Hacettepe University Graduate School of Social Sciences

Department of Business Administration

A SYSTEM DYNAMICS APPROACH TO ECONOMIC GROWTH MODEL FROM A DEMOGRAPHIC PERSPECTIVE: AN ECONOMIC DEMOGRAPHY MODEL PROPOSAL

Gözdem DURAL SELÇUK

Ph. D. Dissertation

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KABUL VE ONAY

Gözdem DURAL SELÇUK tarafından hazırlanan "A System Dynamics Approach to Economic Growth Model from a Demographic Perspective: An Economic Demography Model Proposal" başlıklı bu çalışma, 26 Haziran 2015 tarihinde yapılan savunma sınavı sonucunda başarılı bulunarak jürimiz tarafından Doktora Tezi olarak kabul edilmiştir.

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Gözdem DURAL SELÇUK

To the soul of my life, Alp Demir SELÇUK

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ÖZET

DURAL-SELÇUK, Gözdem. Ekonomik Büyüme Modeline Demografik Bakış Açısı ile Bir Sistem Dinamiği Yaklaşımı: Bir Ekonomik Demografi Modeli Önerisi, Doktora Tezi, Ankara, 2015.

Demografik geçiş sürecinin sonlarına doğru, nüfusun üssel büyümesine dair kaygılar yerini nüfus yaşlanmasına bırakmıştır. Birçok Avrupa ülkesi demografik geçişi deneyimlerken; yaş yapılarındaki değişim beraberinde artan sağlık harcamaları ve emeklilik ödemeleri olarak ekonomik yükler getirmiştir. Aynı demografik geçişin gelişmekte olan ülkelerde de başlamak üzere olduğu görülmektedir. Geçiş sürecinin başında veya sonunda olduğu fark etmeksizin, her ülke kendi toplumsal politikalarını değişen ekonomik ve demografik koşullara göre adapte etmelidir. Bu anlamda, resmi kurumlar ülkenin ekonomik ve demografik dinamiklerini incelemek ve buna bağlı olarak geliştirilecek politika alternatiflerini değerlendirmek için profesyonel karar destek araçlarına ihtiyaç duymaktadır. Bu çalışmada politika yapıcıların doğurganlık, eğitim, insan sermayesi ve teknoloji dinamiklerini derinlemesine inceleyebilmeleri için bir ekonomik demografi modeli geliştirilmektedir. Önerilen model; ekonomik büyüme modelini, geleneksel demografi aracı olan kuşak bileşen yöntemi ile birleştirmektedir. Böylece model, kullanıcısına; ölümlülüğün dışsal değişken olması varsayımı altında, nüfusun yaş ve cinsiyet yapısını; doğurganlık, eğitim, insan sermayesi ve teknoloji içsel değişkenleri ile olan etkileşimi üzerinden sunmaktadır.

Kavramsal modelin geliştirilmesinin ardından, model deneysel açıdan test edilmesi amacı ile sistem dinamiği ortamına aktarılmaktadır. Deneysel çıktılar göstermektedir ki; ekonomik demografi modeli tutarlı bir bütünlük içinde çalışmakta ve güvenilir sonuçlar vermektedir. Buna ek olarak, modelin verifikasyon ve validasyonu için uç koşul testleri ve duyarlılık analizi de yapılmış ve geliştirilen modelin etkililiğinin ve tutarlılığının, uç koşullarda ve değişen parametre setlerinde dahi korunduğu ortaya koyulmuştur.

Anahtar Sözcükler

Ekonomik büyüme, demografik geçiş teorisi, tümleşik büyüme teorisi, sistem dinamiği, kuşak bileşen modellemesi

ABSTRACT

DURAL-SELÇUK, Gözdem. A System Dynamics Approach to Economic Growth Model from a Demographic Perspective: An Economic Demography Model Proposal, Ph. D. Dissertation, Ankara, 2015.

The early concerns about exponential growth of population gave way to population aging towards the end of demographic transition period. Many European countries have gone through the demographic transition and the change in their age structure is accompanied by the evolving economic burdens in terms of high health care expenses and pension payments. The same transition is about to start in developing countries. Either it is at the beginning or at completion of the transition, each country should adopt its public policies due to the changing demographic and economic conditions. In that sense, governmental agencies need professional decision support tools to explore the dynamics of the economy and demography of a country and evaluate possible policy alternatives accordingly. In this study, we develop an economic demography model to aid the policy makers to delve into the fertility, education, human capital and technology dynamics of a population. The proposed model integrates economic growth model with the conventional demographic tool of cohort component modeling. Hence, it provides the user with the population age and sex structure in interaction with the endogenous fertility, education, and human capital and technology variables under the assumption of exogenous mortality.

After the development of conceptual model, we transfer it into the system dynamics environment and test the model experimentally. In the light of the experimental outcomes, we can conclude that the economic demography model works out in coherence and yields reliable results. Furthermore, we perform extreme condition tests and sensitivity analysis for the sake of verification and validation. As a consequence, we demonstrate that the model keeps its effectiveness and coherence even under the extreme conditions and varying parameter settings.

Key Words

Economic growth, demographic transition theory, unified growth theory, system dynamics, cohort component modelling

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LIST OF ABBREVIATIONS

ABPRS: Address Based Population Registry System

ASFR: Age-specific Fertility Rate

B: Balancing

CCM: Cohort-component Modelling

CLD: Causal Loop Diagram

DR: Dependency Ratio

EUROSTAT: Statistical Office of the European Communities

GDP: Gross Domestic Product

G&W: Galor and Weil (2000)

LE: Life Expectancy

MAD: Mean Absolute Deviation

MSE: Mean Square Error

OECD: Organisation for Economic Co-operation and Development

OLG: Overlapping Generations Economy

R: Reinforcing

SD: System Dynamics

SRB: Sex Ratio at Birth

T-ASFR: Target Age-specific Fertility Rate

TFR: Total Fertility Rate

TURKSTAT: Turkish Statistical Institute

UGT: Unified Growth Theory

$\boldsymbol{P_{a-b}}$**:** Population size of ages between a and b

$\boldsymbol{P_{c^+}}$**:** Population size of ages above c.

$\boldsymbol{u_t}$**:** Utility of an individual in time t

$\boldsymbol{c_t}$**:** Consumption level of individual in time t

$\boldsymbol{\tilde{c}}$**:** Subsistence level of consumption

$\boldsymbol{e_{t+1}}$**:** Education level invested in child in time t

$\boldsymbol{n_t}$**:** Number of children born in time t and survived to time $t+1$

$\boldsymbol{h_{t+1}}$**:** Human capital level invested in child in time t

$\boldsymbol{z_t}$**:** Income level of an individual at time t

$\boldsymbol{\gamma}$**:** Weight on fertility in utility function

$\boldsymbol{\tau}$: Fixed time cost of children

$\boldsymbol{x_t}$: Effective resources per worker

$\boldsymbol{A_t}$: Technology level in time t

$\boldsymbol{X}$: Total land which is exogenous and constant

$\boldsymbol{L_t}$: Total adult population in time t

$\boldsymbol{a}$: Labor share

$\boldsymbol{g_{t+1}}$: Technological progress rate from period t to $t+1$

$\boldsymbol{\hat{g}}$: Threshold value for technological progress rate

$\boldsymbol{\tilde{z}}$: Income level where the subsistence level is binding

$\boldsymbol{\rho}$: Portion of the fixed time allocated to children that contributes to the human capital formation function of the child

$\boldsymbol{\alpha(L_t)}$: Scale effect of the population size

$\boldsymbol{a^*}$: Scale effect parameter

$\boldsymbol{\theta}$: Scale effect parameter

$\boldsymbol{P_{fi}}$: Female population size in the age group of i

$\boldsymbol{P_{ti}}$: Population size of the age group of i in time t

$\boldsymbol{Births_t}$: Number of births in time t

$\boldsymbol{Births_m}$: Number of male births

$\boldsymbol{Births_f}$: Number of female births

$\boldsymbol{M_{ti}}$: Net migration to the age group i in time t

$\boldsymbol{D_{ti}}$: Deaths of age group i in time t

$\boldsymbol{S_{ti}}$: Survived population of age group i who are aged to the next age group in time t

$\boldsymbol{SR_i}$: Survival rate of age group i to age group $i+1$

$\boldsymbol{u_{ti}}$: Utility of an individual of age group i in time t

$\boldsymbol{c_{ti}}$: Consumption level of an individual of age group i in time t

$\boldsymbol{en_{ti}}$: Education level invested in the child born by age group i in time t

$\boldsymbol{n_{ti}}$: Number of children born per person by age group i in time t

$\boldsymbol{hn_{ti}}$: Human capital level of adults in time $t+15$ who were born in time t by age group i

$\boldsymbol{z_{ti}}$: Income level of an individual of age group i in time t

$\boldsymbol{e_t}$: Total education level of population at time t

$\boldsymbol{\gamma}$: Weight on fertility in utility function

$\boldsymbol{\tau_i}$: Fixed time cost of children born by age group i

$\tilde{c}_i$: Subsistence level of consumption of age group i

g_{t+15}: Technological progress rate between years t and $t+15$

$\tilde{z}_i$: Age-specific income level where the subsistence level is binding

nb_t: Total number of births in time t (synthetic cohort measure)

S_{x015}: Survival probability of a new born till the age of 15

P_{fit}: Female population size in the age group of i in time t

TFR_t: Total fertility rate in time t

$ASFR_{it}$: Age-specific fertility rate of age group i in time t

L_{mti}: Population size of male of age group i in time t

L_{fti}: Population size of male of age group i in time t

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INTRODUCTION

Researchers and practitioners mainly get use of the management science to achieve the goals of profitability. Although there is a common perception that the management science application area is mostly profit-seeking institutions, the emergence of the field initiated by British Government in World War II. In today's rapid changing world, governments face a new challenge every day. The high technology and changing economic and demographic conditions introduce new burdens for the political environment as well as the society itself. In such a conjuncture, public policy makers need professional decision support systems more than ever and it would be a valuable contribution if the researchers turn their attention to the governmental issues.

In this thesis, we aim to provide an application oriented theoretical frame which eventually provides a decision support tool for the public policy makers in the area of family-size decision making. This work centers on an economic growth model, which presents a unified framework for the historical development of the economy and demography starting from Malthusian era till the sustained economic growth (Galor and Weil, 2000). We, hereby, revisit the so-called unified growth model from a demographic perspective. In particular, we reformulate the economic growth model in a way that it works out in integration with the conventional demographic tool, i.e. cohort component modeling. Hence, it yields more detailed demographic and economic insights for the public policy makers. More specifically, the thesis proposes an economic demography model that explores how people make family size decision from a systems viewpoint and primarily focuses on the interaction between the factors of technology, education and human capital together with the demographic determinants of fertility and mortality. The model assumes endogenous fertility, technology, education, and human capital levels, whereas the mortality is an exogenous factor. Here, an endogenous variable refers to one determined within the model, whereas exogenous variable represents a variable given to the model.

Despite the fact that the technology, education/human capital levels and the population size are the fundamental macro issues of government policies, they are rather based on an individual level decision optimization. Each individual decides on the number of children and the education level of the children together with their own consumption so as to maximize the utility subject to a budget constraint. This individual level decision problem triggers the causal network of the economic demography model and provides the macro-level variables of technology, education, human capital levels and population size. Furthermore, the theoretical framework presented in this thesis is further verified and validated through a system dynamics simulation model. As a result, this thesis presents a practical implementation of management science tools of optimization and simulation in the area of demography and economy.

The prominence of the economic demography model lies in the fact that it aids the users to examine the relationships among the economic and demographic dynamics in deep. By this means, the users will be able to observe how a variable influences the economic and/or demographic condition. Therefore, the user will have insights on the extent of influence regarding an intervention. This enables the decision makers to evaluate, to some extent, the possible impacts of alternative policies in advance. As a consequence, the governmental agencies may take precautionary actions towards the economic and demographic changes and make the governmental resource allocation accordingly.

The organization of the thesis is as follows.

In the 1st chapter, broad information is given regarding the history of humanity and demographic transition process. 2nd chapter continues with the specific theories that try to explain the process of demographic transition. 3rd chapter introduces the economic growth model that presents a unified framework to explain the transition process of the entire history of humanity (Galor and Weil, 2000). In the 4th chapter, a quantitative implementation of the unified growth model is discussed (Lagerlöf, 2006). Chapter 5 mentions the current methodology of prospective demography analysis, whereas chapter 6 is devoted for the proposal of economic demography model. Chapter 7 is reserved for the system dynamics implementation of the model proposed in the previous chapter. After model calibration is presented in chapter 8, model results are discussed in chapter 9. As the last step, the model assessment and testing is mentioned in chapter 10 and the thesis is ended up with concluding remarks.

CHAPTER 1: DEMOGRAPHIC TRANSITION

Humanity has experienced tremendous demographic and economic changes throughout the history. The changing demographic and economic conditions has accompanied diverging ways of living across time and countries. The people who lived 100.000 years ago are named as hunters and gatherers. They survived by hunting and there were no means of living settled. Instead, they were moving in a search for suitable naturel surroundings and towards the source of food. 10.000 years ago, starting from Neolithic age human beings adopted settled living by the agricultural societies. The agricultural development triggered the emergence of the cities, states and nations. The nature of agriculture required huge amount of man power to keep the authority in hand. Those times authority definition was subject to the man power existence. The foundations of feudal system in dark ages are also laid by the agricultural societies. The most powerful ones became land lords and constructed their own community to stake a claim on their lands. Even after the feudal system collapsed, the agricultural societies continued to have tendency to have large families in order to possess the adequate man power to keep up with the burden of farm work. In summary, harsh farm work led the people to adopt a settled living together with a commune. As settled living is largely accepted and the cities are formed, the life style of human beings changed and they started to look for better living conditions. By this means, the ground for the industrial revolution was set. The resources was not much scarce at those times, however the resource utilization was so low that people were facing diminishing returns on production as a result of the rising population size. Therefore, the conditions forced people to find a more efficient way of the resource utilization which can only be possible by technological development. Living in communities reinforced the development and eased the spread of new technologies. Eventually, the history of humanity witnessed the leading-edge milestone of industrial revolution. With industrialization, the people downscaled their agricultural efforts and moved to big industrial cities to rather get into the industrial sector. Hence, urbanization started as an innate outcome of industrialization. During the industrial revolution, the urbanization ratio increased approximately five fold in three centuries in Western Europe. It was 6.1% in 1500, while it increased to 31.1% in 1890 (Maddison, 2001).

Up to now, we summarized the history of humanity in three major stages: hunting/gathering, the agricultural societies and the industrial societies. Caldwell (2004), classifies the evolution of the human history into three modes of production in a parallel way: hunting/gathering, settled agriculture and industrial production. Caldwell claims that each production mode is attributed with a social system, which we indeed defined as different life styles or different ways of living. Especially after the industrial revolution, tremendous changes occurred in people's living. People no more needed to live in large families. Instead, individualism became a common choice. So, they preferred to have smaller families, namely, they preferred to have fewer number of children. Thanks to technological developments, they had better living conditions and a higher level of medical care. Thus, better living conditions surpassed the epidemics and anti-hygiene conditions, which resulted in dramatically increasing life expectancies. The world average life expectancy of 26 years in 1800s increased up to 49 years in 1950 (Maddison, 2001). To sum up the primal effects of industrialization on the human evolution from a demographic perspective we can conclude that the industrialization era is the stage of declining mortality and fertility rates which eventually breed the changes in the population size. Meanwhile, the industrialization era is associated with technological development and urbanization. As it is obviously declared, social systems are the clue of the demographic and economic conditions of the time. Changing life styles are the reflection of the changing demographic and economic conditions. They all go hand in hand that no one can examine one separated from another. This fact brings us to the point that the history of humanity is a promising research field for the demographers and the economists. Moreover, the one who addresses the issue should definitely take care of the interaction between the two disciplines of demography and economy.

Aforementioned changes in population and economy is called as "demographic transition theory" and both the demographers and the economists paid great attention to the transition of the human history through the development stages and investigated the mechanisms behind the transition, as well as the outcomes of the transition. Kirk (1996), identifies three authors as "forerunners" of the literature of this area: Thompson (1929), Landry (1934) and Carr-Saunders (1936). Thompson is the first writer in the English demographic transition literature. He classifies the countries into three groups according to their population growth rates. In Group A countries, the mortality level is low and the fertility levels are declining, resulting in first a stationary than a shrinking population. Group B countries experience an earlier and faster decline in mortality rates, which is far later followed by a fertility decline. So, a Group B country first has a growing population, than a stationary and lastly a declining population with the falling fertility rates. Thompson classifies Group C countries as "Malthusian" (for detailed explanation of 'Malthusian', see section 1.1), where there is no control over either fertility or mortality rates. On the other hand, Landry makes a similar classification and concentrates his study on the demographic transition in France, while Carr-Saunder focuses on the demographic transition in Europe. It wasn't until 1945 that Notestein made the first definition of **"Demographic Transition Theory"** which is accepted to be a classic today. The most crucial differentiation of Notestein among the other forerunners is the fact that he gives explanations about the reasons of demographic transition. According to Notestein, with industrialization people moved to cities and the city life made them more individualistic. Moreover, the new way of living changed their needs for consumption and production habits. As a result of technological developments, need for skilled people is raised up and the education gained importance. Also, with declining mortality rates, more people survived to be looked after and fewer births became preferable. On the other hand, the women got the opportunity to appear in the work force against household and childbearing obligations. The rise up in female labor force participation increased the opportunity cost of child bearing for working mothers and this fact caused the fertility rates to go down. Although the reasoning has been subjected to many questions and has been revisited many times later on, Notestein's explanations are well accepted as the formal definition of the theory of demographic transition.

Caldwell (2004) states that Notestein's modernization explanation is adequate for Western countries till 1930s; however, it does not have any explanatory power for the surprising "Baby Boom" after World War-II. The failure of this theory forced the scientists to propose more explanatory and valid mechanisms for the demographic transition. Succeeding chapters give broad information about the mechanisms proposed for the reasoning of demographic transition. Before addressing the demographic transition theories, we start from defining the milestones in the history of humanity and characterize the time periods in-between these milestones in terms of the demographic and economic conditions. In this study, the period classification is discussed in parallel with the literature, especially as it is mentioned in Galor's book titled "Unified Growth Theory" (2011). We start by explaining Malthusian era, then continue with post-Malthusian regime. We end this chapter with discussing the demographic transition period and also the characteristics of the sustained economic growth.

1.1. MALTHUSIAN ERA

Thomas Malthus first published his study in 1798, in which he discusses how the population growth is in equilibrium with a slowly growing economy. According to Malthus, the population growth is held in equilibrium with the positive and preventive checks. He defines the *"***positive check***"* with respect to the increasing mortality levels due to the depressed wages. He claims that when the population grows faster, it creates a downward pressure on the wages and changes the living condition in a way that an epidemic, a famine or a war occurs. Other effect of the low wages is on the marriage decision of individuals. When they earn less, they postpone the marriage or prefer to use contraception to postpone or lower the child delivery. This postponement action is named as *"***moral restraint***"* by

Thomas Malthus and he calls the resulting fertility decline as *"***preventive check***"*. As a consequence of the positive and preventive checks, the population growth is held in equilibrium accompanied by a very slow growth rate in economy.

When we examine the Malthusian period in a more theoretical way, we can conclude that the income per capita growth is restricted by the resources. The technological development is limited and the resource utilization or productivity cannot be increased. As a result, the growing population lowers the levels of per capita incomes. This means that any increase in the per capita income creates only a temporary effect. It rises the fertility up and the growing population, on the other hand, lowers down the wages back leading the people towards the lower fertility levels once again. Since these ripples keep up as long as the technological progress is limited, Malthus defines a never ending balancing loop between the wages and the population size. One more argument of Malthus is about the cross-country differences in terms of wage levels. According to Malthus, there is a wage convergence all through the world. Since the main determinant of this is the density of population, the income per capita across countries does not change, but their population density may differ. Malthus claims that people would migrate to the places where there are higher wage opportunities and they would also increase the fertility levels due to the higher wage levels. Both actions would result in an increase in the population density and lower the income level back. To conclude, in Malthusian period, the population and the technology are dynamic, whereas the gains in income per capita is just transitory. When we look at the fact that the long-run growth rate of income per capita is very small, it is obvious that the income levels of individuals are stagnated. Galor defines the phenomena of unchanged per capita income within and across countries in Malthusian period as **"Malthusian stagnation"** or **"Malthusian trap"**. His definition of Malthusian stagnation can also be empirically observed by the average growth rate of world income between the years 1000-1820 that is recorded as 0.05% per year by Maddison (2001).

To summarize; Malthusian era is characterized with the direct relationship between the resources and the population. The technological development increases the resource utilization and fertility as a consequence; nevertheless, increased population outperforms the gains in income per capita and lowers it down back to the stagnation levels. Thus, the technological improvement in Malthusian era is so limited that it does not change the living conditions. According to Malthus, the only way to enhance the living standards is to control fertility. This is the main flaw of the Malthusian theory. Better living conditions can well be achieved via higher technological development which will yield higher levels of productivity.

1.2. POST-MALTHUSIAN REGIME

Malthusian era is followed by the period of post-Malthusian regime of which the most appealing characteristic is the accelerated technological progress, which increased the resource utilization. As a result, the offsetting effect of population on the resources was weakened and per capita income levels started to rise up. In other words, technological development supported the economy to escape from **"Malthusian trap"**. Technological development and the resource relationship is well explained with the computer-software package-user metaphor. Suppose that you are a user of a computer and you install a new software package on your computer, which enhances your usage of the computer. The physical capital (computer) and the labor (the user) did not change; but the user's resource utilization (your usage of computer) has improved thanks to the new technology (new software package) (Weil, 2004).

Additionally, the increasing income per capita levels created a population boom with the high fertility rates. Although better living conditions lowered the mortality levels, this fact did not deter people from adopting high fertility. Hence, the direct relationship between the resources and the population is kept valid also for post-Malthusian regime as in the Malthusian era. The annual income growth rate of 0.05% between the years 1000-1820 increased to 1.21 between the years 1820-1998 (Maddison, 2001). Accordingly, the population growth rate of 0.17% in the former time period raised up to 0.98% in the latter (Maddison, 2001).

