It is apparent that since α < 1, then as k approaches infinity, the long-term output per capita growth rate reaches the constant value of

$$\lim_{k \to \infty} \frac{\dot{y}}{y} = -\alpha n - ad + (1 - \alpha)g$$

If we consider this equation without the technology growth rate, then in order to induce positive growth n < -αd/α or n < -d has to hold true. The depreciation rate of physical capital, a rather negligible parameter in case of positive population growth, becomes crucial in the contrary scenario: if the population decline rate is smaller than the negative depreciation rate, long-term per capita growth is possible. Including technology again, n < [(1-a)g]/a − d is needed in order to initiate growth.

In this equation, technological progress has a large beneficial impact as suspected. However, the first finding is especially interesting because there is no long-run per capita growth in the Solow model with standard assumptions. However, sufficiently negative population growth can induce it. These properties are true only if n + d < 0. It is doubtful if Solow originally considered these occasions, more likely the model is built around the assumption that population change rates are high enough for the (n+d)k curve to stay in the first quadrant.

The neoclassical model has proven to fit well to empirical data (Jones 2002:54) and its simplicity makes it appealing. However, the framework suggests that government policies are ineffective in swaying the long-term economic growth rate. Economic growth is entirely produced (excluding the special case of n < -δ) by the inexplicable and unmodeled technological progress variable A. It is reasonable to believe that demograpic changes have an impact on A, e.g. declining population increases human capital investment, which magnifies A, which in turn has a positive effect on growth. Endogenous models try to account for this mechanism.

3.2   Romer-type endogenous model
The diminishing returns to scale effect is eliminated by deriving from equation 2.4 that

$$\dot{A} = \delta H_A A$$

which means that the productivity of researchers increases with the stock of knowledge. In Romer's 1990 framework the economic growth rate is dependent upon the productivity of researchers, the amount of human capital and some behavioural parameters. This model type suggests that growth can be accelerated by increasing

aggregate human capital. Contrary to the neoclassical model, subsidies to R&D cause permanent growth effects rather than simply level effects.
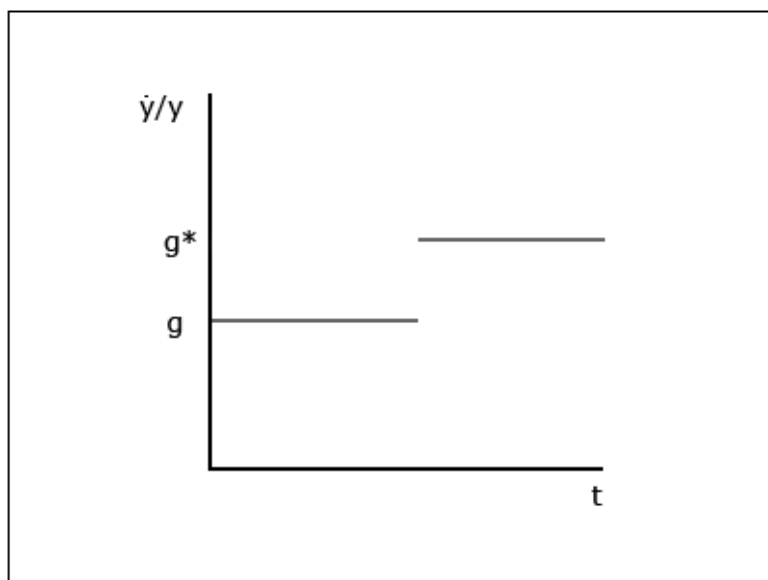
Graph 4.4. Long-term growth effects in the Romer model in case of R&D subsidy