Besides the increasing fertility and income levels, another characteristic of the post-Malthusian regime is the cross-country differences. Since income per capita is a function of the technology and the population density, cross-country differences started to appear due to varying technological progress rates. The differences may be validated by the historical data of GDP per capita levels. Maddison (2001) records that in year 1000, countries' GDP per capita levels were in the range of (400-450) in 1990 international dollars, whereas the range enlarged to (418-1,232) in year 1820 and when we came to the year of 1998, Africa was the region with the lowest GDP per capita of 1,368, where the highest value was observed in Western offshoots with 26,146. This data shows the remarkable change of income divergence through the years.

When we look at the timing of post-Malthusian regime, it had started after the industrial revolution, namely, at the beginning of 19^{th} century in the developed countries, but it was towards the end of the 19^{th} century and start of the 20^{th} century in the developing countries. Galor (2011) defines the Post-Malthusian period as the era of industrialization and urbanization. The 10.6% urbanization ratio in Western Europe in 1800 went up to 31% in 1890 (Maddison, 2001). Industrialization and urbanization, on the other hand, resulted in a declining share of agricultural production in the total output. Changing production trends required different human skills. The human skills requirement in the production gave way to question the production inputs. Before the industrial revolution, where technological development rates were low, conventional production inputs were determined as the land, labor and physical capital. The production output was a function of these three inputs utilized by a technological development coefficient. Note that the labor here meant the brute force man power. After the technological development gained momentum by the industrial revolution, skill requirement provoked the development of **"human capital"** concept and this improvement changed the understanding of labor input in the production function. It is no more a sole man power notion which is a substitute of physical capital, it is a skill source to keep up and complement with the technological developments instead. This has changed the way of thinking towards human beings. To reinforce their skills, they are now rather perceived as a prominent investment source. Hence, as a whole, capital accumulation has shifted from tangible goods to intangible investments. This process of investment and accumulation of skills refers to **"human capital formation"** (for detail information, see section 2.3.1). Galor (2011) mentions the massive educational reforms occurred in the second half of the 19^{th} century as an evidence and summarizes his thoughts of industrialization and human capital formation as below:

> "During the 2^{nd} half of industrialization a major transformation in the production process had taken place. Industrial demand for human capital significantly increased, triggering the onset of human capital formation." (Galor, 2011)

For most of the scientists, including Galor, the human capital formation process is the starting point of the demographic transition. Introducing the human capital concept, Post-Malthusian Regime, the period of industrialization and urbanization, has great prominence in human history.

1.3. DEMOGRAPHIC TRANSITION PERIOD AND SUSTAINED ECONOMIC GROWTH

> "This global demographic transition has brought momentous changes, reshaping the economic and demographic life cycles of individuals and restructuring populations." (Lee, 2003)

It is hard to divide the whole history of humanity into mutually exclusive time periods in terms of demographic changes. The transition is rather a continuum starting from Malthusian stagnation. The demographic transition theory refers to the decline in mortality and fertility levels. It started around 1800s with the declining mortality rates and followed by the fertility rate decline afterwards. Although the theory refers to declining in both, the timing of changes does not fit exactly but overlaps at a certain extent. The period of demographic transition is not noted only with the low mortality and fertility rates but it is also characterized by a resulting decline in the population growth. In modern economies, fertility rates declined so sharply that the total population growth rate has decelerated despite the lower mortality rates and the extended life expectancies. In other words, the observed population growth caused by the lower mortality rates is followed by a sharp decline with the dramatically falling fertility rates. The world population annual average compound growth rate was recorded as 0.93 between 1913-50; 1.92 between 1950-73 and lastly 1.66 between 1973-98. The Western Europe experienced a similar pattern with different rates: 0.42, 0.70 and 0.32 between the years 1913-50; 1950-73 and 1973-98 respectively. The difference stemmed mainly from varying timing and pace of demographic transition process across countries. Accordingly, in addition to the population growth rate, the inter-country differences in take-off from stagnation also revealed a great divergence in the average income levels.

Other main characteristic of demographic transition period is the rapid developments in technology. The technological progress started to accelerate in post-Malthusian regime; however, it gathered a higher momentum in the demographic transition period. As a result of the rapid increase in the technological development, societies had the opportunity to turn the gains of technological progress into the growth of income per capita. Accordingly, the living standards went up with respect to the technological progress. The drop in the population growth rate and the increase in living standards (i.e. increasing income per capita) together triggered the era of **sustained economic growth**, in which the economies experience continuous increases in per capita incomes. Thus, by means of technological development and demographic transition; countries evolved through growing economies after the escape from Malthusian stagnation. This period of growth is also referred as **the modern economic growth** or simply **the modern economies**.

High technological progress rate, on the other hand, boosted the human capital requirement dramatically. Intangible investments to human beings got importance more than ever before. The brute force labor concept disappeared giving its place to the highly skilled labor. Therefore, along with varying timing of takeoff from Malthusian stagnation, the inter country differences in the income per capita levels are also attributed to the different human capital accumulation levels across the countries (Weil, 2004).

The technological development and the corresponding human capital requirement constitute the major highlights of the sustained economic growth period. Apart from the rapid technological progress and the intense human capital requirement, other remarkable characteristic of the era is the effect of the declining population growth rate on the population structure. After-transition period is classified with the sustained growth, however, that growth process is questionable if the population structure tends to change by aging. From this point of view, the demographic transition is not a completed process. According to Lee (2003), no country in the world has yet completed its transition process. Lee, defines the last stage of the transition as **population aging**:

> "Dramatic population aging is the inevitable final stage of the global demographic transition, part or parcel of low fertility and long life. It will bring serious economic and political challenges." (Lee, 2003)

Patterns in fertility, mortality and economic growth bring a systematic change in the population age structure. The population aging is the relative increase of old age people in the total population. The old age group is defined as the dependent population that is financed by the working-age group. Literally, ages between 15-64 is determined as the working-age group, while over 64 is determined as the old age population. Other dependent population is the young group of ages between 0-14. Both the young and the old age needs to be supported financially and they do not contribute to the production sector. The indicator that gives clue about the dependent population's relative size is the dependency ratios. It is the ratio of the population size that is not in labor force to the population in labor force:

$$Total\ dependecy\ ratio\ (DR_{Total}) = \frac{P_{0-14} + P_{65^+}}{P_{15-64}}$$

where P_{a-b} refers to the population size of ages between a and b, while P_{c^+} refers to the population size of ages above c. The dependency ratio is also decomposed of the young and the old. Particularly:

$$Young\ dependency\ ratio\ (DR_{young}) = \frac{P_{0-14}}{P_{15-64}}$$

$$Old\ dependency\ ratio\ (DR_{old}) = \frac{P_{65^+}}{P_{15-64}}$$

Lee (2003) explains the changes in the population age structure in three stages. The first stage refers to the early periods of the transition and associated with the start of the mortality decline. It first declined in the younger ages causing the young dependency ratio to rise up. Accordingly, the achievement of educational goals has become a burden due to the unexpected high number of children. In the second stage, children in the previous stage has grown up and got into the labor force, leading the total dependency ratio to fall down; however it has pumped up the unemployment. In the last stage, the effects of the demographic transition and the sustained economic growth are examined. The better living conditions, lower fertility rates and increased life expectancies result in an increase in the proportion of the old age population. Unless the saving and the asset accumulation mechanisms that encourage people to finance themselves in elderly age is well operated, the modern economies will suffer from the high burden of elderly in the long run.

Last but not least, the demographic transition process is really a promising field for scientists. It is quite easy to look for the historical trends and patterns in demographic indicators, nevertheless it is hard to explain them. On the other hand, understanding the underlying causes would shed light on the past and aid people to decode the human history. By this means, it would be possible to take course of past actions and have a clue about what is expected in the future. Consequently, economists and psychologists give great importance on the explanation of demographic transition.

Psychologists approach the explanation of demographic transition from behavioral perspective and try to understand the people's fertility decisions: why they want to have a child or why they don't. By means of conducting questionnaires and surveys, they try to gather the psychological value people attribute to having an additional child (Hoffman and Hoffman, 1973; Jaccord and Davidson, 1972, 1975; Vinokur-Kaplan, 1978; Townes et al, 1980; etc.). Apart from psychological studies, Bongaarts (1978) deals with the problem from a biological perspective and carries Davis and Blake's (1956) intermediate determinants of fertility framework forward. In his study, he proposes that whatever the reason is whether it is socioeconomic, cultural or environmental; it is actually an indirect determinant and can only affect fertility decisions via direct determinants like late marriage, contraception and etc. The psychological and biological perspectives are lack of explaining the demographic transition as a whole from the viewpoint of population growth and economy interaction. The fertility transition is handled in isolation and neither economy nor the technological developments are taken into account.

Apart from psychologists, economists develop more comprehensive demographic transition theories. Some proposes that the fertility decline is a consequence of the rise in income per capita, while other claims that it is due to the decline in child mortality and one other group focuses mainly on the quality of child and proposes that the fertility decline stems from the rise in the demand for human capital. Each approach is supported by several breakthrough studies that explain the demographic transition from different viewpoints. What economic theories have in common and differentiate from other disciplines is that they investigate the fertility, population and economic outcomes in a holistic framework and consider the interactions in between. In particular, these models estimate the fertility, population growth, as well as the economic growth. Furthermore, some studies also include the effects of the technological development on fertility and economy. The demographic transition theories proposed by economist perspective in the literature are explained in detail in the next chapter.

CHAPTER 2: DEMOGRAPHIC TRANSITION THEORIES

After Notestein's definition of the demographic transition theory in 1945, a restatement of the theory is done by Caldwell in 1976. Caldwell comes up with the famous **"wealth flows theory".** Caldwell claims that fertility is an economically rational decision. According to this economic point of view, there is no means to restrict fertility if you do not expect an economic return. Similarly, if you face an economic burden due to an additional child, there is no means to have one. This idea means zero fertility in the extreme case; however, in reality we do not observe zero fertility in any case. Caldwell explains this dilemma by the social and psychological aspect of the fertility decision. Even though, he asserts that the economic view of fertility is the dominant one. In his wealth flows theory, Caldwell defines two types of flow: one from children to parents and one from parents to children. According to the theory, in traditional societies, where high fertility is observed, it is rational to have many children. They work in farm work, carry out the family duties, look after old age parents or relatives, take on housework and etc. Consequently, children are born with economical expectations, so that the net flow is from children to parents. On the contrary, modern societies experience relatively low fertility levels. As opposed to traditional societies, parents plan to spend on the children rather than getting an economic benefit, which means the net flow is from parent to children. Consequently, Caldwell explains the reason of the demographic transition from high fertility to low fertility with the change in the magnitude and direction of the intergenerational lifetime wealth flows. In modern societies, which have mainly got through the demographic transition process, we interpret that the direction of the wealth flow is from parent to children. Shrinking agricultural production revealed new job opportunities and changed the employment conditions diminishing the need for extended families. Furthermore, compulsory mass schooling forces people to invest in their children at a certain extent. Also, the cultural tendency towards high fertility has disappeared as a consequence of the widespread city life. These three fundamental changes in the communities invited the reversal of the wealth flow and namely the demographic transition.

Another seminal study that assumes fertility to be an economic decision is Easterlin's **"relative cohort size theory"** (1966). According to the relative cohort size theory, as the proportion of younger generation gets higher compared to their parents, they face a distress in the wages and have the desire to control fertility. Consequently, the next generation is a relatively small cohort in working age and they have the opportunity to get better employment with higher wages. This new generation has a tendency for higher fertility rates. The relative cohort size theory is valid for the beginning of the fertility decline or it can be explanatory for the fluctuating fertility rates in pre-transition periods, however, it does not explain the continued fertility decline in the modern economies. Later in 1978, Easterlin introduced a new concept in his relative cohort size theory: **“intergeneration taste effect”**. This new idea tells that the richer generation’s children seek better living conditions in their lifetime. For example, a luxury product in one generation becomes a necessity in the next one. So the new generation expects to earn more to fulfill its habits and tastes inherited from its parents. Easterlin call this phenomena as **“intergeneration taste effect”**. He adds a third constraint of **“subsistence level”** in addition to the production and budget constraints. Easterlin’s subsistence level constraint asserts that the offspring chooses to restrict fertility and prefer to transfer its resources towards their inherited habits and tastes even if they have relatively high wages. Hence, if the subsistence level of newly upcoming generation increases relatively higher than the wages, the fertility continues to decline rather than fluctuating between the generations.

Caldwell’s “wealth flow theory” and Easterlin’s “relative cohort size theory” are both invaluable contributions in the economic theory of fertility literature and they provide great insights regarding the roots of the modern economic growth. Though, the literature involves more comprehensive and theoretically verifiable studies. After introducing two ground-breaking economic viewpoints in the demographic transition literature, we continue with these more comprehensive and theoretically verifiable theories in the field. As it is mentioned earlier, some economists try to explain the transition with the income-fertility interaction and some associates the low fertility rates with the decline in mortality, whereas some others base their theory on the human capital formation taking the technological development in the core of their models. The related literature has evolved from the income per capita theory through the add-on of the mortality theory or/and the human capital theory. The theories of demographic transition will be given with an order in parallel to the evolution of the literature. On the other hand, there exists a huge literature explaining the fertility decline with the theory of **“women empowerment”**. This perspective relies basically on the Notestein’s early definitions that associate the fertility decline with the women’s higher labor force participation rate. The fertility transition via women empowerment is also referred as the theory of “**decline in gender gap**”. According to the theory of “decline in gender gap”; as the roles of the men and women in the work force converges and the wage gap diminishes between the two sexes, the opportunity cost of staying at home and looking after a child is getting more expensive for the women. As a result, the fertility rates go down due to the women’s preference of fewer number of children. However, this study excludes the theory of decline in gender gap. Instead, we assume that fertility decision is a family decision of couples or individuals regardless of sex.

2.1. INCOME PER CAPITA THEORY

Nobel Prize winner Gary Becker is the one who mainly forms the economic framework of fertility decision. In his seminal paper “An Economic Analysis of Fertility” (1960), he introduces the concept of “**quality of child**” and mentions the “**quantity-quality trade off**” for the first time. Becker treats the children as the consumer durables that gets expenditure outlaying taste and utility. The parents do allocate their budget either on their own consumption or on their children. Becker uses the cost spent on a child as a measure of that child’s quality. Becker’s “**quality of child**” definition implies that the higher expenditure a child gets the more qualified he is. The family-size decision maker, say the parents, decide on the quantity and the associated quality level of children so as to maximize the utility gathered from child bearing and own consumption due to a budget constraint allocated to own consumption and the expenditure on the children. In this setting, Becker assumes that the income per capita rise has a positive effect on both the quantity and the quality of the children. However, the quality of child has an offsetting effect on the quantity of children hindering the huge growth rates of fertility. In particular, Becker proposes that the income elasticity of the quality is higher than the income elasticity of the quantity. So, the parents have a trade-off between the quantity and the quality of their children, when they experience a rise in their income levels. This trade-off is also called as “**the substitution effect**” in a way that parents can substitute the quantity with the quality. Becker’s quantity-quality trade off theory is well accepted by the upcoming studies except one single point. Becker has missed the fact that the income elasticity of quantity of children does not have to be necessarily positive. The reality showed just the opposite, such that the declining fertility rates are observed despite the increase in the income per capita levels.

In 1974, Becker and Lewis further discusses the theory of “quantity-quality trade-off” theoretically. They analyze the interaction between the quantity and quality of children in terms of their shadow prices. The cost of an additional child, holding their quality constant refers to the shadow price of children with respect to their number and it gets higher the higher the quality is. In a similar way, shadow price of children with respect to their quality is defined as the cost of a unit increase in quality, holding their number constant and it gets higher the greater the number of children is. They summarize the key issue in the article as:

> “An increase in quality is more expensive if there are more children because the increase has to apply more units; similarly, an increase in quantity is more expensive if the children are of higher quality, because higher-quality children cost more.” (Becker & Lewis, 1974).

In addition to the “quantity-quality trade off” concepts and the rise in per capita income theory, Becker (1974) and Barro (1974) introduce another key concept: “**altruism**” and afterwards publish a joint paper (Becker and Barro, 1988) reformulating the economic theory of fertility from this new perspective. Dictionary definition of altruism is given as: “willingness to do things that bring advantage to others, even if it results in disadvantage for yourself” (Cambridge Dictionaries Online). Becker & Barro (1988) assumes that parents are altruistic towards their children. The altruistic assumption of parents takes the intergenerational transfers into consideration and links the fertility decisions of different generations in the same family. In this study, the individual utility function is replaced with the “**dynastic utility function**”, which is the combination of utilities of all members in a family line. In other words, the head of a family line makes the family-size decision according to the utilities of all his descendants. The combined utility is formed via the “**intergenerational degree of altruism**” coefficient which converts the utility of the children into that of parents. The more altruistic the parents are the more weight they give to their children’s utility. Another novelty of the study is its classification of the child raising cost. Becker & Barro (1988) states that there are two kinds of cost for child raising. One is fixed cost which does neither bring return on investment nor generate a consumption opportunity for children in the next generation. Other one is the bequest left to the child in terms of human capital. Rather than asset bequest, human capital here refers to the skills or quality gained by means of the education invested in children. Besides the model’s theoretical suggestions, the authors also present some preliminary model findings under the assumption of open economy. According to the analytical results, fertility is a positive function of the real interest rate, degree of altruism and growth of child-survival probabilities, whereas it is a negative function of the technological progress rate and the growth rate of social security.

In 1989, Barro & Becker proposes the first neoclassical growth model with the embedded fertility model based on altruism. The paper presents a growth model with endogenous fertility and the model is based on the framework introduced in Becker & Barro (1988); ie. assumptions of dynastic utility function, dynastic budget constraint, altruistic parents, bequest to child in terms of human capital. Endogenous fertility means that the fertility rates are estimated within the model itself. The model also takes the interest rate and wage rates as endogenous under the assumption of closed economy. Besides the fertility model, production system and exogenous technological progress rate are also introduced. According to the findings of the study the population growth is positively related to the degree of altruism towards children and the steady-state long-term interest rate, while it is negatively related with the intergeneration rate of growth in per capita consumption. Moreover, the authors mention that the technological progress may affect the fertility levels and namely the population growth either positively or negatively via increasing income levels. By this means, the Beckerian perspective for the first time accepts the fact that income elasticity of quantity of child may both be positive or negative.

Becker's studies, on the other hand, have been subject to much criticism due to the assumption of treating human beings as consumer goods; that critics, however, do not prevent a huge literature to be built up on the "**economic theory of fertility**" framework. The models that are presented in the succeeding parts have the common assumption of treating children as consumer goods; even though they differ in terms of the add-on features.

2.2. MORTALITY THEORY

Beckerian perspective lays the foundations of the "economic theory of fertility". Although the rise in income per capita theory is criticized and refuted empirically, further studies in the field do not move away from the concept of "cost of children". The economic theory of fertility literature together with the economic growth literature accepts that the children are consumer durables in such a way that they pose either monetary or time cost to parents and parents get utility out of the investment made on the children. The principle quest of researchers in this conjuncture is to use appropriate add-ons in the right setting to present economic growth models with a higher explanatory power. Some group of them suggests that the decline in mortality levels is the key feature to be combined with the concept of cost of child. As we go through those studies in the literature, we see that there is a huge amount that overlaps with the human capital investment notion. Mortality and human capital overlapping studies are discussed in this chapter, whereas the human capital investment models without mortality (with one exception, Jones (2001)) are mentioned in the succeeding section. Besides the model implications, the theoretical background of the human capital formation and its relationship with the economy and the demographic transition is given in detail in the next section.

We start with the studies that are in favor of mortality decline theory to explain the demographic transition. One study in the literature conducts counterfactual experiments in order to investigate the relative effect of the wage rates and the decline in infant and child mortality on the demographic transition process (Eckstein et al, 1999). Eckstein et al uses the Swedish data during the demographic transition period and comes up with the conclusion that the most influential factor in the fertility decline is the decrease in infant and child mortality rates. He also observes a delay in the response of fertility to the decline in infant and child mortality in parallel with the real characteristics of the demographic transition in many countries.

On the other hand, Boldrin & Jones (2002) uses the notion of intergenerational transfer with a slight difference than that of Becker & Barro (1988) and Barro & Becker (1989). In particular, the authors assume that the intergenerational transfer is from children to parents only. The size of the transfer and the fertility choice of parents are taken as endogenous, while the infant mortality levels are the key exogenous variables. The model is calibrated and tested quantitatively. The results show that the proposed model setting is successful for the explanation of Malthusian era, revealing high fertility rates with low survival rates and vice versa. Assuming that the intergenerational transfer is from children to parents, it is not surprising to get a success in Malthusian era.

Kalemli-Özcan is another author, who studies the effect of mortality decline in the field of economic growth literature. She comes up with a stochastic model of mortality, fertility and human capital investment in 2003. This study examines the relationship between fertility and the human capital investment under the effects of declining mortality. She introduces the term "**precautionary demand**" in fertility literature. She proposes that there will be a precautionary demand for children if the marginal utility of a surviving child is convex. In particular, when the survival rates of the children are not known with certainty, the parents add a safety margin on their ideal family-size against the uncertainty of the survival. So, parents tend to diminish the precautionary demand for children as a result of the declining mortality rates. Other effect of the mortality decline is on the educational investment in children. Lower mortality rates encourage parents to put more emphasis on the quality of their children. However, Kalemli-Özcan (2003) states that this empirically observed quality-quantity trade-off is possible if and only if the uncertainty of child survival exists in the family-size optimization problem.

In 2002, Kalemli-Özcan questions whether the mortality decline promote the economic growth and she publishes a model calibration of which theoretical background is actually given in Kalemli-Özcan (2003). The model suggested in this study can be characterized with endogenous infant and child mortality, fertility and education variables. The idea of Kalemli-Özcan on the positive effect of the mortality decline on the education investment is criticized by Galor (2005). Galor argues that it is impossible to evoke the human capital investment with the mortality decline by forcing parents to spend on non-living children. As a response, Kalemli-Özcan (2008) extends the theoretical model presented in Kalemli-Özcan (2003) by separating the family-size decision and the education decision of the parents. In the study of year 2003, the parents are deciding on the family-size and education of children simultaneously. In the study of 2008, she let the parents to decide on the education investment after they know the number of survived children with certainty. However, the change in the problem setting does not change the results. In summary, according to the theoretical and the empirical studies of Kalemli-Özcan; the mortality decline lowers the levels of precautionary demand, i.e. fertility rates, and increases the human capital investment. As a consequence of higher quality investment, higher growth is observed in the production system. Meanwhile, declining fertility levels mean either a slow or no population growth, which consequently enhances the impact of the growth of production on per capita income. As a result, together with the fertility decline, the increase in the quality investment results eventually in economic growth.

Lagerlöf (2003), on the other hand, handles mortality in a different way and examines whether it is possible to explain the three regimes from Malthusian era through post-Malthusian regime and modern growth by random mortality shocks. In this study, the growth model presented in Galor and Weil (2000) (mentioned in the next section and discussed in more detail in the succeeding parts) is tested including the mortality shocks caused by epidemics. According to Lagerlöf (2003), epidemics are positively related with the population density. That is, it is easier to spread an epidemic in crowd. Also, epidemics are negatively related with the human capital level, because higher levels of human capital means higher skills and better medical care. The novelty of the study is that it shows the demographic transition is inevitable; but the differential timing and the random development path of the process is under the impact of mortality shocks.

Weisdorf (2004) again tries to construct a model explaining all three regimes based on the model of Galor & Weil (2000) by adding endogenous child mortality rate that is an inverse function of the parent's standard of living. Other differentiation from Galor & Weil (2000) is that it does not estimate technology over population level but over population growth rate as it is in Jones (1995). Additionally, Weisdorf assumes that fertility and human capital act independent of mortality on the contrary to Kalemli-Özcan (2002) and Lagerlöf (2003). In the study of Weisdorf, transition from stagnation to growth is assumed to be triggered by an exogenous shock to technology and the model reveals a mortality revolution before the demographic transition begins.

Another scientist of the field, Tamura, presents a paper (Tamura, 2006) complementary to the works developed by Doepke (2004), Galor and Weil (2000), Galor and Moav (2002), Hansen and Prescott (2002), Jones (2001), Kalemli-Özcan (2002, 2003), Lagerlöf (2003), Weisdorf (2004) and Tamura (2002). Note that some of the articles mentioned are explained in the next part. Tamura (2006) presents an equilibrium model of fertility and the human capital investment with endogenous young adult mortality rates. The young adult mortality rate is assumed to be a negative function of the human capital accumulation. As the human capital accumulates, a mortality decline occurs and this decline enhances the human capital investment. In return, the rising human capital accumulation again decreases the mortality rates and provokes the economy to go through the industrial revolution and transition afterwards. The model is calibrated with the historical data of various rich and poor countries and the proposal of human capital and mortality relationship is demonstrated empirically. On the contrary to expectation, the results state that not only the young adult mortality rates are influential on the decision of the human capital investment but also the infant mortality rates have a negative effect on the decision of the human capital investment.

On one hand mortality decline is claimed to have an explanatory power for the demographic transition process, on the other hand there are other studies which address the mortality-fertility interaction and cannot find any influential evidence. The rest of this section is devoted to the studies of this kind.

Fernandez & Villaverde (2001) constructs a model with endogenous fertility, mortality and education. He calibrates his model with the data of England. The model includes the production sector with firms of two kinds; one for the consumption goods and one for the investment goods. The dichotomy in the production sector emphasizes "**capital-skill complementarity**". As it is mentioned in the preceding sections, the skilled labor gained importance against the physical capital with the industrial revolution and further technological developments. From this perspective, Fernandez & Villaverde claim that the fall in the relative price of the capital changed the balance of the quantity-quality tradeoff for children in the framework of "capital-skill complementarity". That is, it is more efficient to substitute unskilled labor with relatively cheap physical capital and complement it with skilled labor, which yields an increasing demand for the skilled people. So, this study proposes that the decline in fertility is explained by the decrease in the relative price of capital and increase in income per capita. After all, they conclude that the mortality decline has no effect on the fertility decline.

Another study from Mateos-Planas (2002) examines the effects of three factors; mortality, technological change and cost of child, in the framework of Barro & Becker (1989). He conducts a quantitative analysis with the European data and also adds uncertainty over survival. He concludes the study stating that the most influential factors on the demographic transition are the cost of child and the technological change concepts, while mortality has a very limited effect.

Likewise, Doepke (2005) examines the effect of the decline in child mortality in the framework of Barro & Becker (1989). First extension to the base model is done by adding stochastic mortality rates. In the second extension, he takes the same model in the first extension but with the assumption of sequential fertility choice. In the second problem setting, parents are able to decide on fertility conditional on the survival of older children. He examines the effect of the mortality decline in both problem settings and concluded that the mortality decline has a negative effect on the fertility rates; nevertheless it is not as much as it is observed in reality. Then, he examines the same effect in a third problem setting, where he adds "quantity-quality trade off" to the first extended case. In the third model, the altruistic parents are able to invest in the education of their children under the assumption of stochastic survival probabilities. After three examinations, he concludes that the rising wages increase the role of the human capital investment more in education by depressing fertility rates. As opposed to the expectations, the mortality decline does not strengthen the fertility decline, rather it slows down the decline in fertility in the quantity-quality setting of the altruistic parents with uncertain survival rates.

To summarize, the demographic transition and the economic growth literature mainly tries to explain the mechanisms behind the past transition periods and the current growth process. There are not only divergence of explanation but the authors also expose contradiction about the explanatory factors. For instance, some explains the transition process via mortality, some other shows evidence that there is no interaction between the mortality and the fertility rates. Meanwhile, the rise in income per capita theory has already been refuted by the empirical data. The only concepts that are well accepted by all the authorities are the "**quantity-quality tradeoff**" and "**capital-skill complementarity**" which are generalized in the "**theory of human capital**". Next section is devoted to the theory of human capital and its implication in the economic growth and/or the demographic transition field.

2.3. HUMAN CAPITAL THEORY

After the industrial revolution, the production function that is composed of physical capital and labor is enriched by the human capital ingredient. It is either added as a third source or it is embedded into the formula as the production technology which shows the degree of resource utilization. This section discusses the human capital theory in detail. In the first part, we explain what human capital is, how the concept is evolved through the literature and how it can be measured or quantified. In the second part, we mention the role of human capital formation in the literature of the economic growth and demographic transition via special implications in the literature.

2.3.1. Human Capital Formation

> "The skills, knowledge and experience possessed by an individual or population, viewed in terms of their value or cost to an organization or country." (Oxford Dictionaries)

> "The abilities and skills of any individual, especially those acquired through investment in education and training that enhance potential income earning." (Collins Dictionary)

> “Employees, and all of the knowledge, skills, experience, etc. that they have, which makes them valuable to a company or economy” (Cambridge Dictionary)

Apart from the economic terminology, the “human capital” term entered even into the conventional dictionaries. It is actually a relatively new term without any history before industrialization. It was not until 1960 that the first formal definition of human capital was made by Schultz (1960).

In ancient times, what the children of hunter / gatherers need was to survive biologically and the way of survival was to know what their parents know already. This situation did not change until the industrial revolution. Before the industrial revolution, the technological progress level was so low that the production system did not evolved much even in the agricultural societies. The know-how was again a hereditary knowledge passing from parent to offspring. On the other hand, the emergence of land lords in the agricultural societies characterized the era with the physical property rights which were the only source of wealth. Meanwhile, the production function those times was composed of land and labor with diminishing marginal returns observed due to the fixed land factor. After the industrial revolution, the technological progress accelerated and the resource utilization went up without any change in the resources. Despite the fixed land factor, people made use of higher returns due to higher utilization. Another crucial result of the evolution of the production system from agriculture to industry is the fact that the feudal system of land lords has collapsed and wealth has started to change hands. The change in wealth ownership showed that people can get returns and earnings independent of their physical property rights. This fact revealed the existence of an intangible form of capital besides the physical capital.

In this contemporary world, the brute force labor is substituted with machines. Thus, the labor factor in the modern production function is renovated and it is mainly referred to as the skills and experiences of workers. In this conjuncture, the hereditary transfer of knowledge has become obsolete and people need to possess a lifetime knowledge accumulation to be able to compete in the market and get wealth. This lifetime knowledge accumulation notion created the term of “**human capital**”.

Human capital is defined as an innate property of an individual. It is formed by the accumulation of lifetime attainments. It not only involves the formal education but also further training and experience gathered throughout the life. Additionally, the parental education and health care services that a person receives are also assumed to be accumulated in the human capital property of an individual. As a result of the accumulation, people receive economic and/or social earnings. OECD report (2001) on human and social capital defines the human capital as “The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being." This thesis mainly adopts this definition of human capital throughout the document.

According to the OECD report (2001), the learning and acquisition of skills and knowledge take place from birth to death. It starts within the family, enhances with formal education and training, and continues with on-job training and daily social life through learning via social networks. Schultz (1961) summarizes the factors contributing to human capital in five categories: health services, on-job training, formal education, study programs by adults and finally migration towards job opportunities. Schultz states that these five factors are the sources of human investment that yield return over a long period. Similar to the OECD report (2001), Schultz assumes that the human capital is the main determinant of income. This assumption can also be interpreted in a way that the differential human capital levels among the individuals are the source of income inequalities.

Besides the lifetime accumulation, another key feature of the human capital is its dynamic nature. That is, it accumulates and also depreciates against developing technology. The dynamic nature and lifetime characteristic of human capital is emphasized in the studies of Mincer (1958, 1962) and Becker (1962). Mincer (1958) studies relationship between income and human capital investment. He takes the education (i.e. formal schooling) as an indicator of human capital investment. He also includes on-job training as an investment factor. In this study, Mincer states that the time spent on schooling diminishes the time left for earning, in other words, people enter the labor force later. However, people with higher investment levels earn higher wages once they enter into the labor force. The accumulation of human capital also continues in labor force by on-job training and the workers also get experienced with years, again having a positive effect on incomes. However, after a certain age, deterioration of knowledge begins and life-time earnings of workers accordingly reveal an inverted U-shape distribution. In particular, their income increases with age until a threshold value where knowledge depreciation becomes dominant over the acquisitions and income levels starts to go down afterwards. In 1962, Mincer focuses his study particularly on on-job training. In this study cost of investment and rate of return are compared between the two sources of investment tools: schooling and on-job training. Mincer again implements the life-cycle approach and assumes the bell-shaped income distribution across the age. This study also recommends that the lifelong earning should include the preschool (i.e. learning at home) period together with the post-school, which is on-job training. In parallel with the age-income pattern argument in Mincer, Becker (1962) mentions age-income relationship stating that earnings are low during the education investment at younger ages and high at older ages. The novelty of this study lies in taking the subject from firm's perspective and questions whether firms should think of funding the human capital investment in employees. As a result, he claims that the return of human capital investment financed by firms do belong to firms itself, not to individuals. Thus, a firm’s investment in its employees is not a waste of source, on the contrary the return is totally received by the firm itself. In 1967, Ben-Porath uses the same age-income pattern and defines an appropriate human capital production function. Afterward, he tries to show how the properties of the human capital production function determine the optimal investment and the life cycle earnings theoretically.

As it is stated here, most preliminary studies on human capital define the human capital formation via schooling and training. Health services and early at home education are also mentioned as well as the social life learning. However, due to the fact that it is more convenient to quantify education investment, it dominates the other human capital accumulation factors. For instance, Barro (2001) examines the effect of human capital on GDP growth and basically quantifies the human capital level by years of schooling. Barro also investigates the effect of the quality of education investment. He quantifies the quality by comparable examinations in science, mathematics and reading. The study is concluded with the positive relationship between the human capital and the GDP growth and it is stated that the quality of education effects GDP growth more than the quantity of education.

To summarize, human capital is a lifelong accumulation of skills and knowledge which is embodied in individuals and provides the individual with future earnings. The human capital notion has gained importance especially after the technological progress has accelerated after the industrial revolution. The capital-skill complementarity gave way to wealth formation via skills rather than sole physical properties. In measuring the human capital investment, different attributes can be taken into account; such as education, at-home learning and the health services received. Nevertheless the most common and convenient way to measure human capital is made by means of the investment in the formal schooling. Last but not least, the term of human capital and the return on human capital investment concepts are used to explain many speculative issues like income inequality and economic growth. Succeeding section discusses the studies which explain demographic transition and economic growth via human capital formation.

2.3.2. Human Capital and Economic Growth

Besides the aforementioned theories of rise in income per capita and decline in mortality, a group of economists explains the fertility decline and economic growth with the theory of human capital formation. Some of these studies are mentioned in the mortality theory section, since they examine the mortality effects with a human capital formation model. Those studies mentioned earlier are not restated in this section. This section is reserved for the studies that takes the human capital formation as the sole source of the transition and the economic growth.

The theory is based on the idea that the technological development increases the resource utilization. Even if the amount of physical capital do not change, people earn higher wages by the means of higher resource utilization. From the other perspective, more is produced with less or same resource levels, which eventually triggers the economic growth. However, higher technology levels require higher skills. Hence, the altruistic parents who care about the welfare of their offspring in the future get to think of enhancing the human capital investment in their children. This movement empowers the quality-quantity tradeoff in such a way that the preferences of parents change towards the fewer number of higher quality children. As a result, a fertility transition from high to low is observed together with the economic growth. The best examples for growing economies as a result of the technology and the human capital investments are the countries so-called Asian tigers: Japan, Taiwan, South Korea and Singapore. They grew relying on the well-educated labor force that made excellent use of the modern technologies.

The studies in the literature that handles the human capital formation as the main reason of the transition has significantly increased in number mostly after 1990s. Although this theory is relatively recent, its foundations go back to 1960s' Beckerian economic perspective of fertility with "cost of child" and "quantity-quality tradeoff" concepts.

Becker et al. (1990) differentiates the Malthusian economies and the modern growth economies. According to Becker (1990), production in Malthusian economy is based on physical capital, whereas it requires skilled and qualified labor in modern economies. This study proposes a model with endogenous fertility and assumes that the rate of return on human capital rises as the human capital stock accumulates. As a result, the model dictates that after a threshold value of human capital accumulation countries may switch from Malthusian trap to the modern growth. Notably, there are two steady states in the model. One is the high fertility, large family case with low stock of human capital and low returns. The other one is the low fertility, small family case, where there is higher human capital stock that yields higher returns on human capital investment and increases the substitution effect of quality instead of quantity. This model also explains the difference between the poor countries with large families and the rich ones with small families. A similar study about the heterogeneity of human capital levels among countries belong to Tamura (1996). Human capital heterogeneity refers to different human capital stocks across countries. According to Tamura (1996), this difference enhances the human capital growth of poorer countries. In parallel with the previous study mentioned, Tamura differentiates two economies of the modern growth and Malthusian economy with a threshold value of the human capital stock in-between, called the critical human capital level. This level is the point where parents are indifferent between the growth and decay. Below the critical human capital level, there are no means to invest in the children; while above this critical level the altruistic parents prefer to invest in their children for the sake of higher levels of human capital. Higher levels of human capital stock in the rich countries increase the overall human capital stock of the world. Tamura assumes that this external effect of the overall human capital level diminishes the critical level for poorer countries, leading the rate of return on human capital investment to rise up. As a result of the external effect of general human capital level, poorer countries are assumed to grow faster.

In the new millennia, Galor and Weil (2000) (G&W) present the break-through study of "**Unified Growth Theory**" (UGT) in their seminal paper "Population, Technology and Growth: From Malthusian Stagnation to the Demographic Transition and beyond". This article presents an endogenous model of technology, fertility and human capital. The model is named as "unified", because it is shown to be valid for the entire evolution process of the humanity starting from Malthusian economy through the industrial revolution, demographic transition and the period of sustained economic growth. Before Galor and Weil's ground-breaking model, no one claimed the existence of a comprehensive endogenous growth model that can explain the whole transition process in a continuum. In UGT, individuals decide on the quantity and quality of children in order to maximize their utility over own consumption and child rearing subject to a budget constraint. Their budget constraint is restricted by the wage levels at the upper bound and by a "**subsistence level of consumption**" at the lower bound. "Subsistence level of consumption" refers to the minimum amount of consumption level by which an individual barely survives. Below that threshold value, individuals cannot think of allocating any resource to child rearing. Once they afford the subsistence level of consumption, they decide on the allocation of the rest of their budget. The resources reserved for child rearing is separated by two components. The first part stands for the fixed cost of child rearing, which depends on the fixed time allocated to a child regardless of the quality of that child. The second part is the variable cost depending on the level of education attributed to children. Education of a child defines the human capital level of that individual when he gets in the adulthood. Endogenous technology is also embedded into the model in such a way that the technological progress rate influences the quality decision of individuals, while the technological progress rate is a function of the education level and the population size. Galor and Weil (2000), proves the model theoretically by steady state equilibrium conditions and demonstrates them via phase diagrams in a pairwise fashion.

After Galor and Weil's UGT, there have been further studies suggesting models representative for the period from Malthusian stagnation to the economic growth (e.g. Jones, 2001; Hansen & Prescott, 2002), so far, they are not as comprehensive as the "Unified Growth Theory". Jones (2001) introduces the term of the idea generation and accumulation instead of technology and human capital. On the other hand, he assumes endogenous mortality as a function of the average level of consumption per capita relative to the subsistence consumption. Taking endogenous mortality, Jones presents an invaluable study but his definition of idea accumulation causes some ambiguity in terms of technology and human capital differentiation. In a similar way, Hansen and Prescott (2002) proposed a model of transition from land intensive economy to Solow economy where production is defined over two sources only: capital and labor. They do not mention either endogenous fertility or endogenous technology. The novelty of these two studies is that they present quantitative analysis with data calibration and results are shown to fit to the real data.

Tamura (2002), on the other hand, focusses on the production sector and uses endogenous technology to explain the switch of economy from agriculture to industry. This study suggests that the production sector goes through a transition as a result of the human capital accumulation, which has implications over fertility decisions. Two production sectors are modeled separately with two steady states. Proposed model cannot be solved analytically, but Tamura presents simulation results for per capita income and production style replicas of the history.

Galor & Moav (2002) extends G&W by assuming that each individual is not identical; but they differ in terms of their preference of quantity and quality of children. They also assume that this preference among quantity-quality is hereditary. For instance, if an individual has a tendency towards higher quality, his child will also have a tendency towards higher quality. By this means, Galor and Moav divides population into distinct parts according to the different choices between quantity-quality. Their aim is to examine the relationship between the population composition and the rate of technological progress as well as the timing of transition. They resemble the change in the population composition in the Darwinian Theory of evolution and natural selection. In particular, the model states that the population structure is reshaped due to the survival of specific types of individuals under changing technological and economic conditions and this will end up with a rise in the proportion of the most advantageous individual type.

Doepke (2004) states that although the overall pattern of the demographic transition is same, the timing of the transition shows cross-country differences. Doepke uses a unified growth model to determine the effects of governmental policies on the cross-country variation in fertility decline. This study is an extension of various studies in the literature, i.e. Galor and Weil (2000), Jones (2001), Hansen and Prescott (2002) and Tamura (2002). The model contains two kinds of individuals; skilled, unskilled and two sectors of production; agricultural, industrial. The results presented show that the governmental policies are quite important to understand the cross-country variations during transition, especially the educational and child labor policies have large effects on the fertility transition. This is an appealing study, which uses UGT to account for governmental policies and differential timing of demographic transition.

Besides the quantitative analysis presented by Jones (2001), Hansen and Prescott (2002), Tamura (2002) and Doepke (2004); Lagerlöf also publishes an outstanding quantitative study in 2006. Lagerlöf (2006) takes Galor and Weil's theoretical unified growth model and redefines the relationships in a parametric form without violating any assumption of the original model. Afterwards, the parameterized model is calibrated and simulated. Lagerlöf demonstrates the variables, which are presented in bilateral relationships in G&W, separately across time in terms of time paths. The simulation results reveal that the time paths of the parameterized model are perfect replicas of the reality. In addition to theorethical perspective, by this study, G&W is also verified to explain the demographic and economic transition from an empirical perspective as well.

In all aforementioned models, demographic change and economic growth are assumed to be hand in hand. It is implicitly assumed that the transition contains changes both in demography and economy at the same time. A recent study of Liao (2011) explicitly questions the importance of the demographic change on the growth process. The paper defines three channels for the linkage between the demographic change and the economic growth. First one is the fertility decline which changes the age distribution and namely, dependency ratios together with the labor-force participation rate. Second channel is defined as the mortality decline effecting saving decisions of people and boosting accumulation of physical capital, because as people have longer lives they need to save more for their retirement. The last channel that links demographic change and economic growth is the quantity-quality trade off in fertility which determines the human capital accumulation. Liao proposes a model with endogenous fertility in which the demographic change effects the economic growth through changes in the dependency ratio, physical and human capital accumulations. The model is calibrated with the data of Taiwan and it is claimed that the demographic transition accounts for the one-third of the output growth in Taiwan. This study is actually a recap of the demographic transition theories. It proves the theories of fertility decline, mortality decline and human capital formation from a different perspective by constituting a causality between the demographic transition and the economic growth.

To summarize, although the human capital theory is the last comer in the scene, it's unarguably the most dominant and prominent explanatory theory that accounts for the transition from Malthusian economy to the modern growth. Appealing property of human capital theory is that its effect on demographic transition and economic growth is accepted in consensus. There does not exist any single study that denies or refutes the explanatory power of human capital accumulation for the demographic transition and the economic growth. The unchanged companion of human capital is technological development. It is assumed that there is a reciprocal reinforcing relationship between the technological progress and the human capital accumulation. The technological development boosts the need for human capital investment and the human capital accumulation also enhances the technological development, because skilled people use technology more efficiently. Moreover, skilled people promote the creation of new technologies and they further adopt and spread new technologies in a faster way. Among the studies in the literature, Galor and Weil's unified growth theory with endogenous fertility, technology and human capital accumulation is the most promising one. It is the most comprehensive model with three key endogenous variables that account for the whole transition process in a continuum; starting from Malthusian stagnation to post-Malthusian era, through demographic transition and finally to the sustained economic growth period. Galor and Weil's ground-breaking study (2000) pioneered a new stream in economic growth literature: "Unified Growth Theory". Although it does not have a long-standing background, taking almost 1500 citations, it is a valuable contribution and has been widely accepted in the literature. The authors of the article present an analytical model, while Lagerlöf (2006) demonstrates the same model in an empirical setting. Galor and Weil's unified growth theory is explained in detail in the succeeding part.

CHAPTER 3: PRELIMINARIES

3.1. GALOR & WEIL'S MODEL OF UNIFIED GROWTH THEORY (G&W)

The demographic transition starting from Malthusian era, continuing with post-Malthusian regime and the sustained economic growth have different characteristics in terms of economy, technology and fertility levels. The literature on the fertility estimation or the economic growth modelling is mainly concentrated on the demographic transition and the sustained economic growth. They are quite successful to explain the dynamics of the modern growth; however, they are unsuccessful to explain previous periods of the demographic transition process. Non-unified theories fail to reflect the human history but they are able to replicate a cross section in the timeline. The unified growth theory, on the other hand, is the most comprehensive endogenous growth model that can replicate the behavioral structure of the associated components through the whole history regardless of the time section of interest in a continuum.