Equation 2.7 shows a peculiar property of the Romer model: the solution does not include a population growth rate. Therefore, on the balanced growth path, the rate of scientists, thus also population, has to be constant. Equation 2.5 displays that if this was not the case and L_A was also increasing alongside the productivity of researchers, the growth rate of technology, and consequently an economy, would explode, causing infinite growth. The opposite case with a decreasing population is more complex: growth rates depend on the values of productivity increase and the decline in the number of scientists. Similarly to Solow's model, this framework does not take into consideration the age structure of an economy.
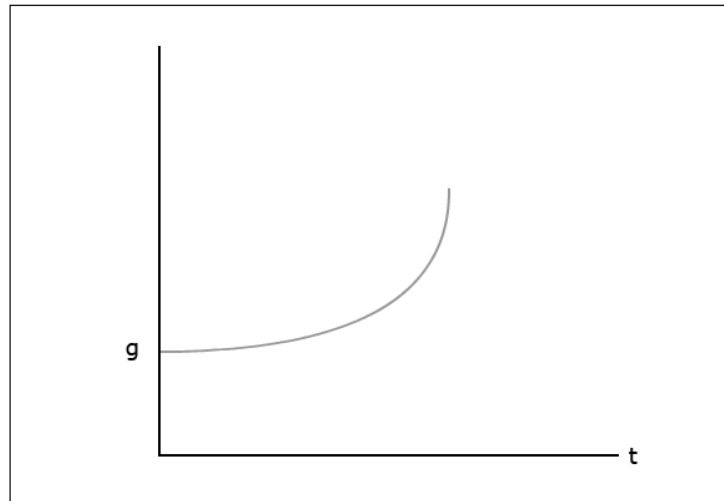
Graph 4.5. Growth in the Romer model with increasing population.

A common mistake in the analysis of this first generation endogenous model is that population size is assumed to have scale effects. To be precise, in the original Romer (1990) paper, it is the total amount of human capital that has scale effects as depicted in graph 4.6. Romer explicitly points out: „The correct inference from this model from this model is that the effect of an increase in L … is ambiguous, something that *a priori* theorizing cannot resolve.“ (Romer 1990:S94). Therefore, the Romer 1990 framework does not imply that a larger population automatically boosts the economic growth rate, as is often alleged in literature.

This is important to remember when considering the effect of population decline. If population declines *ceteris* paribus, then it also hampers economic growth due to decreased aggregate skilled labour force. However, as chapter 1.4 argued, per capita human capital is most likely positively affected by population decline and the latter process might be beneficial to long-term growth rates. This only holds true if the aggregate amount of human capital does not decrease.
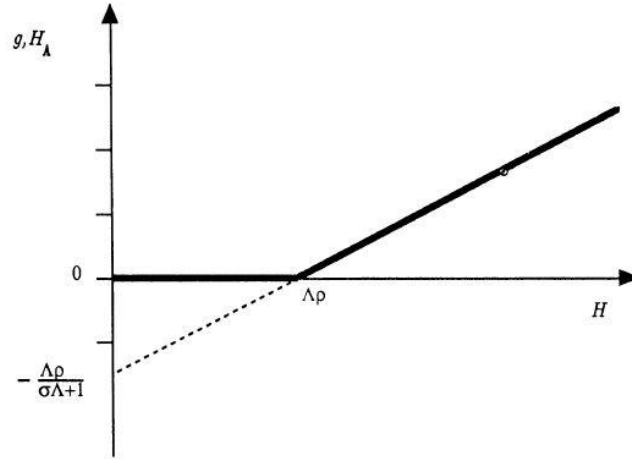
Fɪɢ. 2.—Growth rate and amount of human capital in research as a function of total human capital (for δ = 1).