In particular, Galor & Weil's unified growth model generates a dynamical system that accounts for: Malthusian stagnation, escaping from Malthusian trap and rise in income per capita, emergence of human capital formation, start of the demographic transition, and finally the era of the sustained economic growth (Galor, 2011). As it is stated in the previous chapters, in the Malthusian stagnation period, the technological progress is at low levels, such that the rise in income per capita is always balanced by the population growth and income levels stick to an equilibrium point. On the contrary, as the technological progress speeds up, the rise in income levels is at higher rates and that it does not decline back to the equilibrium levels despite the growing population. The period of higher technological development, leads the society get out of the Malthusian stagnation and start a new era of the human capital formation, because further developments in technology force the people to compete in terms of skills rather than man power. With the skills biased technologies, parents get a new understanding of child rearing. They now have to think of the quality of the child they own, so a tradeoff between the quantity and quality of child comes to the scene. This trade off changes parents' tendency towards quality rather than quantity in high technological development case. That is, parents prefer fewer children with higher human capital levels in case of the high levels of technological advancement. Parents' propensity to have more qualified children results in a remarkable decline in fertility levels. At the same time, the technological developments enhance human being's health conditions and decline the mortality levels as well. The coincidence of the decline of these two demographic processes is named as the era of demographic transition. When we look today, fertility levels are either declining or staying constant at low levels according to the development level of the society. In the developed countries, where the demographic transition has come to an end and a post-transition period is experienced, fertility levels are stuck to a very low level, so that they make use of a sustained economic growth by the improvement in technology. However, in sustained economic growth period, it is even a harder challenge to catch up with the high level of technology, hence the human capital formation gains a higher prominence for new generations. At this point, we can conclude that the main triggering effect on the economic growth process is characterized by the role of the technological development both on income per capita and human being's preferences over child quantity and quality. G&W's unified growth model is the one that proposes an overarching framework that accounts for the whole story starting from the Malthusian era to the sustained economic growth.

The proposed framework by G&W covers the interaction of the income level per capita, the technological development and the human capital formation process. The unified growth model links quantity-quality tradeoff decision to the technological progress. According to the unified growth model, parents response to the technological development by preferring highly qualified but fewer numbers of children. The technology-quality relationship in the model is assumed to be reciprocal such that the parents' decision of providing higher levels of education to their descendants enhances the technological progress as well. Generations with higher levels of education adopt advance technologies more rapidly. On the other hand, technological progress is assumed to have a positive relationship with the population size. Even the education level is zero, technology would continue to develop as a natural result of the growing population, because it is assumed that there is more room to spread a new technology in larger populations. Another factor under the influence of technology is the production function. The unified growth model represents a traditional production model characterized by fixed factor of land and changing labor force utilized by endogenous technology level. Meanwhile, the individuals' budget constraint is bounded below by a subsistence level of consumption, under which people cannot survive. As long as the technological progress allows income levels to be over subsistence level of consumption, population grows. In the absence of the technological development, the income levels per worker would decline back to the subsistence level with the growing adult population. Sustained technological growth, on the other hand, guarantees output per worker, namely, income levels to rise continuously. After discussing the model dynamics from a broad perspective, we continue with explaining the model structure in detail.

The model assumes an overlapping generations economy (OLG). In an OLG economy, the system is composed of agents from different generations who are in interaction at some period in their lives. Agents have a finite life but they live long enough to interact at some period. The most basic OLG system is composed of two generations: young and adult. The decision of adult generation affects the young generation. The OLG concept is introduced by Allais (1947) and developed by Samuelson (1958) and Diamond (1965) afterwards. G&W also assumes a two generation OLG model. Each agent in the same generation is assumed to be identical but independent. In G&W model, each agent is referred as an individual and each individual in young generation has a single parent. Individuals have a life of two periods. In the first period an individual is passive and lives subject to the decisions of his parents, whereas in the second period he becomes an adult, and hence, is an active decision maker. More specifically, he decides on how many children to have and how much resource to allocate for their children's education, namely the human capital formation. An individual makes his decision so as to maximize his utility subject to a budget constraint. Utility of an individual is a function of his consumption and the utility gathered from raising children. Utility gathered over child rearing is a positive function of the human capital level of the children and it is assumed to be the same for all children an individual can have. That is, parents do not differentiate their children in terms of devoted education levels.

The resource allocation proportion among child rearing and individual consumption is estimated over time allocation of the individual. Such that, individuals are assumed to have a fixed unit of time endowment, which is either allocated to raising children or consumption. The model assumes that raising a child requires a fixed cost regardless of the quality of the child. So, it takes a fixed time unit to raise a child, apart from the additional time required in child's education to achieve the target quality level of the child. Besides child expenditure, the agent allocates the resources to own consumption. The resource allocation is assumed to be the proportion of time endowment and the sum up of all is one unit. That is, if the individual does not allocate any resource to his child, he can consume the whole income for his own consumption.

The utility maximization problem mentioned above is modelled as follows:

$$\text{maximize}\, u_t = (1-\gamma)\ln c_t + \gamma \ln(n_t h_{t+1}) \quad (3.1)$$

$$subject\ to$$

$$c_t = z_t[1-(\tau + e_{t+1})n_t] \quad (3.2)$$

$$c_t \geq \tilde{c} \quad (3.3)$$

$$n_t\,, e_{t+1} \geq 0 \quad (3.4)$$

$where$

$u_t = utility\ of\ an\ individual\ in\ time\ t$

$c_t = consumption\ level\ of\ individual\ in\ time\ t$

$\tilde{c} = subsistence\ level\ of\ consumption$

$e_{t+1} = education\ level\ \ invested\ in\ child\ in\ time\ t$

$n_t = number\ of\ children\ born\ in\ time\ t\ and\ survived\ to\ time\ t+1$

$h_{t+1} = human\ capital\ level\ invested\ in\ child\ in\ time\ t$

$z_t = income\ level\ of\ an\ individual\ in\ time\ t$

$\gamma = weight\ on\ fertility\ in\ utility\ function$

$\tau = fixed\ time\ cost\ of\ children$

Equation 3.1 is the objective function of the optimization problem, where equation 3.2 stands for the budget constraint. Equation 3.3 refers to the constraint of the subsistence level of consumption, which restricts the consumption to be at least at the subsistence level. It states that an individual cannot think of having babies, unless he can afford the subsistence level of consumption. Equation 3.4 is the non-negativity constraints of number of children and the education level attributed to children.

The resource endowment of an individual is identified by his income level, which is a function of his human capital level and effective resources per worker. The latter can simply found by dividing the total effective resource to the total adult population. The total effective resource, on the other hand, is a function of the technology level and the total land. The technology level is an endogenous variable calculated within the model, while total land is an exogenous constant. The expression of income of an individual is given as,

$$z_t = h_t^{\alpha} x_t^{1-\alpha} \tag{3.5}$$

$where\ x_t = \frac{A_t X}{L_t}$

$x_t = effective\ resources\ per\ worker$

$A_t = technology\ level\ in\ time\ t$

$X = total\ land\ which\ is\ exogenous\ and\ constant$

$L_t = total\ adult\ population\ in\ time\ t$

$a = labor\ share$

Besides effective resources per worker, the main component of the income level is the human capital of the individual, of which key determinants are the education level and the technological progress rate:

$$h_{t+1} = h(e_{t+1}, g_{t+1}) \tag{3.6}$$

where g_{t+1} denotes the technological progress rate from period t to t+1 and it is formulated as the percentage change between two consecutive periods:

$$g_{t+1} = \frac{A_{t+1} - A_t}{A_t} \tag{3.7}$$

According to the G&W model, human capital level increases with the education level but at a decreasing rate. On the other side, the technological progress rate makes the information obsolete (which is called the "**erosion effect"**) and the human capital level decreases as the technological progress rate rises, again with a declining marginal effect. Nonetheless, this erosion effect could be weakened by education. That is, the technological progress level raises the return to investment in education. This assumption is well explained with a comparison of two societies of agriculture and high-tech. In the agricultural society, it is adequate to learn what your father knows in order to carry on the agricultural activities. However, in a high-tech society, children have to get an advanced education to catch up with the current development. They need a higher level of human capital to survive in competition.

Optimization model maximizes the utility according to three constraints: the budget constraint (3.2), the subsistence consumption constraint (3.3) and the non-negativity constraints on education and number of surviving children (3.4). The utility of an individual is as a convex function of n_t and e_{t+1}.

The first order conditions with respect to n_t give the optimal decision for number of surviving children as follows:

$$n_t[\tau + e_{t+1}] = \left\{ \begin{array}{c|c} \gamma & if\ z_t \geq \tilde{z} \\ 1 - \tilde{c}/z_t & if\ z_t \in (\tilde{c}, \tilde{z}) \\ 0 & if\ z_t \leq \tilde{c} \end{array} \right\} \tag{3.8}$$

where $\tilde{z}$ denotes the income level where the subsistence level of consumption is binding. The formulation of the number of surviving children differs depending on the situation of the constraint of subsistence level of consumption; whether it is binding or not.

Optimization with respect to n_t implies that if the income level is high enough to guarantee that the consumption is above the subsistence level people spend γ amount of time for their children and dedicate the rest $(1-\gamma)$ for the labor-force participation. So, $\tilde{z} \equiv \tilde{c}/(1-\gamma)$ where the subsistence consumption is binding, $c_t = \tilde{c}$. If the income level cannot even afford the subsistence consumption, people do not have any child. If the income level is in between the subsistence level and $\tilde{z}$, the number of surviving children is derived as $1 - \tilde{c}/z_t$. In particular, people spend their income first to afford the level of subsistence consumption and allocate the rest for child rearing.

Similarly, first order conditions for education level, e_{t+1} implies that:

$$G(e_{t+1}, g_{t+1}) \begin{Bmatrix} = 0 \middle| if\ e_{t+1} > 0 \\ > 0 \middle| if\ e_{t+1} = 0 \end{Bmatrix} \tag{3.9}$$

where

$$G(e_{t+1}, g_{t+1}) \equiv (\tau + e_{t+1}) h_e(e_{t+1}, g_{t+1}) - h(e_{t+1}, g_{t+1}) \tag{3.10}$$

Note that $h_e(e_{t+1}, g_{t+1})$ refers to the first order derivative of $h(e_{t+1}, g_{t+1})$ with respect to education. The function of $G(e_{t+1}, g_{t+1})$ defines the education level invested in children as an implicit function of the technological progress. As long as e_{t+1} is above zero, assumptions about $h(e_{t+1}, g_{t+1})$ mentioned above imply that e_{t+1} is increasing ing_{t+1}. Furthermore, G&W assumes that there is a positive technological progress rate, below which people do not invest in their children's education and e_{t+1}takes the value of zero.

Thus, there exists a threshold value $\hat{g}$, such that e_{t+1} is zero where $g_{t+1} < \hat{g}$:

$$e(g_{t+1}) \begin{Bmatrix} = 0 \middle| if\ \ g_{t+1} \leq \hat{g} \\ > 0 \middle| if\ \ g_{t+1} > \hat{g} \end{Bmatrix} \tag{3.11}$$

Remember the aforementioned example of two societies. In an agriculture society, it is enough to learn what your parents know. On the contrary, in a high-tech society, you have to take special education and invest in yourself to catch up with the know-how development. Hence, after a threshold value of technological progress rate, people need education investment to survive.

The G&W model also assumes that the technological progress rate is derived by the education level and the adult population size.

$$g_{t+1} = g(e_t, L_t) \tag{3.12}$$

The education level of adults at time t has a positive effect on the technological development. In a similar way, the adult population size has a positive influence on technology in such a way that in a large population, it is easier to spread a new technology. Positive effect of population size on the technological development is named as the "**scale effect**" by the authors and it is assumed to have an upper limit. Once maximum threshold value of population size is reached, it has no effect on the technological development and $\lim_{L\to\infty} g(e;L)$ is finite. It is also assumed that even there is no investment in education, technological progress rate takes positive values under positive population size, that is, $g(0,L_t) > 0$.

After presenting the difference equations and formulating the assumptions of the model in mathematical forms, the model is degraded to the dynamics of three elements: technology, education and population. This unified growth model actually represents an endogenous growth theory, which estimates the population size within a dynamical system consisting of interacting components: education and technology. The formulation summarizing this full dynamical system is given below:

$$A_{t+1} = [1 + g(e_t, L_t)]A_t \tag{3.13}$$

$$g_{t+1} = g(e_t, L_t) \tag{3.14}$$

$$e_{t+1} = \varphi(e_t, L_t) \tag{3.15}$$

$$L_{t+1} = n(A_t, g_t, e_t, L_t)L_t \tag{3.16}$$

To sum up, technology level is equal to the technology level of previous year enhanced by the technological progress rate which is a function of education level and adult population size. Education level invested in children is determined by the technological progress rate, thus, by the education level and the adult population size accordingly. Population size of the next period is given by the multiplication of the number of surviving children per person and the previous year's adult population. This implicitly assumes that the adult population of previous year totally dies out, and the new born babies constitute the adult population of the next time period. This simplification is also mentioned in the beginning of the section that people lives for two periods throughout their life: one is childhood and the other is adulthood.

3.2. LAGERLOF'S QUANTITATIVE IMPLEMENTATION OF THE G&W MODEL

After defining and explaining the dynamics of the model, Galor & Weil support their model's validity by investigating the equilibrium conditions at steady states and show how it replicates the historical evolution of population, technology and education output via phase diagrams. Phase diagrams used in the article show the bilateral relationships between the variables, but they do not individually show the behavioral trends across time. However, G&W does not provide any numerical evidence.

In 2006, Lagerlöf comes with a quantitative exercise of G&W model, showing how successful it is to estimate time paths in historical development of population and economic growth. This study does not claim to estimate the variables in nominal values; rather they achieve time path replicas for each variable in the model; namely, population size, education, income, technology and consumption levels and per-adult effective resources. Before the simulation, Lagerlöf transferred G&W closed form formulations into parametric form equations without violating any assumption of the original G&W model. Lagerlöf parameterization provides the user to work with numerical values and get use of simulation techniques to observe the time paths of model variables separately, which is impossible to do with original closed form equations.

Parametric forms of functions in G&W model are given below, starting from the equation of human capital level. G&W defines the human capital formation function by education level and technological progress rate. In the original model, it is assumed that technological development has an erosion effect on education that diminishes return to education and results in lower levels of human capital. This relationship is explained in parametric form as follows:

$$h_{t+1} = h(e_{t+1}, g_{t+1}) = \frac{e_{t+1} + \rho\tau}{e_{t+1} + \rho\tau + g_{t+1}} \qquad (4.1)$$

where $\rho\epsilon(0,1)$ and taken as exogenous, and denotes the portion of the fixed time allocated to children that contributes to the human capital formation function of the child. This assumption is consistent with the basic idea of the human capital formation theory. It starts from birth and it is a lifetime accumulation. So, the preschool period spent in the family is also included into the human capital formation function. It can be interpreted from the formula that the numerator is the effective education of an individual and it is subject to the erosion effect of the technological progress rate shown in the denominator.

Following the relationship between education and technology (3.10) derived by the first order derivative of the utility function (3.1) with respect to e_{t+1}, e_{t+1} is parameterized as a function of the technological progress rate as given below:

$$e(g_{t+1}) = max\{0, \sqrt{g_{t+1}\tau(1-\rho)} - \rho\tau\} \tag{4.2}$$

Equation (4.2) satisfies the assumptions stated with the equations (3.10) and (3.11). That is, education is an increasing function of the technological progress rate and there is also a technology level below which people have no need to invest in the education of their children.

Next, Lagerlöf mentions the positive effect of the education and the population size on the technological development and assumes that the technological progress rate takes the following form:

$$g_{t+1} = g(e_t, L_t) = (e_t + \rho\tau)\alpha(L_t) \tag{4.3}$$

The first component is the effective education having a positive effect on technology, while the second component of the equation is used for the scale effect of the population size. Recall that the positive effect of the population size is limited and this notion is named as the "scale effect" by the authors. Scale effect is assumed to be equal to:

$$\alpha(L_t) = min\{\theta L_t, a^*\} \tag{4.4}$$

This implies that the population size affects the technological progress linearly until it reaches a threshold value of $L_t = a^*/\theta$ where a^* and θ are the scale effect parameters.

The equation of education can be rewritten by means of plugging the technological progress rate equation (4.3) into the education formula (4.2) as:

$$e_{t+1} = max\{0, \sqrt{(e_t + \rho\tau)\alpha(L_t)\tau(1-\rho)} - \rho\tau\} \tag{4.5}$$

Recall that the income formula of G&W (3.5) has the form of $z_t = h_t^{\alpha} x_t^{1-\alpha}$. Integrating the equation of the human capital formation function (4.1) in this income formula gives the following parametric equation:

$$z_t = \left[\frac{e_{t+1} + \rho\tau}{e_{t+1} + \rho\tau + g_{t+1}}\right]^{\alpha} \left[\frac{A_t X}{L_t}\right]^{1-\alpha} \tag{4.6}$$

After transferring the closed form formulation into the parameterized difference equations, Lagerlöf calibrates and simulates the system with numerical values and explores the outputs in time path graphs rather than two-dimensional phase diagrams given in G&W's study. As a result, Lagerlöf catches a point that G&W did not mention. That is, population growth reveals an oscillatory behavior in Malthusian epoch and the oscillations die out after a sustainable technological progress rate is reached. The underlying reason of this behavior is the cyclic behavior in Malthusian era depending on the per capita income. As the population size grows, per capita income diminishes due to the low technological development and the population shrinkages in the next cycle. Once the population size decreases, per capita income increases leading to a rise up in the population size in the next cycle. This oscillatory behavior keeps up till the technological development is high enough to prevent per capita income going down with the increasing population. Furthermore, the novelty of the study is that it tests and proves the validation of the original model. By this means, the most comprehensive theoretical model of endogenous growth is tested empirically.

Consequently, the success of G&W model on replicating the history is now demonstrated once more and this creates an enthusiasm to question whether the original G&W model would yield promising future insights for policy makers. As we examine the model, we find out that simplifications of the model provide the user with general country level indicators (e.g. overall education and technology level, total population size) but does not aid the users to get any further detailed information. Even the parameterized model gives time path replicas; but it does not mention any nominal values of the variables. On the other hand, time period assumption of the model is also questionable. Working on a thousand year long period may be reasonable for retrospective studies in which the past is estimated, nevertheless policy makers need shorter periods as well as the long ones for prospective studies. In general, the policy makers would aim to make a policy, take actions and see the results to be able to take corrective actions and redo the planning process. Besides the shorter period lengths they would probably want to know more about the population structure in addition to the overall indicators. Neither G&W nor Lagerlöf mentions age and sex distribution of the population. Also, they do not consider ages beyond 40, because the model assumes that agents live for two periods of 20 years length each. Another crucial simplification of G&W is the mortality aspect. G&W assumes that the whole young generation will survive to the next time period, while the whole adult generation will die out. In the entire document, it is discussed that the economy and demography goes hand in hand. However, as we examine G&W model, we see that it does not provide the user with detailed demographic information due to the simplifications. Succeeding parts will question how to tackle with those simplifications and extend the G&W model in such a way that it provides more clearly prospective insights for the policy makers.

Beforehand, prospective demography models that aim to estimate the future will be discussed in the next part.

3.3. PROSPECTIVE DEMOGRAPHY ANALYSIS AND CURRENT METHODOLOGY

This section is devoted for the prospective demographic analysis and its methodology evolution in the literature. The core of the demographic change can be characterized by shifts in the population size and age/sex composition, which mainly stem from three main demographic processes: fertility, mortality and migration. After Willekens' comprehensive review in 1990, a detailed complementary study about the demographic forecasting methodology is published by Wilson and Rees (2005). As it is stated in the review articles, demographic forecasting has gone through an evolution towards the end of the 20th century. Extrapolative forecasting gave way to more explanatory studies and later led to causal models, which involve exogenous variables to explain the demographic processes. Extrapolative forecasting methods aim to predict the future with respect to the historical data, e.g. exponential smoothing, weighted average, etc. This method assumes that the past is the best predictor of the future world. So, it cannot catch up with the changes in trends, it is rather a convenient method for stationary data. Evolution towards the explanatory studies tries to handle the drawback of the extrapolative studies by questioning the possible reasoning behind changes in the trends. Explanatory studies seek for the answer of how and why the trend changes. They also use past data; but they use variety of associated data sources to explain a trend of a variable in the future. For example, it is possible to predict the future sales of a product by looking at the historical data of advertisement campaigns and customer's reactions to these campaigns in the past. On the other hand, causal models carry demographic forecasting one step forward and questions causality rather than correlation like in the explanatory forecasting. That is, in causal modelling a researcher investigates a hypothesis via different possible causes, which are also in interaction between themselves and also under the influence of exogenous parameters.

Likewise, Booth (2006) also reviews demographic forecasting studies between the years 1980 and 2005 and classifies them into three categories similar to the previous classifications: i.e. Extrapolation, expectation, and theory based structural modeling. In the extrapolative models, the past is carried forward by various time trend applications, whereas the expectation models rely on expert judgments. In the theory based structural modeling, the theoretical relationship between exogenous variables and explanatory factors is the key point to explain the demographic change. The researcher tries to fit the historical data on a theory and aims to present prospective results relying on this theory. This theoretical background in structural modelling provides high descriptive power but it carries the risk of little predictive power as a consequence of model misspecification (Booth, 2006).

Beyond the methodology evolved from extrapolative models to structural models, there is one basic theory that combines three demographic processes and estimates the population size preserving the age and sex structure: Cohort-component modeling (CCM). It is started to be used widely since 1980s (Booth, 2006) and preferred by the agencies like United Nations, World Bank, and TURKSTAT. Apart from the models associating the population growth rate with the explanatory factors; the cohort component model involves three demographic transition processes of births, deaths and migration (Rowland, 2003). In cohort component models, population is disaggregated into age groups and each age group is subject to the standard aging process through the years with respect to the corresponding survival probabilities. That is, the population in a particular age group is carried to the next one with an age specific survival rate. The "**cohort**" is the group of people who has born at the same year. So, newborns of each year constitute a new cohort and each group is, namely, referred as a cohort.

For the first age group, the flow starts with the birth rate. Each age cohort is also subject to migration and mortality. While migration could both refer to inflow and outflow, deaths only stand for outflows. By this method, a base population is chosen and rolled through years by being exposed to three main demographic processes. The rates in the model are taken as deterministic. However, it is also possible to try different rate combinations and conduct scenario analysis accordingly. Using further methods to estimate the rates representing these three demographic processes would also be an additional choice.

There exists widely used free software (e.g. DemProj, PADIS-INT) that conduct cohort component modelling. Those software provide the user with the forecast of the total population size on a yearly basis with the age brackets starting from 0-1 to 80^+.

These free CCM software requires the following input data:

- Starting population by age and sex
- Total fertility rate (**TFR**)
- Age specific fertility rate (**ASFR**)
- Sex ratio at birth (**SRB**)
- Life expectancy at birth by sex (**LE**)
- Model life table

The base population is given with age and sex differentiation. Then the total fertility rate (TFR) and the age-specific fertility rates (ASFR) are given to calculate the number of newborns. TFR stands for the number of births per woman in reproductive age, while ASFR defines the contribution of each reproductive age-group to total births. It is actually the distribution of the births according to the age groups in reproductive period. By the data given, the number of births is calculated with the following formula:

$$Births = \sum_{i=1}^{i=7} TFR * ASFR_i * P_{fi} \tag{5.1}$$

where P_{fi} stands for the female population size in the reproductive age group of i and i refers to the age groups between 15-49 with 5 years age brackets, e.g. 15-19, 20-24 … Note that it is also possible to use age brackets other than 5 years, however 5 year range is the most widely used one in demography. For the sake of convenience the formulations assume 5 year age brackets throughout the document.

The newborns are then differentiated by two sexes according to the sex ratio at birth (SRB). It is the ratio of the male births to hundred female births, e.g. 105 male births to 100 female births. The sex differentiation of the newborn population is done with the following formulation:

$$Births_m = \left(\frac{Births}{SRB + 100}\right) * SRB \tag{5.2}$$

$$Births_f = \left(\frac{Births}{SRB + 100}\right) * 100 \tag{5.3}$$

where $Births_m$ denotes the number of male births, whereas $Births_f$ is for the number of female births. After the inflow is calculated for the first age-group, aging procedure is repeated for each age-group for both sexes. The following formula stands for the flow equation of the first age group:

$$P_{t0} = Births_t + M_{t0} - D_{t0} \tag{5.4}$$

where

$P_{t0} = population\ size\ of\ the\ first\ age\ group\ in\ time\ t$

$Births_t = number\ of\ births\ in\ time\ t$

$M_{t0} = net\ migration\ to\ the\ first\ age\ group\ in\ time\ t$

$D_{t0} = deaths\ of\ first\ age\ group\ in\ time\ t$

Births are inflows, while deaths are outflows and the net migration can either be in or outflow. On the other hand, flow equation of the last age group is given below:

$$P_{t16} = S_{(t-1)16} + S_{(t-1)15} + M_{t16} - D_{t16} \qquad (5.5)$$

where

$P_{t16} = population\ size\ of\ last\ age\ group\ 80^{+}$ at time t

$S_{(t-1)16} = survived\ population\ of\ last\ age\ group\ from\ the\ previous\ time\ period$

$S_{(t-1)15} = survived\ population\ from\ the\ previous\ age\ group\ who\ are\ aged\ to\ the$

$last\ age\ group\ in\ time\ t$

$M_{t16} = net\ migration\ to\ the\ last\ age\ group\ in\ time\ t$

$D_{t16} = number\ of\ deaths\ of\ last\ age\ group\ in\ time\ t$

The size of the last age group's population is calculated by the summation of the survived population of the same age group and from the previous age group at the previous year and also the net amount of migrants, subtracting the number of deaths realized in that time period at the last age group of 80 and over. Meanwhile, the flow equation of intermediary age groups is displayed by the following formulation:

$$P_{ti} = S_{(t-1)(i-1)} + M_{ti} - S_{ti} - D_{ti} \qquad (5.6)$$

where

$P_{ti} = population\ size\ of\ age\ group\ i\ in\ time\ t$

$S_{(t-1)(i-1)} = survived\ population\ from\ the\ previous\ age\ group\ who\ are\ aged\ to$

$the\ last\ age\ group\ in\ time\ t$

$M_{ti} = net\ migration\ to\ the\ age\ group\ i\ in\ time\ t$

$S_{ti} = survived\ population\ of\ age\ group\ i\ who\ are\ aged\ to\ the\ next\ age\ group\ in$

$time\ t$

$D_{ti} = number\ of\ deaths\ of\ age\ group\ i\ in\ time\ t$

The intermediary age groups receive the survivors of previous age groups as well as the migrants and outflows the aging survivors to the next age group together with the deaths of the age group in that time period.

Deaths and survivals of each age group are determined by a predetermined value of life expectancy at birth and the model life table chosen. These two data sources together provide the user with the survival rates between the ages. The deaths and survivals are calculated accordingly as below:

$$D_{ti} = P_{ti} * (1 - SR_i) \tag{5.7}$$

$$S_{ti} = P_{ti} * SR_i \tag{5.8}$$

where SR_i stands for the survival rate of age group i to age group $i + 1$. An example model life table showing the survival rate is given in Appendix-1.

It is important to remark that CCM model considers demography in isolation and ignores the interaction with the economic phenomena. In other words, the demographic transition components; fertility, mortality and migration are taken as independent. Therefore, collocation of these components together with other economic indicators in a dynamic fashion is lacking. There is a need for a refreshment to combine demographic processes with economic aspects. The problem should be viewed from a broader perspective and the solution should be sought in the interaction of demographic processes with its economic environment.

CHAPTER 4: MODEL PROPOSAL

4.1. THE G&W MODEL REVISITED FROM A DEMOGRAPHIC PERSPECTIVE: A MODEL PROPOSAL FOR AN ECONOMIC DEMOGRAPHY MODEL

There is an extensive literature that investigates the demographic and economic dynamics; but Galor and Weil's unified growth theory with endogenous fertility, technology and human capital accumulation is the most appealing and promising one among the others. It is the most comprehensive model with three key endogenous variables that account for the whole transition process in a continuum; starting from Malthusian stagnation to post-Malthusian era, through demographic transition and finally to sustained economic growth period. Galor and Weil's ground-breaking study (2000) pioneered a new stream in economic growth literature: "Unified Growth Theory". Although it does not have a long-standing background, taking almost 1500 citations, it is a valuable contribution and has been widely accepted in the literature. However, the simplifications of the model hinder the user to get use of the detailed demographic indicators. As it is mentioned in the previous chapters, G&W assumes that an individual has a life of 2 periods with a length of approximately 20 years each (Lagerlöf, 2006). Moreover, according to the G&W model a young individual absolutely survives to adulthood, while an adult individual dies after 40 years. On the other hand, there is no age and sex differentiation in the population. Furthermore, the fertility in the model is defined as the number of births per person. Consequently, no conventional demographic terms such as TFR or ASFR are mentioned. As a result, it can be concluded that the G&W model does not touch the mortality concept in a realistic way and it also does not aid the user to comment on the conventional demographic indicators of fertility and population structure within reasonable time periods.

At this point we reformulated the model presented in Galor & Weil (2000) by combining it with the conventional CCM. Herewith, we make use of the explanatory power of the unified growth theory (UGT), and gather the population age and sex structure with reasonably short time brackets by the means of cohort component modeling (CCM). Additionally, on the contrary to G&W we approach the mortality concept in a realistic way by taking into account the age-specific survival rates. Meantime, we will get the estimate values for the education, human capital and technology levels as a result of the combined model of "**economic demography model**".

For simplification purposes the **economic demography model** assumes that there is no migration. On the other hand, mortality is taken as exogenous, while fertility is an endogenous variable estimated via unified growth theory. Similar to the original G&W model, the model structure is built upon OLG economy. As it is discussed before, in an OLG model, a person has two main stages in his life; one is active and the other one is passive. Note that the reproductive period is assumed to start at age 15 and end at age 49. So, people between the ages 15-49 are called to be the active members of the population in terms of fertility and child decisions, where the ones below age 15 are to be passive members. In addition, working age group is classified as the period between the ages 15-64. People who are a member of working age group are assumed to be actively involved in the labor force participation. People in age group 65plus are the retired people who are categorized as passive like the ones below the age of 15.

Age groups in the model is divided into five year periods being consistent with most demographic models, and each age group in the reproductive period is assumed to be a single decision maker. While the optimization problem is identical within an age group it differs across different age groups in terms of age-specific parameters. By decomposing the population into age groups, demographic reformulation of G&W model also decomposes one single optimization problem into smaller identical sub problems with different parameter settings.

Each decision maker in the model optimizes his utility subject to a budget constraint. Decision maker's utility is a function of own consumption and the quality of the children born and raised up to 15. The quality of a child is measured by his education and namely by the human capital levels. There is a subsistence level of consumption at which people get to survive and below which they cannot think of having babies. Above that level of consumption, decision makers allocate their income between their own consumption and child expenditures. Each age group, that is each decision maker, has its own parameter set. Accordingly they have different levels of income and subsistence consumption. It is possible to validate that assumption by observing different consumption needs at different ages. As a result, each age group in the reproductive age contributes to the total fertility at different rates. In the same manner, parents of different age groups attribute different levels of education to their newborns.

In the light of the above discussions, the optimization problem is formulated as follows:

$$\text{maximize}\, u_{ti} = (1-\gamma)\ln c_{ti} + \gamma \ln(n_{ti} hn_{ti}) \tag{6.1}$$

$$subject\ to$$

$$c_{ti} = z_{ti}[1-(\tau_i + en_{ti})n_{ti}] \tag{6.2}$$

$$c_{ti} \geq \tilde{c}_i \tag{6.3}$$

$$en_{ti}, n_{ti} \geq 0 \tag{6.4}$$

$where$

$u_{ti} = utility\ of\ an\ individual\ of\ age\ group\ i\ in\ time\ t$
$c_{ti} = consumption\ level\ of\ an\ individual\ of\ age\ group\ i\ in\ time\ t$
$en_{ti} = education\ level\ invested\ in\ the\ child\ \ born\ by\ age\ group\ i\ in\ time\ t$
$n_{ti} = number\ of\ children\ \ born\ per\ person\ by\ \ age\ group\ i\ in\ time\ t$
$hn_{ti} = human\ capital\ level\ of\ adults\ in\ time\ t + 15\ who\ were\ born\ in\ time\ t\ by$
$age\ group\ i$
$z_{ti} = income\ level\ of\ an\ individual\ of\ age\ group\ i\ at\ time\ t$
$\gamma = weight\ on\ fertility\ in\ utility\ function$
$\tau_i = fixed\ time\ cost\ of\ children\ born\ by\ age\ group\ i$
$\tilde{c}_i = subsistence\ level\ of\ consumption\ of\ age\ group\ i$

Since the demographic reformulation decomposes the optimization problem into equivalent sub problems with different parameter settings without violating any assumption of the original model, the equilibrium conditions of the original model that are stated in part 3 holds also for the economic demography model. Similarly, the new model proposal does not violate any single assumption regarding the relationships among the variables. So, parameterized forms presented by Lagerlöf are also compatible with the new model proposal with an arrangement for age specific definitions in a setting of five year time brackets. The parameterized forms of the new model's equations are presented as below:

Human capital at adolescence of the new born by age group i at time t is:

$$hn_{ti} = h(en_{ti}, g_{t+15}) = \frac{en_{ti} + \rho\tau_i}{en_{ti} + \rho\tau_i + g_{t+15}} \tag{6.5}$$

$where$
$$g_{t+15} = \frac{A_{t+15} - A_t}{A_t}$$
$g_{t+15} = technological\ progress\ rate\ between\ years\ t\ and\ t + 15$
$A_t = technology\ level\ at\ time\ t$
$\rho = portion\ of\ fixed\ time\ cost\ of\ children\ that\ contributes\ to\ human\ capital$
$formation, \rho \in (0,1)$

The human capital level at adolescence directly depends on the education level attributed at birth and the technological progress rate over the last 15 years. The education of the children is assumed to include also the preschool period spent in the family. Together with the formal education it composes the total education level attributed to a child. There is an inverse relationship between the human capital and the technological progress rate, because it is assumed that the technological developments make the knowledge obsolete and weakens the education's positive effect on human capital.

Education level attributed at birth to a cohort born by age group i at time t is written as:

$$en_{ti}(g_t) = max\{0, \sqrt{g_t \tau_i (1-\rho)} - \rho \tau_i\} \quad (6.6)$$

Accordingly, education level apart from the preschool period of new born is a function of technological progress rate and the time devoted to the children. As the technology develops at a faster rate, parents tend to give higher levels of education to their children. Because at higher rates of technological progress, education will also be obsolete at higher speed and they have to give higher levels of education in order to reach the desired level of human capital at adolescence.

The technological progress in period $t+1$ is equivalent to the technology level of period t increased by the technological progress rate of g_t:

$$A_{t+1} = A_t(1 + g_t) \quad (6.7)$$

Technological progress rate, on the other hand, is a function of education level and population size:

$$g_t = g(e_t, L_t) = (e_t + \rho\tau)\alpha(L_t) \quad (6.8)$$

$where$
$e_t = total\ education\ level\ of\ population\ at\ time\ t$
$\tau = average\ fixed\ time\ cost\ of\ children$
$\alpha(L_t) = scale\ effect\ component\ (see\ section\ 4, equation\ 4.4\ )$

Total education level of population at time t, e_t is calculated by the weighted average of education levels of different age groups in working age period, i.e. 15-64. Likewise, average fixed time cost of children, τ is again calculated by the weighted average of different age groups in the reproductive age period, i.e.15-49.

Each age group makes an independent decision and new born babies of different age groups do not share the same attributes. Various levels of education is invested at birth and that reveals different levels of human capital at adolescence. However, the children born in a specific year constitutes a single cohort, which has to be attributed with common education and human capital levels. Therefore, the education and human capital levels of the new born cohort are calculated as the weighted averages of the new born babies' education level and human capital level attributed by their own parents. Meanwhile, the education and human capital levels of whole population are calculated as the weighted average of the working age group's education and human capital levels (15-64 years).

Technological progress rate has a positive relationship with the education levels and the average time allocated to children. Moreover, the size of population also enforces the development rate but at a certain extent. The scale effect component refers to the limit of the effect of population size on the technological progress rate.

Education level equation is revised by writing technological progress rate equation (6.8) into education formula (6.6):

$$en_{ti} = max\left\{0, \sqrt{(e_t + \rho\tau)\alpha(L_t)\tau_i(1-\rho)} - \rho\tau_i\right\} \qquad (6.9)$$

Income formulation of age group i at time t is as follows:

$$z_{ti} = [h_{ti}]^{\alpha}\left[\frac{A_t X}{L_t}\right]^{1-\alpha} \qquad (6.10)$$

where h_{ti} is the human capital level of age group i that is calculated by the weighted average of the human capital levels of the cohort composed of the children born by different age groups.

Lastly, optimal decision rule for number of surviving child is reformulated as:

$$n_{ti}[\tau_i + en_{ti}] = \left\{\begin{array}{c|c} \gamma & if\ \ z_{ti} \geq \tilde{z}_i \\ 1 - \tilde{c}_i/z_{ti} & if\ \ z_{ti} \in (\tilde{c}_i, \tilde{z}_i) \\ 0 & if\ z_{ti} \leq \tilde{c}_i \end{array}\right\} \qquad (6.11)$$

As mentioned earlier, number of child decision is a function of income and subsistence consumption. Also, it is an outcome of the tradeoff between the child's quantity and quality as well as the tradeoff between the utility of having children and utility gathered from the individual's own consumption.

After giving the parameterized form of the economic demography model we turn our attention to the implication of the model. The demography model defines the fertility over TFR and ASFR whereas UGT defines it rather by the number of children per person born by the specific age group in the reproductive period. In order to implement the economic demography model, what we need is to interpret the fertility term of number of children per adult in terms of the demographic indicators of TFR and ASFR.

If the population size of each reproductive age group is known, the total number of babies born can be calculated with the equation below:

$$nb_t = \sum_{i=1}^{i=7} {P_{it} n_{it}} / {S_{x015}} \qquad (6.12)$$

$where$
$nb_t = total\ number\ of\ births\ in\ time\ t$
$P_{it} = population\ size\ of\ age\ group\ i\ in\ time\ t$
$n_{it} = number\ of\ child\ per\ person\ born\ by\ age\ group\ i\ in\ time\ t$
$S_{x015} = survival\ probability\ of\ a\ new\ born\ till\ the\ age\ of\ 15$
$i = 1\ refers\ to\ the\ first\ age\ group\ in\ reproductive\ age\ period\ and\ i = 7$
$refers\ to\ the\ last\ one$

The unified growth model assumes that the number of children per person stands for the number of children surviving till the age of 15. So, an adjustment with respect to survival rates is required in order to get the exact number of newborns. Meanwhile, the population in the unified growth model is the so called **synthetic** population, whose members are assumed to live till the end of their reproductive age. Therefore, the number of child decision of the individuals is actually a lifetime decision. By definition, we can calculate the value of TFR for period t by dividing the total number of children born by the size of the female population in reproductive period. This is written as:

$$TFR_t = {nb_t} / {\sum_{i=1}^{i=7} P_{fit}} \qquad (6.13)$$

$where$
$P_{fit} = female\ population\ of\ age\ i\ in\ time\ t$

In a similar fashion, ASFR is estimated by the distribution of births among the age groups:

$$ASFR_{it} = {}^{P_{it}n_{it}}/_{nb_t} \tag{6.14}$$

Calculated TFR and ASFR measures are "**synthetic cohort measures**" which use information about many cohorts in a single year as opposed to "real cohort measures" that uses information about a single cohort over many years (Rowland, 2003).

Each time TFR and ASFR rate is estimated by the reformulated unified growth model, CCM is run for one time step with these parameters and the population age & sex structure is revised. Afterwards, the unified growth model is rerun with the updated population data and creates the new TFR and ASFR values over the endogenously updated economic and technological indicators. This reciprocal relationship between these two models is illustrated in Figure 1.

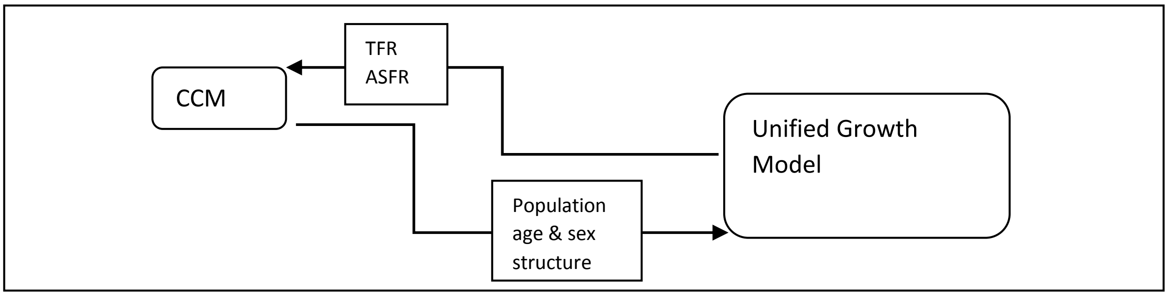


FIGURE 1 Relationship between CCM and the Unified Growth Model

In the economic demography model, TFR and ASFR are estimated by the reformulated unified growth model and fed into CCM, whereas the unified growth model takes the updated population age and sex structure and recalculates the TFR and ASFR for the next period. Meantime, the unified growth model updates the economic, technological and educational indicators. As a result, besides the population age and sex structure, the model provides indicators that are influential on people's birth and education decisions. Correspondingly, we get a deeper insight over the population structure and the way it behaves as fertility determinants change through the time. Furthermore, we get an understanding on the education and human capital level of the society, and where the fertility trend goes according to that indicators together with the technological level as well. This insight will shed light on the way of public policy makers to manage the fertility decisions and the public expenditure plans especially for education and technology.

4.2. SYSTEM DYNAMICS APPROACH TO ECONOMIC DEMOGRAPHY MODEL

In social systems, acquiring insight on the system behavior before the realization is a great challenge. Analyzing the behavior afterwards is though too late to take an action. So, there should be a way to facilitate decision makers to experiment the system behavior in advance and take the precautionary policy actions. Up to this point, we have concentrated on the conceptual model and did not mention how to conduct an empirical implementation. The pairwise causalities presented in the model can well be supported by economic and demographic theories in the literature, though, we do not handle the problem in a piecemeal fashion. We rather want to show that the entire model has an explanatory power from a holistic perspective. As a result, we are in a quest for finding an appropriate methodology compatible with the holistic and the dynamic nature of the proposed model. Simulating the model would deliver a dazzling performance in that sense. It would provide the decision maker to experiment the system beforehand and get insight about the working principle of the key elements in the system.

On the other hand, the unified growth model is a good representative of the concepts of feedback and accumulations such that the evolution of economic environment and initial population occurs as a consequence of either reinforcing or balancing feedback mechanisms defined via deterministic difference equations. Hence, the characteristics of the model structure associate actually with the key properties of **system dynamics modeling** (explained in detail in section 7.1). Also, relationships between the variables display causality rather than correlation and this property enhances the explanatory power of the proposed model. The explanatory feature is a perfect match for system dynamics methodology in a manner that it answers the question "why" as well as the question "what if" via causal interactions.

SD methodology is widely used in complex social systems. The first system dynamics model for population was "World Dynamics" by Jay Forrester (Forrester, 1971), who is the pioneer of the study area of system dynamics. Those days, the main concern was the scarce resources and the exponential growth of the population. People worried about the exhausting natural resources and the future of human being. "World Dynamics" is a system dynamics model that explores the complex interaction between economy, population and ecology. It is immediately followed by "Limits to Growth" (Meadows et al., 1972) and "Dynamics of Growth in a Finite World" (Meadows et al., 1974). The extensions of these studies are published in 1992 and in 2004 afterwards (Meadows et al., 1992, 2004). The main interacting systems for all these successor models of "World Dynamics" listed above are food, industry, population, non-renewable resources and pollution. Ultimately, the analogy between the proposed model and the primary studies in the field also support our choice of methodology.

Next section is reserved for the key features and the terminology of system dynamics modelling. Afterwards, the system dynamics representation of the proposed model will be discussed in section 7.2.

4.2.1. System Dynamics Terminology

This section introduces the basic concepts and the tools of system dynamics modelling.