Graph 4.6. Aggregate human capital scale effects in the Romer framework (Romer 1990:S95)

3.3   Semi-endogenous growth model

Equation 2.7 suggests that the growth rate of semi-endogenous models depends only on the population growth rate and some parameters. On first glance, then, it appears that population decline has inevitable detrimental effects to economic growth. However, it is again useful to check if this holds true in the case of negative population growth rates. This analysis has been done by Christiaans who found that the relationship between variables is non-monotous, positive economic growth is possible again with sufficiently negative population growth rates (Christiaans 2011:2670).
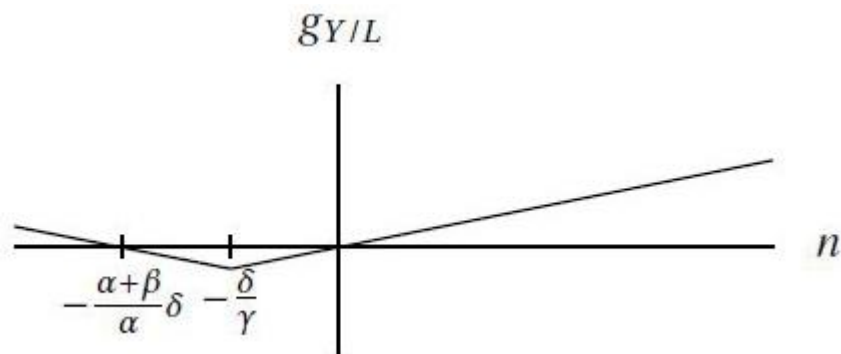
Graph 4.7. Dependency of per capita growth rates on population growth rate n in a semi-endogenous framework (Christiaans 2011:2671)

This surprising result indicates that yet again even the simplest modeling constructs are inconvenient in the case of negative population growth rates. Again, age heterogeneity is unmodelled. Whether policies induce growth or level effects becomes apparent by diving equation 2.4 by A.

$$\frac{\dot{A}}{A} = \delta \frac{L_A}{A^{1-\phi}}$$

If the relative share of scientists to technology $\frac{L_A}{A}$ increases over the optimal value, for example due to R&D subsidies, the growth rate of technology exceeds the population growth rate n, therefore the scientists to technology ratio eventually declines to its steady state value. Dynamics are similar to the ones implied in the graph depicting population change level effects in the Solow framework. Contrary to the Romer case, population growth has to be positive on a steady state balanced growth path in order to compensate for the effect of new discoveries becoming more difficult due to $\phi < 1$.

3.4 Fully endogenous growth models

Endogenous models avoid the invariant conclusions of semi-endogenous theory. Demographic variables do not determine long-run growth rates, but they nonetheless affect them. A main feature of endogenous models is that policies can influence long-term growth rates. The extent and exact effects of demographic changes depends on the specific modeling framework, but generally population decline has a detrimental effect on long-term growth rates, similarly to the semi-endogenous models. However, the dynamics are more diverse because population decline may also have a medium-term beneficial effect to an economy. Population size effects may exist in the Schumpeterian model, but they have level rather than growth effects.

Equations 4.1, 4.2, 4.3 and 4.4 indicate an important property of the typical Schumpeterian model with horizontal and vertical innovation. The balanced path solution consists of an exogenous part pinned down by the population growth rate and an endogenous component which can be affected by public policies or changes in human capital. In a simplified manner:

$$g_y = n + e$$

Accordingly, population decline will still negatively affect the long-term growth rate of an economy, but if the connection between variables was proportional before, it is linear

now. A negative population growth rate does not necessarily also determine a negative economic growth rate, if the effect from the endogenous summand is large enough. Age heterogeneity is unaccounted for and there are no population size effects.