Causal relationships and feedback loops constitute the main building blocks of a system dynamics model. The methodology uses **Causal Loop Diagrams** (CLD) to represent these causalities and feedback loops.

The **causality** is displayed by arrows between two variables. The direction of the arrow shows the direction of the effect. **Link polarity** is also displayed on the arrows. A plus sign (+) on the arrow tells that there is a positive relationship within the two variables, whereas a minus sign (-) stands for the negative relationship. There is no limitation on the causality and polarity. That is, a single variable can effect multiple factors, with different polarities. In the same manner, a single variable can also be effected by multiple factors. See the examples below (Figure 2-3).

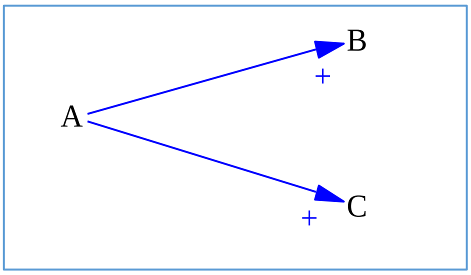


Figure 2 Causality representation-I

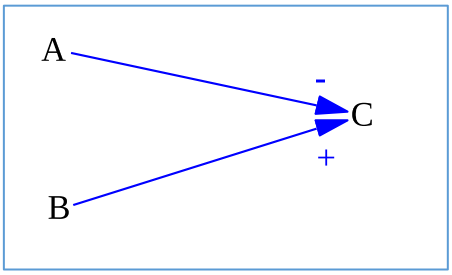


Figure 3 Causality representation-II

Feedback loops are composed of a chain of causal links constructed by at least two variables that eventually returns to the beginning. Particularly, the change in the first variable ultimately effects again that variable after the chain of causalities are traced. Feedback loops have a polarity that is derived according to the any causal relationship incorporated into the loop. Loop polarity is either **reinforcing** or **balancing**. When the feedback is positive the loop is identified as reinforcing and the causal links accelerate the change in the first variable. Likewise, the loop is identified as balancing if the feedback is negative dampening the effect of the change of the first variable. Notation for the feedback loops are **R** and **B** or +/- signs written in a circular arrow that is drawn in the same direction with the loop itself. A basic example is given below (Figure 4).

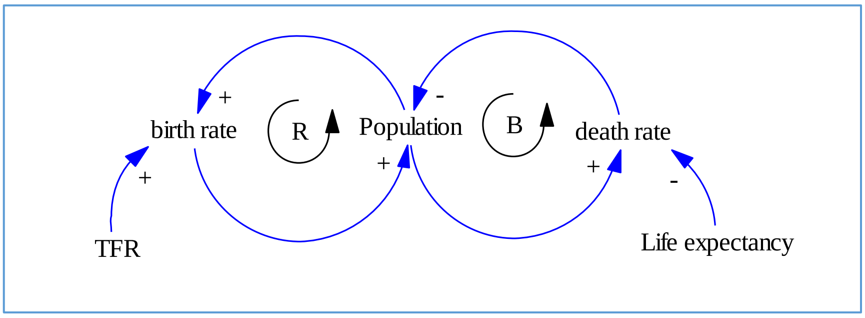


Figure 4 Example for Causal Loop Diagram (population system)

The variables in a system dynamics model stand for **stocks**, **constants** or **auxiliaries**. Stocks represent the accumulations in the system. They show the states of the variables that increase with inflows and decrease with outflows. Causal loop diagrams lack in showing the stocks and flows, therefore system dynamics methodology offers to use **stock-flow diagrams**. In a stock-flow diagram rectangles represent the stock variables and the arrows with valve on the top stands for the inflows and outflows. Clouds denote the sources and sinks of flows. Variables that are not depicted as a rectangle is either a constant or an auxiliary. Constants are the user-defined parameters and they are not effected by any causal relationship in the model. On the other hand, auxiliaries stand for the intermediary variables. They are introduced for the sake of user’s understanding of the model. Auxiliaries are mostly derived by the mathematical formulations of stocks, flows and constants.

The type of variables in a system dynamics model are exemplified in the below stock-flow diagram of the small population system represented in Figure 5.

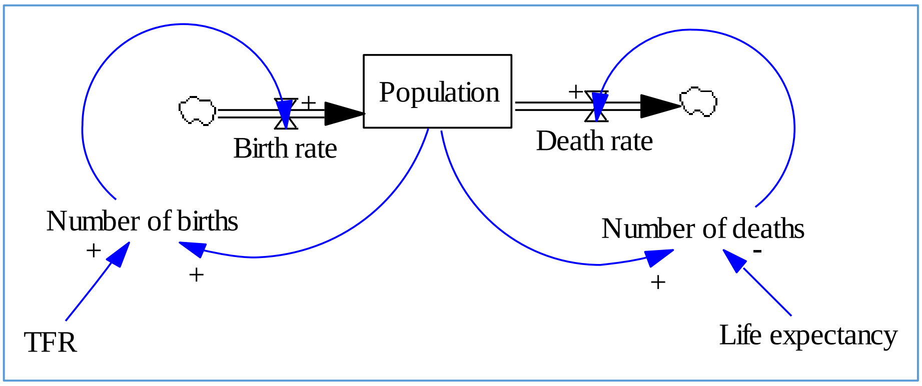


Figure 5 Example for Stock-flow Diagram (population system)

The stock variable of the above figure is the population and the flows are the birth and death rates. Life expectancy and TFR are the constants, whereas the number of births and number of deaths are the auxiliary variables. The number of births is defined by the function of TFR, and population, whereas the number of deaths is a function of life expectancy and again population. As it is seen in Figure 5, the use of feedback loop polarity, either it is reinforcing or balancing, is up to the user. The user does not strictly have to display the feedback loop polarities. He can prefer to display none or only the most important ones.

The figures in this section is used for the definition of the terminology. They are not representative of any of the MODELS discussed in the context of this thesis.

4.2.2. System Dynamics Representation of the Economic Demography Model

The economic demography model is composed of two main sub-models. The first is the cohort component model that ages the initial population through the years and gives output of the population age and sex structure for the given birth and death rates. The second sub-model is the unified growth model that works with CCM in a reciprocal relationship by feeding it with endogenously estimated birth rates depending on the population age and sex structure resulted from CCM model. The unified growth model estimates the fertility rates over the population's education, human capital, and income levels and as well as the technology progress rate. The whole system is visualized by the causal loop diagram given in Figure 6:

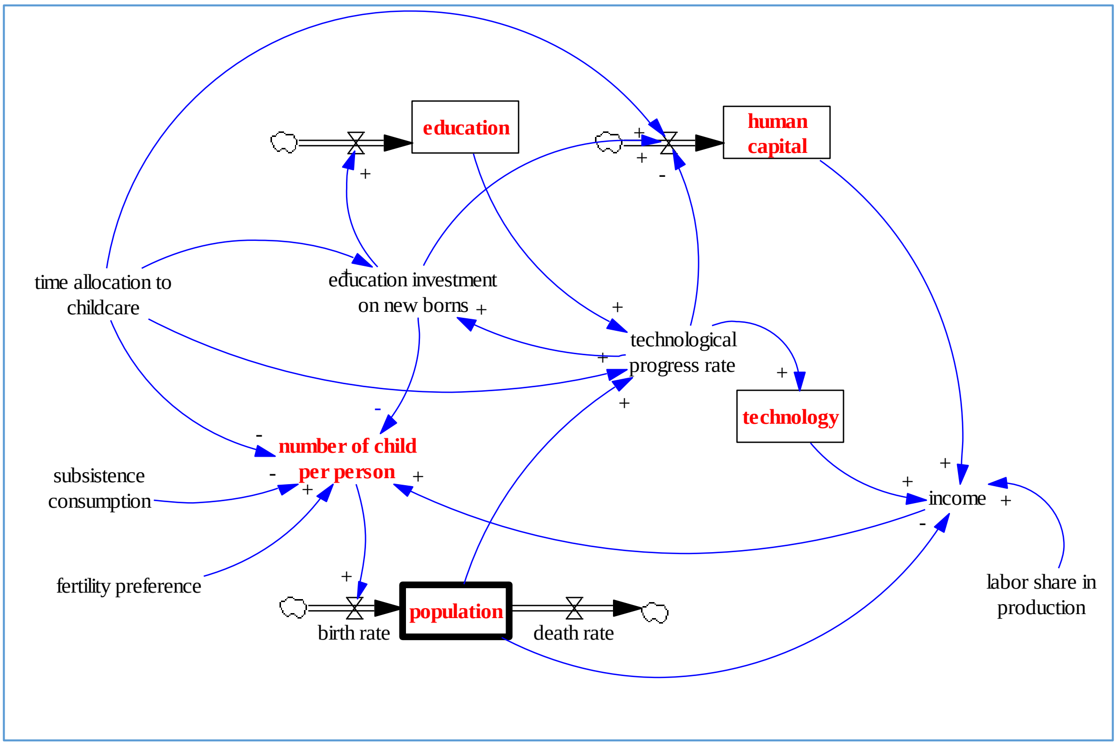


Figure 6 CLD of the economic demography model

The population rectangle is showed in bold to differentiate it among the others, because it actually stands for the CCM sub-model, while the rest of the figure is representative of the unified growth sub-model.

In the preceding sections, dynamics of the model has been discussed; however, we explain it one more time following the given causal loop diagram. Education level of the society is fed with the education investment plan for new born babies. As the education level of society goes up, it reinforces the technological development. Meanwhile education investment planned for new born babies is a function of technological progress rate and time allocated to child care. At higher rates of technological progress, people decide to invest more on their children; because the education level depreciates more against technology. As the parents spend longer times with their children, they invest more on their educational development. On the other hand, the higher levels of time allocation and the higher levels of education investment stimulates the tradeoff between the child quality and quantity leading the parents tend to have less children with high quality.

Beyond the education investment and time allocation, other determinants of number of child per person are the subsistence level of consumption, fertility preference and income level. People cannot think of having babies unless they are over the subsistence level of income. They also maximize their total utility over child and own consumption subject to their budget constraint which is restricted with their income levels. The tradeoff between utility of consumption and child rearing is quantified by the parameter of fertility preference.

The estimated value of number of child per person constitutes the main input of the CCM sub-model, i.e. birth rate. Within the CCM sub-model, population size is estimated with the birth rate result of the unified growth sub-model and it is influential on technological progress rate and income levels. Other three determinants of income are human capital, technology level and labor share in total production. Human capital is a state variable that is determined by the new born babies' educational investment levels and the time allocated to them, however, there is a negative effect of technological progress rate in such a way that technological development makes the knowledge obsolete that weakens the positive effect of education level on human capital.

To sum-up, the economic demography model is composed of two sub-models: CCM and unified growth sub-model. Accordingly, unified growth sub-model is composed of three state variables; two of which is taken as age specific: education and human capital, whereas the technology is a country level indicator updated by five year periods. In a similar way, variables of unified growth sub-model apart from the labor share in total production and the fertility preference are taken as age-specific.

Further explanations about the causal relationships within the sub-models are given in the following sections.

4.2.2.1. CCM Sub-Model

An illustration of CCM in a system dynamics fashion is given in Figure 7. In the aforementioned causal loop diagram of the economic demography model (Figure 6), cohort component model is represented with a single state variable with one inflow and one outflow. It is actually composed of an **aging-chain** with five year age brackets. "**Aging-chain**" stands for the system dynamics model in which total stock (total population) is disaggregated into multiple categories (age groups). Each category graduates (ages / survives) to the next one without any limitation on the flows. That is, it is possible to observe an increase or decrease in the stock size of a category due to the external inflows and outflows (migration or death) besides the graduation process.

In particular, surviving population size from a younger age to older one is determined by the multiplication of the younger age population size and age specific survival rate. At the same time, age specific survival rate is derived from the model life tables together with the value of life expectancy at birth. Births are inflows to the first age group, while deaths and aging population are outflows of each age group except the last one having only deaths as an outflow. Deaths from a specific age group are calculated by the population size of that age multiplied by the age-specific death rate, whereas the aging / surviving population stands for the remaining part of the population of that age group. Furthermore, births are calculated by the aid of TFR and ASFR values multiplied by the size of female population in reproductive period. Formulations of the flows of this aging chain has already been discussed in section 5, however, they are also reviewed here from a system dynamics perspective for the sake of integrity.

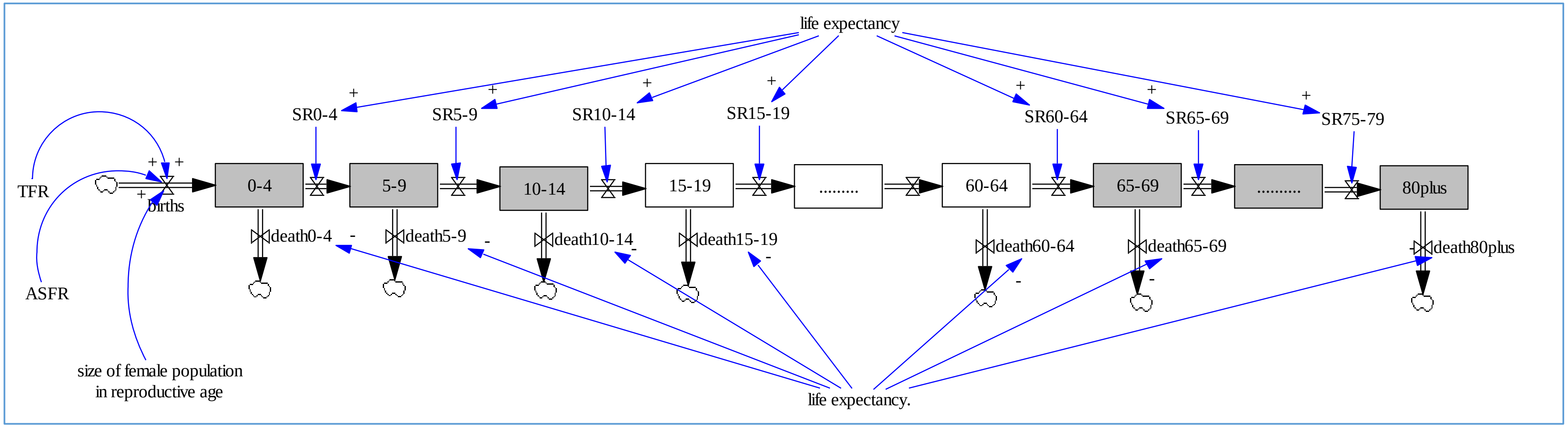


Figure 7 Stock-flow diagram of CMM sub-model

(SR: survival rate, TFR: Total fertility rate, ASFR: Age-specific fertility rate)

CCM sub-model actually consists of two aging-chains for both sexes; but one representative aging chain is displayed here. Succeeding three figures show the working principle of CCM sub-model in detail. Figure 8 displays the stock-flow diagram of the first age group. TFR value is gathered from the unified growth model by accounting female population size in reproductive age groups in the CCM sub-model. Afterwards, birth rate is calculated accordingly together with the ASFR data obtained from the unified growth sub-model and female population size in CCM. Outflows of the first age group are survival and death rates determined by user defined life expectancy. Meantime, being a sub-model, unified growth model is displayed with a diamond.

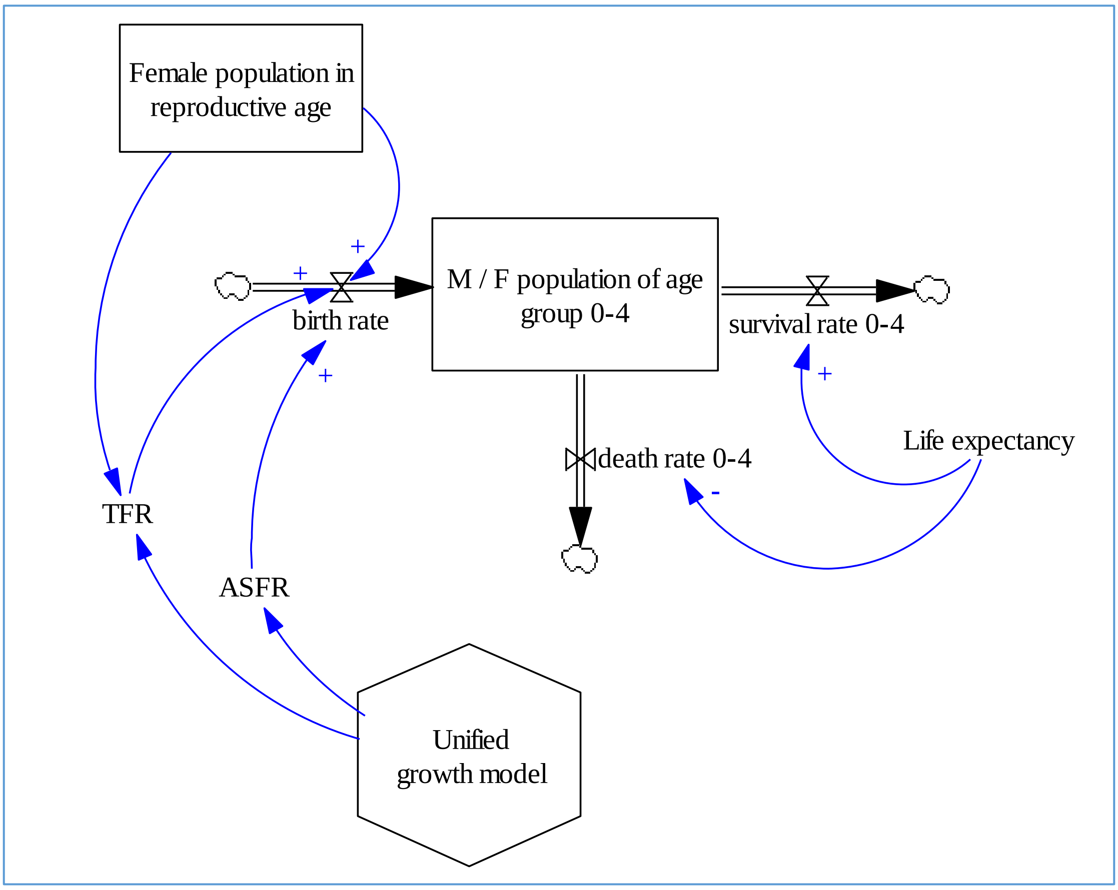


Figure 8 Stock-flow diagram of first age group in CCM sub-model

Figure 9 demonstrates the stock-flow diagram of the intermediary age groups starting from 5-9 and ending with 75-79. Inflows are the survival rates from the previous age group, whereas outflows are aging to the next age group and deaths. Determinant of death and survival rates is again the user-defined life expectancy.

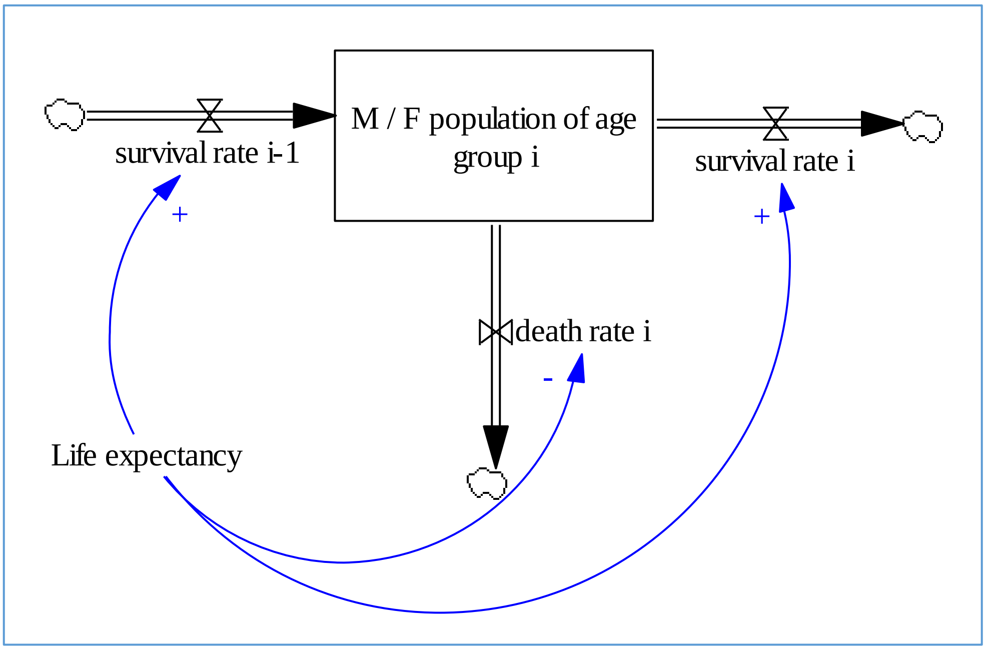


Figure 9 Stock-flow diagram of intermediary age groups in CCM sub-model

Figure 10 represents the stock-flow diagram of the last age group, 80Plus. In this age group no more aging is observed and the only outflow is death, while the only inflow is survival rates from the previous age-group 75-79.

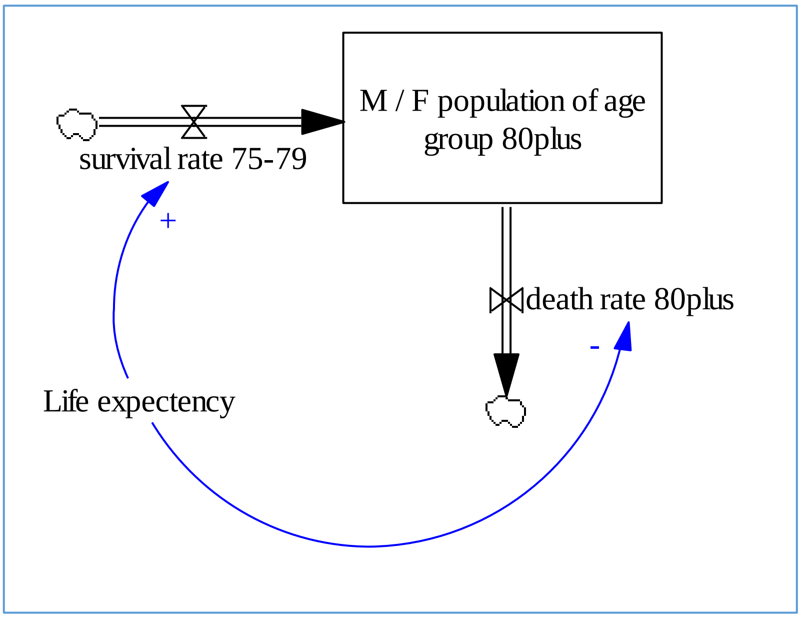


Figure 10 Stock-flow diagram of last age group in CCM sub-model

To sum up, flow in aging-chain starts with births determined by the reproductive population size in CCM sub-model and the fertility rate outputs of unified growth sub-model. Flow continues between the age groups according to age-specific survival rates which are a function of user-defined life expectancy. Meanwhile, some of the members leave the population with an age-specific death rate in each age-group. The same flow is replicated for both sexes.