3.5   Model framework comparison and demographic analysis

Model type	Neoclassical	Romer	Semi-endogenous	Endogenous
Knowledge production function	N/A	Increasing returns	Decreasing returns	Constant or increasing returns
Effect of policy	Short-term	Long-term	Short-term	Long-term
Effect of population changes	Short-term	Long-term	Long-term	Long-term
Important demographic variables	Population growth rate	Population size, aggregate human capital	Population growth rate	Population growth rate
Population decline	Beneficial due to capital concentration	Mostly ambiguous	Detrimental due to fall in relative research effort	Ambiguous, detrimental in the default framework
Population ageing	Negative	Ambiguous	Negative	Ambiguous
Steady state path dependent on	Exogenous technology	Aggregate human capital	Population growth rate	Population growth rate, endogenous productivity
Human capital accumulation	Positive	Positive	Positive	Positive
Strengths	Good empirical validity, especially useful when analysing traditional production technologies	Allows for endogenous growth, emphasises the important role of human capital	Eliminates scale effects, good empirical validity, emerges as a general case mathematically	Good empirical validity, effective policy, growth possible with constant population
Weaknesses	Technological change inexplicable, policy invariant	Empirical data does not support key assumption, population constant in steady state	Growth requires increasing population	Requires two knife-edge conditions

Table 4.1. Comparison of different growth model families

The above table summarises the differences between general frameworks of the most common model families in the theory of economic growth. Population decline has a definitive detrimental effect in semi-endogenous and an ambiguous detrimental effect in fully endogenous frameworks. A direct impact does not exist in the Romer model but if it is assumed that a long-term decline in population also decreases the aggregate human capital, then the effect is detrimental as well. On the other hand, if human capital accumulation is assumed to increase with population decline, this has a positive effect. The neoclassical Solow model suggests that a decrease in population is beneficial due to increased capital intensity per worker.

None of the models take into consideration the age heterogeneity of a society. In order to analyse population ageing in a satisfactory manner rather than equalising it with decreased labour force, one has to employ an extended framework introduced in the previous chapter. As for scale effects, population size has a beneficial effect only in the Romer framework and not directly, but through either the aggregate human capital or the number of people employed in R&D. Some endogenous two-sector models rarely use scale effects but this depends on the author. Policy has growth-inducing effects in the endogenous frameworks and lacks them in others.

The long-term economic growth rate equilibrium displays peculiar characteristics if population growth rates are negative enough. The semi-endogenous model connects the two variables in a non-monotonous manner as shown by Christiaans. This is contrary to the result from equation 2.7. As shown in this paper, similar dynamics are true for the Solow model. Although these solutions are stable, they are not achieved within an economic steady state equilibrium. Therefore, the original models probably did not account for negative population growth rates and these default frameworks are not favourable for analysing such phenomena.

Two-sector semi-endogenous and fully endogenous models are the most contemporary tools used in analysis due to empirical weaknesses of the Romer model and inexplicability in the neoclassical framework. When compared from a modeling perspective, semi-endegenous theory emerges as the victor because Schumpeterian models rely on two knife-edge assumptions (Li 1999:12). Moreover, it has been suggested that the number of knife-edge conditions depends on the amount of R&D sectors included in the model: one in the classic Romer model, two in a two sector

construct etc (Li 2003:41). The real world consists of multiple types of technological progress and this suggests that semi-endogenous growth holds true in reality.

In addition, two-sector endogenous theories rely on the notion that there are no knowledge spillovers between R&D sectors: a highly doubtful attribute in the real world. However, from a normative perspective it is highly desirable to develop a model which allows for effective policy interference and is not fully determined by demographic variables. In addition, studies do not confirm the proposal of semi-endogenous theories that income growth is proportional to population growth (Dinopoulos & Thompson 1999).

Schumpeterian models also fare better in some general empirical tests. Comparing the knowledge production function with international data, Madsen found that the fully endogenous model is consistent with time-series evidence but not with cross-sectional evidence, while the semi-endogenous model was inconsistent with both (Madsen 2008:28). Testing British historical growth data since 1620, Madsen et al. found „very strong support" for Schumpeterian rather than semi-endogenous growth (Madsen et al. 2010:287). Banerjee has examined the same data for Australia since 1840 and also found significant proof of the Schumpeterian theory (Banerjee 2011:1).

The evidence from extended frameworks strongly suggests that human capital accumulation is the key mechanism connecting demographic changes and growth. Whether it be the model of Elgin & Tumen, Fernandez-Villaverde, Prettner & Prskawetz, Fougère et al., Bucci, Dalgaard & Kreiner or Tournemaine, the robust beneficial effect of human capital accumulation remains. By including endogenous education or equivalent human capital decisions, it is possible to sustain long-term growth and negative population growth even in models, which originally predicted the exact opposite.

The author of this paper finds that in order to further study demographic effects on economic growth, it is needed to specifically focus on the intermediate mechanism of human capital. While population decline has been quite intuitively assumed to be negatively connected with human capital accumulation, the effect of ageing remains more ambiguous. If ageing is considered *ceteris paribus*, it has strong negative implications to growth perspectives. Therefore, it is essential to further study whether ageing increases human capital accumulation and if this can countervail this effect.

Conclusion

The main question raised by this work was whether societies possess inherent mechanisms which could reverse the decreasing economic growth rates caused by unfavourable demographic changes. It is found that economic theory indeed provides these solutions both on an intuitive level, as well as in complex growth models. This paper concludes that human capital accumulation is the principal counterforce against negative economic impacts of population ageing and decline in Europe. An alarming notion is that both of the most popular contemporary modeling frameworks – semi-endogenous and endogenous growth models – show population decline as detrimental to long-term economic growth. However, once endogenous human capital accumulation is introduced, all four model types allow population and economic growth rates to be negatively connected.

Further research should logically focus on the specific human capital mechanism and its effects on growth when population is ageing and declining. The positive effect of human capital is clear, however, the size of this effect is crucial in determining whether this mechanism can serve as a genuine transforming force against demographic impacts. If the increase in per capita human capital accumulation is not large enough, it only serves as a „softening" factor and many countries face an inevitable decrease in economic growth rates.

In addition to the human capital channel, several other mechanisms can boost growth in the short term. Age structure accounting effects can be beneficial thanks to the demographic dividend concept. The initial decrease in fertility lags behind the mortality drop and the consequent large cohort of workers has a large beneficial effect on the economy due to increased labour force, savings and investments. However, this group of people eventually has to retire, causing increasing burdens on growth. Behavioural responses to population changes such as increased savings, larger female and old age participation rates are also lucrative but both the accounting and behavioural effects are most likely only transitional.

This paper suggests that the alarmist views on population ageing and decline are overly pessimistic. In the worst case scenario, per capita growth rates slightly decrease in Europe due to bigger old age dependecy ratios and a smaller inflow of scientists to the

R&D sector. In the opposite case, if the hypothesis that population ageing and decline stimulate human capital accumulation holds true, the economy will actually benefit from these demographic trends as it readjusts from labour-intensive production to one that supports an ageing and declining population.

References

Aghion, P. and Howitt, P. (1999). Endogenous Growth Theory. The MIT Press.

Baldwin, R. E. (1966). Economic Development and Growth, John Wiley & Sons, Inc.

Banerjee, R. Population growth and endogenous technological change: Australian economic growth in the long run. (2011). MPRA Paper No. 30892.

Barcenilla-Visus, S., López-Pueyo, C. and Sanau, J. (2008). Semi-endogenous growth theory versus fully-endogenous growth theory: a sectoral approach. WIOD Conference of Industry-Level Analyses of Globalization and its Consequences.

Barro, R. J. and Sala-i-Martin, X. (1999). Economic Growth. The MIT Press.

Becker, G. S. and Lewis, G. H. (1974). Interaction between quantity and quality of children. Schultz, T. W. (ed), *The Economics of the Family: Marriage, Children, and Human Capital,* 81-90.

Bloom, D. E., Canning, D. and Fink, G. (2011). Implications of population aging for economic growth. National Bureau of Economic Research. Working Paper 16705.

Bloom, D. E., Canning, D. and Fink, G. (2008). Population Aging and Economic Growth. PGDA Working Paper No. 31.

Bloom, D. E., Canning, D. and Sevilla, J. (2001). Economic growth and the demographic transition. National Bureau of Economic Research. Working Paper 8685.