4.2.2.2. Unified Growth Sub-Model

Unified growth sub-model can be examined in three main modules: education/human capital, technology and fertility.

4.2.2.2.1 Education/Human Capital Modules

Education and human capital levels are the co-flows of the individuals who are the members of aging chain in CCM sub-model. Co-flows are the attributes of individuals that travel through the stock and flow structure of the system (Sterman, 2000). Individuals carry the education level determined by the parent's investment decision given at birth as an attribute throughout their lives. Since each age group in reproductive period is taken as a single decision maker with age specific parameters, any single cohort born by each age group is assigned a different education level at birth. But as a whole, they constitute a single new born cohort for a given time frame. On the other hand, since any age group is required to have a single education level, here we must gather a unified value of education associated with the cohort. To do so, we opt for taking the weighted average of individual education levels of the new born cohort. This value forms the education level of the first age group 0-4 and it is re-calculated in each time step by means of the new comers' level of education, leading the ex-value flow directly to the next age-group, 5-9. Education level flows in parallel with the aging population till the age group 80plus. Though, passive age-groups' education levels are used for representative purposes but not included in the total education level.

In a similar way, human capital is also a co-flow of aging population, however it starts from the age of 15 and ends at the age of 80plus. Education level attributed to a child at birth is assumed to form the human capital of that individual after 15 years. The value of the human capital depends also on technological progress rate, which shows how much of the education investment is depreciated across technological development. Due to the reason that they are not in work force, human capital levels above the age of 64 are not included in the total human capital level.

A representative visualization of education and human capital co-flows is given in Figure 11.

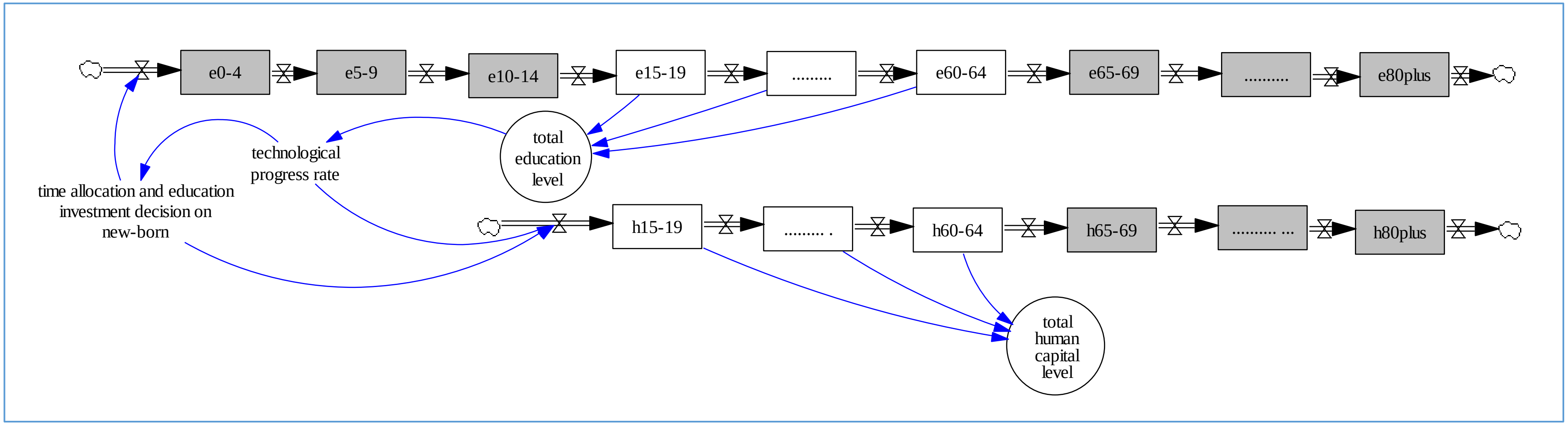


Figure 11 Stock-flow diagram of education/human capital module

4.2.2.2.2 Technology Module

Technology is the state variable directly influencing income levels. The growth of the technology level is cumulative and inflow is determined by endogenous technological progress rate. While level of the state affects income levels only, growing speed is the main determinant of the education and human capital levels. On the other hand, technological progress rate is estimated over the education level, time allocation to child care, and population size limited by the scale effect.

Stock-flow diagram of technology module is given in Figure 12.

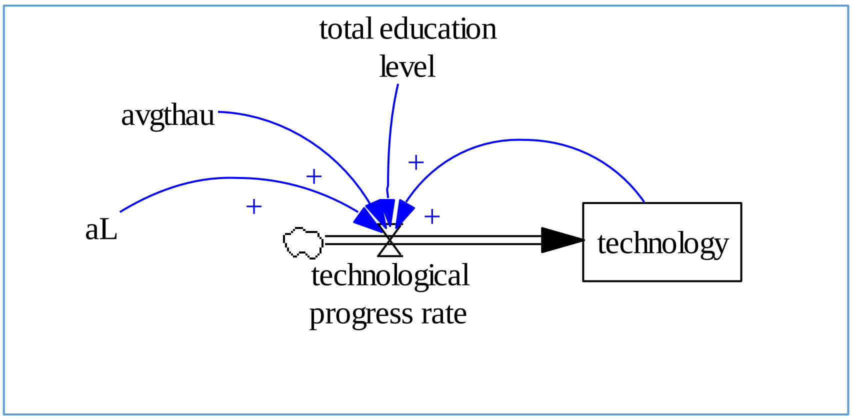


Figure 12 Stock-flow diagram of technology module

‘Avgthau’ in Figure 12 represents time allocation for child care, where ‘aL’ is used to show the scale effect of the population size on technological development.

4.2.2.2.3 Fertility Module

Fertility module is the conjunction point of the two sub-models: CCM and unified growth model. It consists of series of auxiliary variables. First, the number of child per person is calculated for each reproductive age group. Then they are multiplied by age-specific population sizes to find the total number of births. Afterwards, total number of births value is divided by survival probability of living from birth to age 15, because the former value stands only for the children who are assumed to be alive at age 15. The final value for total number of births is a synthetic measure of the unified growth sub-model and it is converted to TFR value by dividing it by real female population size in the reproductive period. At this point, cohort component sub-model is ready to be run with endogenously estimated fertility levels. Other fertility measure gathered by unified growth sub-model is ASFR.

Since the fertility indicator is calculated by age, the number of births are also age-specific. So, ASFR is gathered by taking the proportion of age-specific birth numbers to total births. Stock-flow diagram of fertility module is displayed in Figure 13.

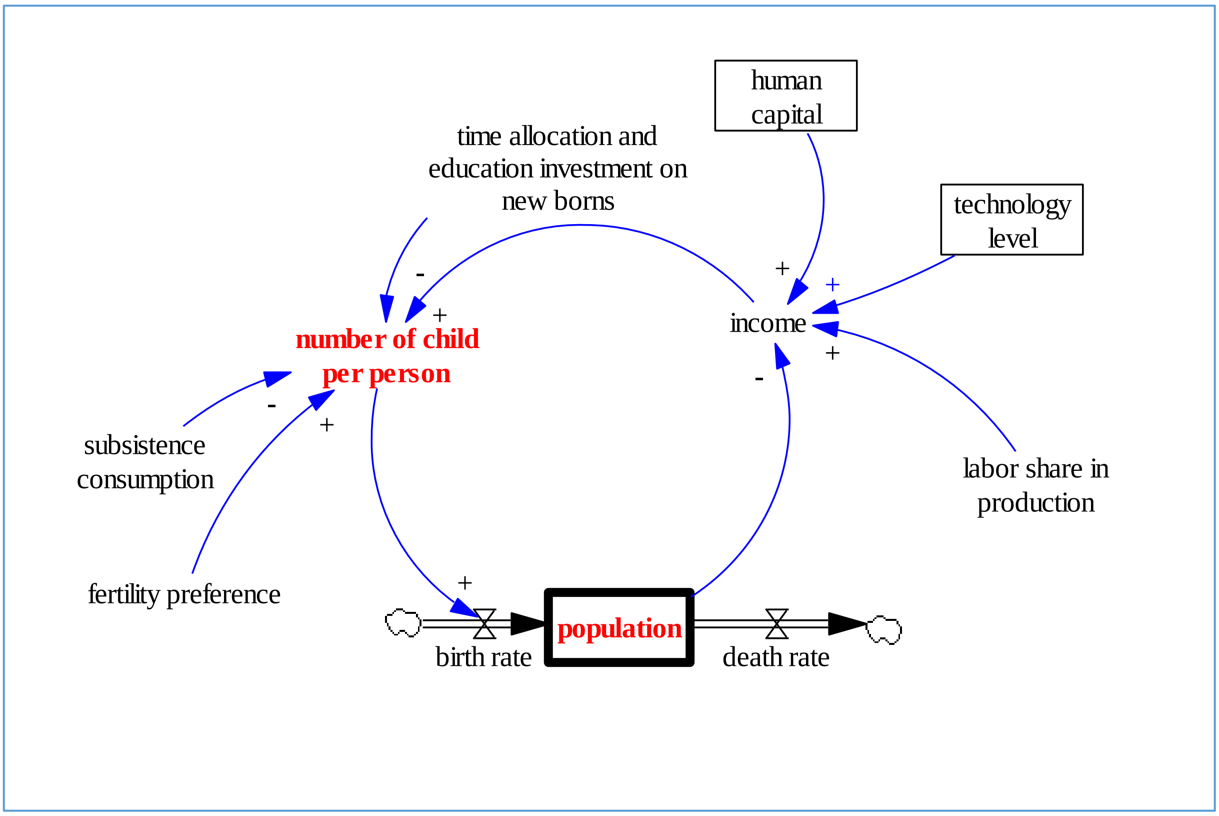


Figure 13 Stock-flow diagram of fertility module

CHAPTER 5: MODEL IMPLEMENTATION

5.1. MODEL CALIBRATION

Model calibration is the step where the necessary input for a simulation run is acquired. Thus, it is the process of setting the values of parameters and initial state conditions of a model. The calibration of the economic demography model is done with public data sources. Turkish data is mostly used when it is available. If the required data cannot be found for Turkey, parameter values are calibrated over the initial state conditions. In particular, they are derived by rewriting the difference equations with the determined initial state values. If even the calibration over initial state is not possible, parameter optimization is performed (explained in section 8.1). As a result, parameter and initial state values do not belong to the same year. They are not gathered from the same data source as well. Accordingly, calibrated model is not a representative of a real world country. Thus, the model is not claimed to have a projective power. Even so, calibration is done to test the conceptual model and behavioral patterns of key variables. It is questioned whether the model behaves as it is expected on conceptual basis and the causalities introduced work out when they all come together or the model reveals unexpected results. Besides testing purposes, the results of the empirical model offer the user a further insight on the causality among the variables as well as the behavioral patterns, consequently giving a chance of making preliminary analysis for policy implementation.

Primary data source used in calibration is TURKSTAT (Turkish Statistical Institute) and ABPRS (Address Based Population Registry System). United Nations data source is used for model life tables. Beyond the data gathered from official data sources, the ones that cannot be found are determined either by assumption or by calibration over initial states. For one parameter (τ) which we could not find a reliable data source and cannot derive from the initial state, parameter optimization is performed.

Table 1 is prepared for the calibration of point parameters. Labor share (α) is assumed to take the value of wage compensation proportion in Turkish GDP of year 2006. Educational part of τ_i (ρ) and scale effect parameter (a^*) are derived from initial education level and technological progress rate by the formulas (6.6) and (6.8) respectively, while the scale effect of population size is assumed to reach the maximum value of a^*. In a similar fashion, weight on fertility in the utility function (γ) is derived over the number of child per person formulation (6.11) given the initial fertility level assumption. Scale effect parameter (θ) and land (X) have no effect after the calibration, so they are assumed to be equal to zero as in the original article of Lagerlöf (2006).

Sex ratio at birth (SRB) is assumed to be equal to 105. That is the number of new born babies of male over hundred female. Life expectancies for the first 8 time steps are given in Table 1 for representative purposes. As it is seen in the table, life expectancies are not equal to standard values used in the life tables that are given either in 2.5 year or 5 year increments. Consequently, survival rates are calculated by linear interpolation technique with respect to Coale-Demeny West Life Table prepared by United Nations.

Point Parameters	**Description**	**Value**								**Year of data**	**Data source**
α	Labor share	0.262								2006	TURKSTAT
ρ	Educational part of τ_i	0.1946								-	Calibration
a^*	Scale effect parameter	0.4617								-	Calibration
γ	Weight on fertility on utility function	0.6677								-	Calibration
θ	Scale effect parameter	1								-	Assumption
X	Land	1								-	Assumption
SRB	Sex ratio at birth	105								-	Assumption
S_x	Survival rate	CD West Life Table								-	United Nations
LE_f	Female life expectancy	77.2	78.8	79.9	80.0	80.0	80.0	80.0	80.0	-	Assumption
LE_m	Male life expectancy	74.3	75.4	76.5	77.7	78.8	79.9	80.0	80.0	-	Assumption

Table 1 Calibration for point parameters

Subsistence level of consumption ($\tilde{c}_i$) and fixed time cost of children (τ_i) parameters are defined as age-specific and the data used in the model is given in the following table. While subsistence level of consumption is obtained from 2006 household consumption survey of TURKSTAT and calculated as the percentage of the age specific average income per capita; there is no available data for fixed time cost of children. There is indeed "Household time usage survey" conducted by TURKSTAT in 2006 and there is also a report written by EUROSTAT (Statistical Office of the European Communities), which gathers several time usage surveys of various countries in a common study. Nevertheless, these two data sources display inconsistency. In TURKSTAT survey there is not an explicit data item for child care. Time allocation to child care can be guessed by household and home care time allocation which yields 50% of the total time available beyond sleeping. In EUROSTAT data, there are more detailed data items about time allocation for exact child care purposes and they yield a result between 20% and 30% on average. As a consequence of the inconsistency between these two data sources and the lack of age-specific data, we decided to apply parameter optimization for time allocation constant which will be explained in detail in the following sub-section (section 8.1).

Age-specific parameters	**Description**	**Value**							**Year of data**	**Data source**
$\tilde{c}_i$	Subsistence level of consumption by age	0.3849	0.4299	0.4265	0.4551	0.4582	0.5064	0.5469	2006	TURKSTAT
τ_i	Fixed time cost of children by age	0.731	0.250	0.250	0.343	0.829	0.857	0.780	-	Parameter optimization

Table 2 Model calibration for age-specific parameters

In addition to model parameters, model should be supplied with the values of initial state conditions, which are shared in the proceeding table (Table 3). Firstly, education level by age is provided. Age-group's education level is derived by combination of three data sources of TURKSTAT. In 2002, education expenditure per student by education level data is declared. In 2008, we have the data of education level by age. By combining these two data sources, we gathered the education level by age in monetary terms. Then we standardize the derived education levels by converting them into the percentage of GDP per capita of year 2002. Meanwhile, initial technology level is assumed to be equal to unity, which represents actually the 2006 value of research and development labor force proportion per ten thousand employees. The initial technological progress rate is calculated by the development between the years 2005 and 2006. Human capital levels are calculated by the given education levels and technology data. Based on the determined human capital levels, income level is derived by the income formula of the model (6.10). Lastly, simulation is started by the population state of 2008 ABPRS (Address Based Population Registry System).

Initial state conditions	**Description**	**Value by age**																	**Year of data**	**Data source**
		0-4	**5-9**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**	**60-64**	**65-69**	**70-74**	**75-79**	**80+**		
z_{0i}	Initial income by age				1.2416	1.1970	1.1939	1.2065	1.2416	1.2386	1.2417								2006	Calibration
e_{oi}	Initial education level by age		0.0742	0.0742	0.0742	0.0833	0.0891	0.0861	0.0801	0.0708	0.0667	0.0636	0.0561	0.0512					2002 and 2008	TURKSTAT
h_{0i}	Initial human capital by age				0.7153	0.6049	0.6153	0.6395	0.7369	0.7339	0.7172	0.7143	0.7069	0.7021					-	Calibration
L_{m0i}	Initial male population by age	3082338	3242581	3322041	3171917	3187625	3300291	2939518	2680941	2397706	2153427	1824582	1423445	1035261	783680	575433	492226	437754	2008	ABPRS
L_{f0i}	Initial female population by age	2915920	3075551	3150156	3013187	3068933	3218546	2870589	2649543	2342544	2130748	1818591	1454659	1153037	917704	699248	618556	839616		ABPRS

Table 3 Initial state conditions

5.1.1. Parameter Optimization

Parameter optimization method is well accepted in system dynamics literature in case of data unavailability. Optimization algorithm minimizes the deviation between the estimate values and the predetermined target values deciding on the decision variables that are subject to parameter optimization. In our case, we will conduct parameter optimization for the variable of fixed time allocated to children by age (τ_i).The challenge here is to decide on the target variable subject to which allocated to children by age (τ_i).The challenge here is to decide on the target variable subject to which optimization is done. It should be a variable on which the time allocation parameter has a direct influence. So, we set ASFR values of 2006 Turkish data as target values of the optimization problem. In particular, we perform parameter optimization for τ_i values of seven age groups in reproductive age period with respect to target ASFR values of 2006 Turkish realizations which are $T - ASFR = \{0.0946, 0.2837, 0.3050, 0.193.9, 0.0851, 0.0331, 0.0047\}$.

Decision variables are first found by the built-in optimization tool of system dynamics simulation software, Powersim. Working principle of the tool is based on an evolutionary search algorithm. At the beginning of optimization, maximum iteration number, offspring and parent numbers are introduced. As it runs, model generates offspring set from parents in each iteration and finds the new parents among the best-performing offspring. In the next iteration, the model generates new offspring parameter set from the pre-determined parents. This procedure continues till either the maximum iteration number is reached or the target deviation criterion is met. As the maximum iteration number increases, the model precision is expected to increase as well. Powersim optimization is done with a time horizon of 20 time steps with 3 parents and 15 offspring in each generation. 300 and 1000 maximum generation numbers are tried. Optimization results are summarized in the Table 4.

Age group	**Optimized Thau Value**	**Optimization conditions**	
15-19	0.87	max generations	300 / 1000
20-24	0.21	parents	3
25-29	0.32	offspring	15
30-34	0.30		
35-39	0.73		
40-44	0.62		
45-49	0.82	**MSE**	**0.0030**
Average	**0.5529**	**MAD**	**0.0375**

Table 4 Parameter optimization (Powersim result)

No enhancement is observed between the maximum generation number of 300 and 1000. However, the time elapsed for optimization increased exponentially. So, no further generation number is tried. On the other hand, Powersim software document do not provide any detail about parent and offspring generation process. Therefore, we transferred the Powersim model in the programming language Python and conducted parameter optimization with a random search algorithm. Random search algorithm generates a random set of $\tau_i$values from a set of discrete values created with 0.01 step size in range, $(0.25{,}0.85)$ in each iteration, runs the economic demography model and calculates ASFR with respect to the random τ_i set. Calculates the average deviation from $T - ASFR$ and records the value of deviation and random parameter set of τ_i. In the next generation it generates a new random set for τ_i values and follows the same steps. If the newly calculated deviation is smaller than the previous one, it modifies the deviation value and τ_i set with the new ones. Otherwise, it moves to next iteration without any change in parameter set and deviation value. Same procedure continues till the maximum iteration number is reached. This procedure can be summarized with the pseudo-code given below:

$current\ deviation = a\ big\ number$

$result = \{\ \}$

$while\ (x < max.iteration\ number)$:

    $for\ each\ age\ group$:

        $Generate\ random\ \tau_i\ \in R = \{0.25, 0.26, 0.27, \dots, 0.85\}$

    $Calculate\ ASFR\ and\ deviation$

    $If\ deviation < current\ deviation$:

        $current\ deviation = deviation$

        $result = ASFR$

Outputs of the random search algorithm reveal smaller error measures relative to the outputs of the Powersim optimization tool. Random search is done over one million and three million generations. Parameter search set is composed of numbers starting from 0.25 up to 0.85 with 0.01 step size, ie. 0.25, 0.26, etc.

Age group	Optimized Thau Value	Optimization conditions	
15-19	0.61	max generation	1000000
20-24	0.25	step size	0.01
25-29	0.25	Range of Thau	(0.25,0.85)
30-34	0.39		
35-39	0.82		
40-44	0.77		
45-49	0.78	**MSE**	**0.0022**
Average	**0.5529**	**MAD**	**0.0413**

Table 5 Parameter optimization-I (1 million iteration)

Age group	Optimized Thau Value	Optimization conditions	
15-19	0.70	max generation	3000000
20-24	0.25	step size	0.01
25-29	0.25	Range of Thau	(0.25,0.85)
30-34	0.30		
35-39	0.79		
40-44	0.81		
45-49	0.74	**MSE**	**0.0020**
Average	**0.5486**	**MAD**	**0.0356**

Table 6 Parameter optimization-I (3 million iteration)

Random search is moved one step further and new ranges for each τ_i are defined according to output values of the search with 3 million iterations. Outputs are taken as the mean values and allowable minimum and maximum values are determined by ± 0.05; but minimum value of 0.25 is preserved. In this new setting, precision is increased and parameter set for search is determined with a step size of 0.001, ie. 0.250, 0.251, 0.252, etc. Output results yield even smaller values for error measures. The result given below Table 7 is the ultimate τ_i values after parameter optimization.

Age group	Optimized Thau Value	Optimization conditions	
15-19	0.731	max generation	3000000
20-24	0.250	step size	0.001
25-29	0.250	Range	$(\tau_i \pm 0.05)$
30-34	0.343		
35-39	0.829		
40-44	0.857		
45-49	0.780	**MSE**	**0.0019**
Average	**0.5771**	**MAD**	**0.0351**

Table 7 Parameter optimization-II

Resulting τ_i distribution displays a U-shaped pattern with an average around 57%. Magnitude is consistent with the value estimated by TURKSTAT Time Usage Survey conducted in 2006. Shape of time allocation distribution gathered from optimization also seems reasonable. U-shape distribution means that at the beginning and at the last years of reproductive age period, people allocates higher proportion of their time to child care, whereas at the middle ages of reproductive period, they reduce the proportion allocated to child care. This situation can well be explained by the fact that people are at the peak levels of their careers between the years of 25 to 35, so, they have to allocate more time to work rather than child rearing.