Bloom, D. E. and Sousa-Poza, A. (2010). Economic consequences of low fertility in Europe. FZID Discussion Papers, No. 2010/11.

Bucci, A. (2008). Population Growth in a Model of Economic Growth with Human Capital Accumulation and Horizontal R&D. *Journal of Macroeconomics,* Vol. 30(No. 3):1124-1147.

Christiaans, T. (2011). Semi-endogenous growth when population is decreasing. *Economics Bulletin*, Vol. 31(No. 3):2667-2673.

Crenshaw, E. and Robison, K. (2010). Socio-demographic Determinants of Economic Growth: Age-Structure, Preindustrial Heritage and Sociolinguistic Integration. *Social Forces*, Vol. 8(No. 5):2217-2240.

Dalgaard, C. and Kreiner, C. T. (2001). Is Declining Productivity Inevitable? *Journal of Economic Growth*, Vol. 6(No. 3):187-203.

Dinopoulos, E. and Sener, F. (2007). New Directions in Schumpeterian Growth Theory. Hanusch, H. and Pyka, A. (eds.), *Elgar Companion to Neo-Schumpeterian Economics,* Edward Elgar Pub.

Dinopoulos, E. and Syropoulos, C. (2006). Rent protection as a barrier to innovation and growth. *Economic Theory*, Vol. 32(No. 2):309-332.

Dinopoulos, E. and Thompson, P. (1999). Scale effects in Schumpeterian models of economic growth. *Journal of Evolutionary Economics,* Vol. 9(No. 2):157-185.

Elgin, C. and Tumen, S. (2010). Can Sustained Economic Growth and Declining Population Coexist? Barro-Becker Children Meet Lucas. Bogazici University Working Paper No. 2010/11.

Fernandez-Villaverde, J. (2001). Was Malthus Right? Economic Growth and Population Dynamics. University of Pennsylvania. Institue for Economic Research. Working Paper No. 46.

Ferrara, M. (2011). An AK Solow Model with a Non-positive Rate of Population Growth. *Applied Mathematical Sciences,* Vol. 5(No. 25):1241-1244.

Fougère, M., Harvey, S., Mercenier, J. and Mérette, M. (2009). Population Ageing, Time Allocation and Human Capital: a General Equilibrium Analysis for Canada. *Economic Modelling*, Vol. 26(No. 1):30-39

Gómez, R. and de Cos, P. H. (2008). Does population ageing promote faster economic growth? *Review of Income and Wealth*, Vol. 54(No. 3):350-372.

Gordo, L. R. (2006). Compression of Morbidity and the Labor Supply of Older People. IAB Discussion Paper No. 200609.

Horvath, G. T. (2007). Modeling Demographics and Life-Cycle Details in Models of Overlapping Generations. Master's thesis, University of Vienna.

Jones, C. I. (2002). Introduction to Economic Growth. W. W. Norton & Company, Inc.

Jones, C. I. (1995). Time Series Tests of Endogenous Growth Models. *The Quarterly Journal of Economics,* Vol. 110(No. 2):495-525.

Li, C. R&D-based Growth Models. (2003). Lectures at University of Zurich.

Li, C. Endogenous vs. Semi-endogenous Growth in a Two-R&D-Sector Model. (1999). *The Economic Journal,* Vol. 110(Issue 462):109-122.

Li, C. and Tuljapurkar, S. (2004). Life, Death and the Economy: Mortality Change in Overlapping-Generations Model. Michigan Retirement Research Center. Working Paper No. 2004/72.

Lindh, T. and Malmberg, B. (2009). European Union economic growth and the age structure of the population. *Economic Change and Restructuring*. Vol. 42(Issue 3):159-187.

Madsen, J. B. (2008). Semi-endogenous versus Schumpeterian growth models: testing the knowledge production function using international data. *Journal of Economic Growth.* Vol. 13(No. 1):1-26.

Madsen, J. B., Ang, J. B., Banerjee, R. (2010). Four centuries of British economic growth: the roles of technology and population. *Journal of Economic Growth*, Vol. 15(No. 4):263-290.

Malthus, T. (1798). An Essay on the Principle of Population. Electronic Scholarly Publishing Project, http://www.esp.org/books/malthus/population/malthus.pdf, 20.05.2013

Prettner, K. (2011). Population ageing and endogenous economic growth. PGDA Working Paper No. 72.

Prettner, K. and Prskawetz, A. (2010). Decreasing fertility, economic growth and the intergenerational wage gap. *Empirica,* Vol. 37(No. 2):197-214)

Prettner, K. and Prskawetz, A. (2010). Demographic Change in Models of Endogenous Economic Growth. A Survey. Vienna Institute of Demography. Working Paper No. 1008.

Prettner, K. and Trimborn, T. (2012). Demographic Change and R&D-based Economic Growth: Reconciling Theory and Evidence. Center for European Governance and Economic Development Research, Discussion Paper No. 139.

Prskawetz, A., Fent, T., Barthel, W., Crespo-Cuaresma, J., Lindh, T., Malmberg, B. and Halvarsson, M. (2007). The Relationship Between Demographic Change and Economic Growth in the EU. Vienna Institute of Demography. Research Report 32.

Romer, P. M. (1990). Endogenous Technological Change. *The Journal of Political Economy*, Vol. 98(No. 5):S71-S102

Tournemaine, Frederic. (2007). Can population promote income per-capita growth? A balanced perspective. *Economics Bulletin*, Vol. 15(No. 8):1-7.

Kokkuvõte

Majanduskasvumudelite võrdlev analüüs rahvastiku vähenemise ning vananemise valguses

Antud bakalaureusetöö eesmärgiks on uurida rahvastiku vähenemise ning vananemise mõju pikaajalise majanduskasvu perspektiividele. Selleks on kasutatud nelja enim levinud majanduskasvumudeli tüübi võrdlevat analüüsi. Selgub, et eelnimetatud demograafilised faktorid on tavapärastes mudelites kasvule pigem negatiivse mõjuga. Eriti kehtib see vananemise kohta, mis suurendab ühiskonnas sõltuvate inimeste arvu. Kui aga mudelitesse sisestada endogeenne inimkapitali akumulatsiooni mehhanism, siis on igas raamistikus võimalik modelleerida rahvastiku- ning majanduskasvu vastassuunalist liikumist. Niisiis võib rahvastiku kahanemine modelleerimise perspektiivist olla majanduskasvule lausa positiivse mõjuga.

Seetõttu leiab autor, et edasine töö peaks keskenduma juba spetsiifiliselt inimkapitali akumulatsiooni kui demograafilisi faktoreid ning majanduskasvu ühendava mehhanismi uurimisele. Kui *per capita* inimkapitali akumulatsioon rahvastiku vähenedes ja vananedes piisavalt kiirelt kasvab, siis võib see majanduskasvu aeglustumist ära hoida. Kui see efekt ei ole aga piisavalt tugev, on inimkapitali akumulatsioon pigem majanduskasvu langust pehmendav faktor, kuid mitte reaalne vastujõud.

Lisaks inimkapitali mehhanismile ühendab demograafiat ja majanduskasvu veel mitu erinevat faktorit: näiteks rahvastiku vanusestruktuuri või indiviidide säästu- ning tööturuosaluskäitumise muutused. Nendest tulenevad efektid majanduskasvu pikaajalisele määrale on aga nii intuitiivselt kui ka mudelites pigem lühiajalise või keskmise mõjuga. Üldiselt aga näib rahvastiku vananemise ja vähenemise mõju majanduskasvule olevat väiksem kui on kardetud, ulatudes pessimistlikumate prognooside puhul vaid mõõduka kasvukiiruse aeglustumiseni.