5.2. MODEL RESULTS

Model results are gathered with the parameter set introduced in the preceding section. This part is devoted to the evaluation of the preliminary results and thus testing the model conceptually. We will examine whether the simulation run outputs are consistent with the conceptual model expectations. Time horizon of the trial run is 20 time steps, each of which consists of 5 years, so the total time horizon elapsed is 100 years.

Starting population is at a level around 72 million and goes up steadily throughout the simulation up to a level of 140 million.

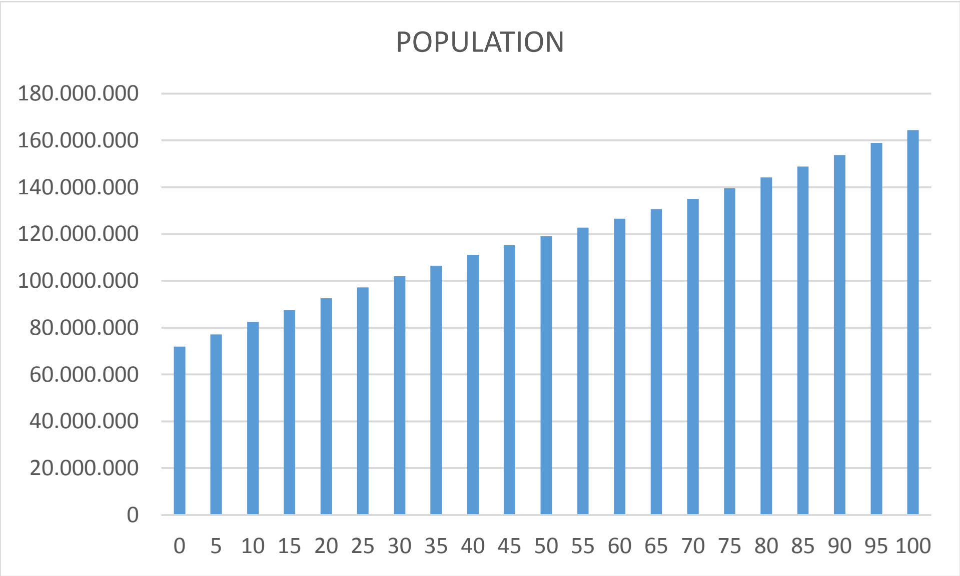


Figure 14 Population size across years

In addition to total population size, model results also yield the population distribution by age and sex. Change in the population structure through years is displayed in the age pyramids in Figure 15. Each bar in an age pyramid represents the relative population size of each sex at each age group. The bars at the bottom stand for the first age group, whereas the bars at the top represent the older age groups. As it is seen in the graphs, the representative population goes into a process of population aging. The bottom of the pyramid shrinks, while the top of it gets relatively larger. The population age structure still preserves the pyramid shape but it gets closer to a rectangle. Thus, the proportion of the old age population is getting larger. Meantime, the population is distributed symmetrically by sex.

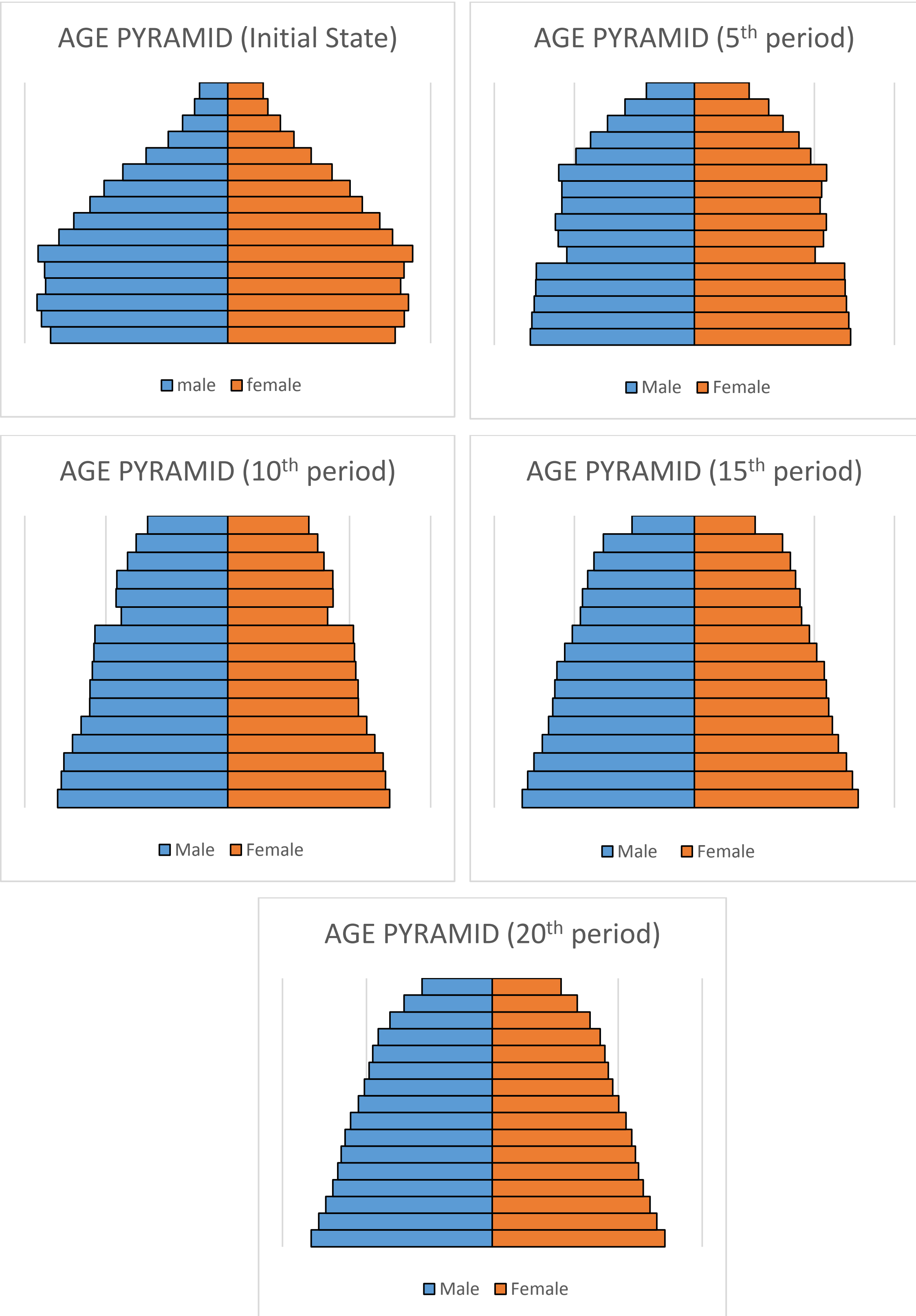


Figure 15 Age pyramids

TFR value face a slight decline followed by a sharp increase in first 30 years. After a while, it shoots steady-state and oscillates around the steady-state TFR value of about 2.4. Then, the oscillations get smaller as the time flows. The decline at the beginning show that parents have propensity to have higher quality children first; however the technological progress rate changes the trend afterwards and their weight on quantity gets relatively higher, paying less attention to the education investment.

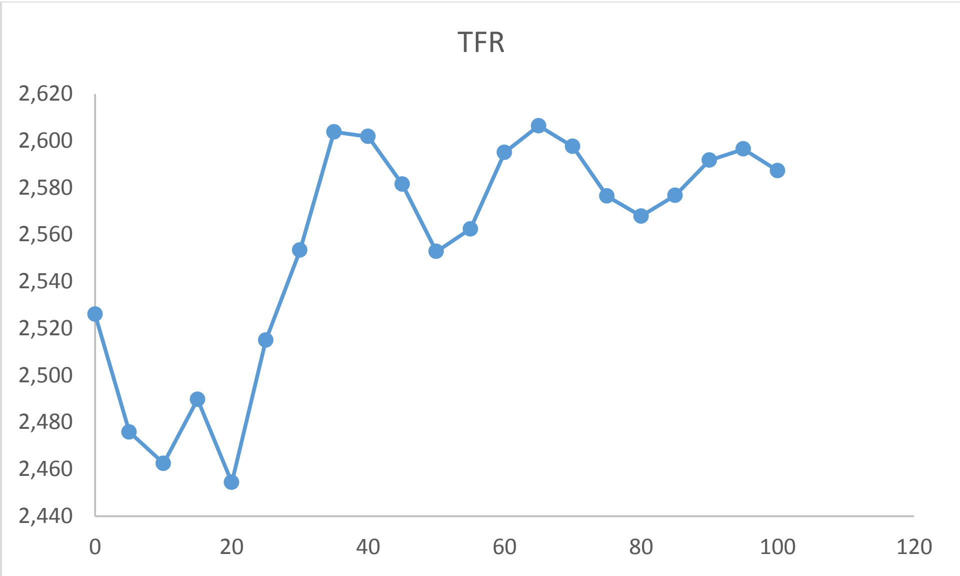


Figure 16 TFR across years

Figure 17 displays the ASFR rates. Each line in the figure represents the ASFR distribution for a single time period. According to the graph, ASFR rates reveal a bell-shaped distribution in parallel with reality, indicating that the motherhood age is mostly around 25-29. People prefer to have fewer children at younger and at older ages. Even income levels increase with age, they prefer fewer children with increasing opportunity cost of having child.

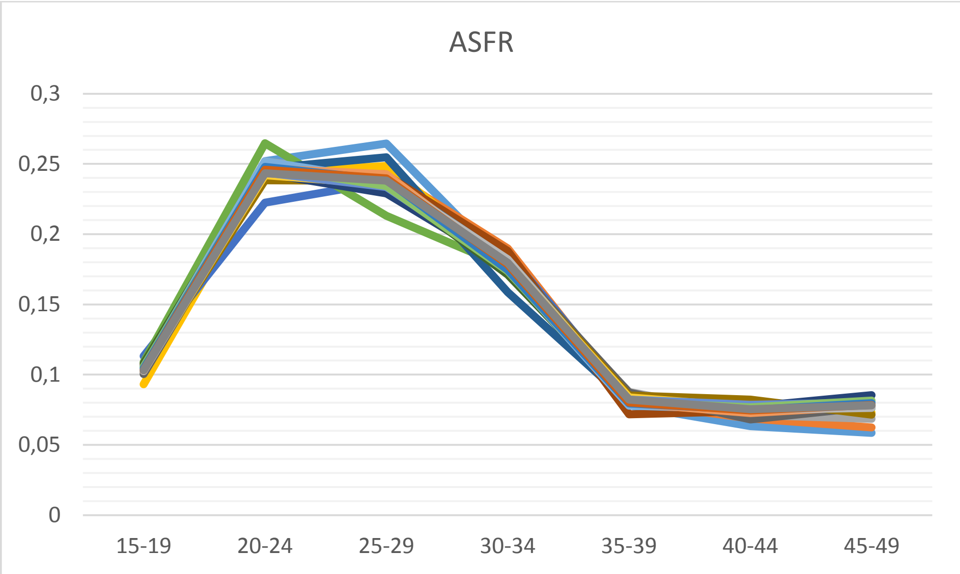


Figure 17 Age-specific fertility rate across years

Up to this point, we mentioned conventional demographic indicators. Henceforward, we turn our attention on the variables related with the technological development and human capital formation process. We start with the stock variable, technology. Figure 18 visualizes the exponential growth in technology level. The graph in Figure 19, on the other hand, tells that the technological progress rate is observed as non-negative and non-decreasing. A remarkable point is that technology level does not display any jumps or oscillations, because the unified growth sub-model does not include technology imports. The only source of technological improvement is the endogenous growth. Meantime, it can be inferred that the graphs of technological progress rate and TFR are complementary to each other. Parents do react to the changes in the technological progress rate with the changing tradeoff between the number of children and quality of children. Strictly speaking, decline in TFR values coincide with the increase in the technological progress rate. Likewise, the inverse of the oscillations in technological progress rate is observed in the graph of TFR (Figure 16).

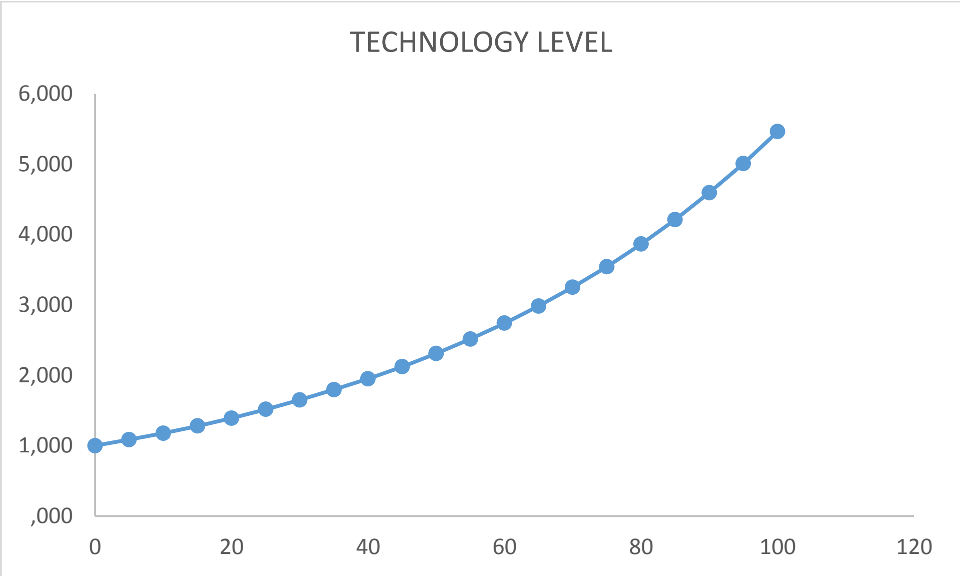


Figure 18 Technology level across years

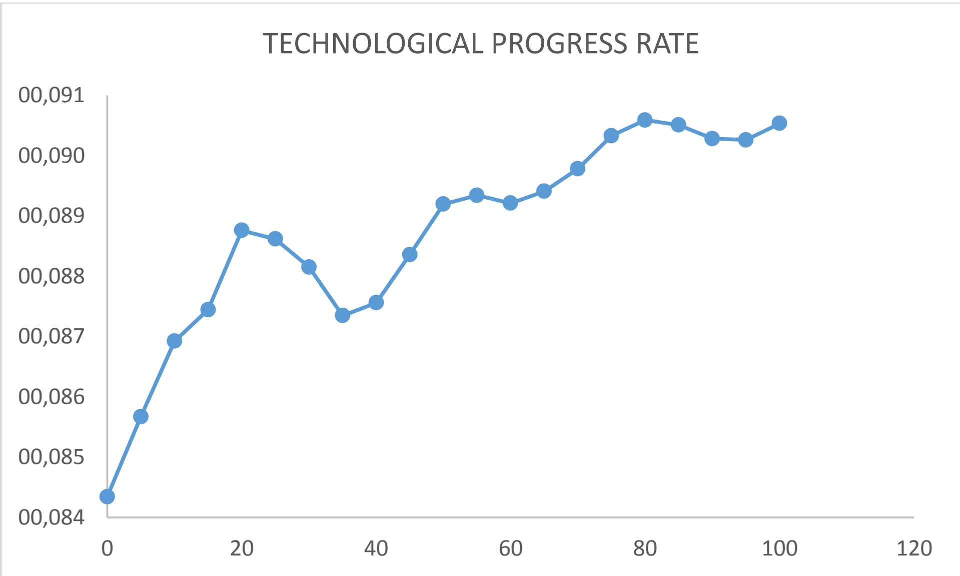


Figure 19 Technological progress rate across years

There are two possible ways that the education and human capital levels get affected from the technology outcomes: first, education level increases enough resulting in an increase in human capital levels; second, education level increases in an inadequate way so that knowledge get obsolete against technology and human capital levels either stay unchanged or even get lower.

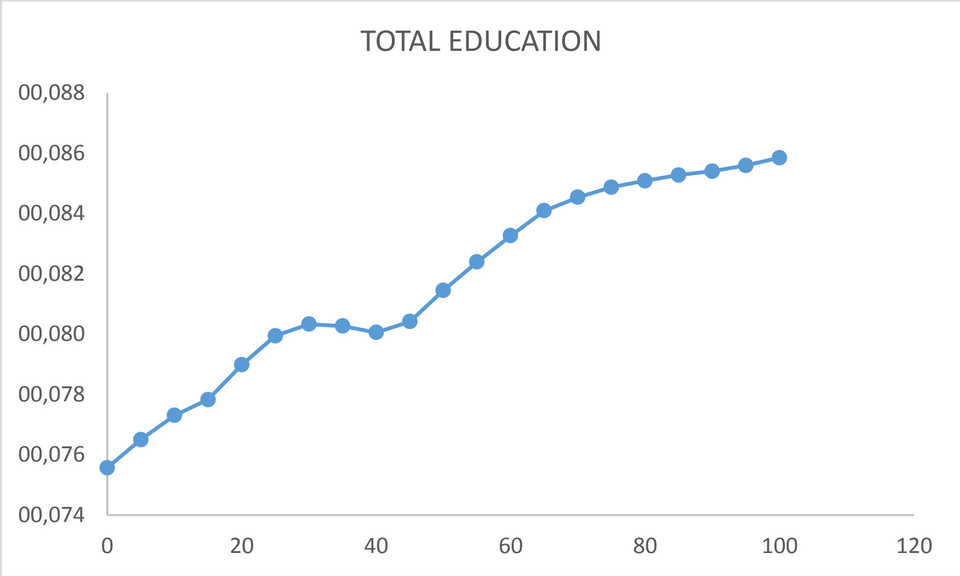


Figure 20 Total education level across years

As it is displayed in the Figures 20 and 21, boost in education level is not adequate to struggle with technological progress rate and human capital levels start to decline in consequence. Then, it hits steady state towards the end of time horizon. Ultimately, it can be concluded that any attempt to increase education level after steady state is just to struggle with the depreciative power of technological growth rate.

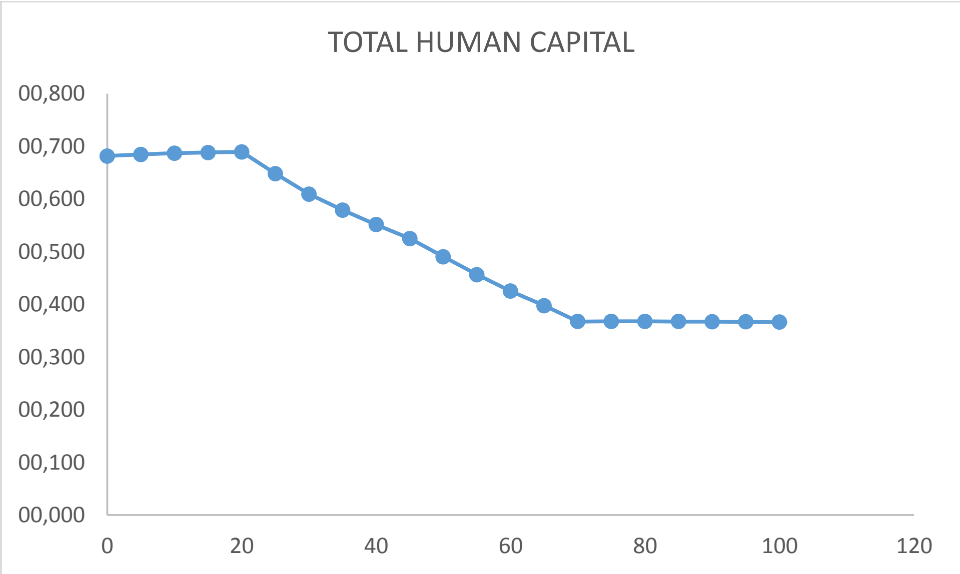


Figure 21 Total human capital level across years

On the other hand, age distribution of the education and human capital levels reveal an interesting outcome. Difference between the age groups disappear as the system reaches steady state towards the end of horizon. Age-specific education levels reach a steady state at higher levels, whereas human capital levels meet at a lower level being defeated across technological progress. As a result, ending population reaches a convergence in terms of education and human capital levels. Early year difference is actually stem from the initial state structure. In Turkish education data, older ages are less educated and younger ages are highly invested in terms of education purposes. As time passes, less educated older ages leave the system by mortality and highly educated young ages create a new population with an evenly distributed education level.

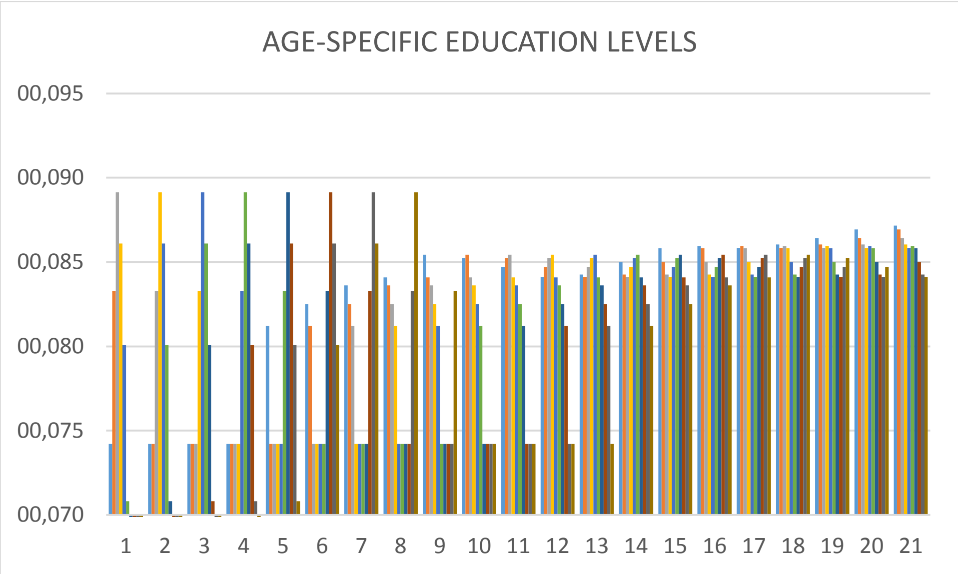


Figure 22 Age-specific education level across years

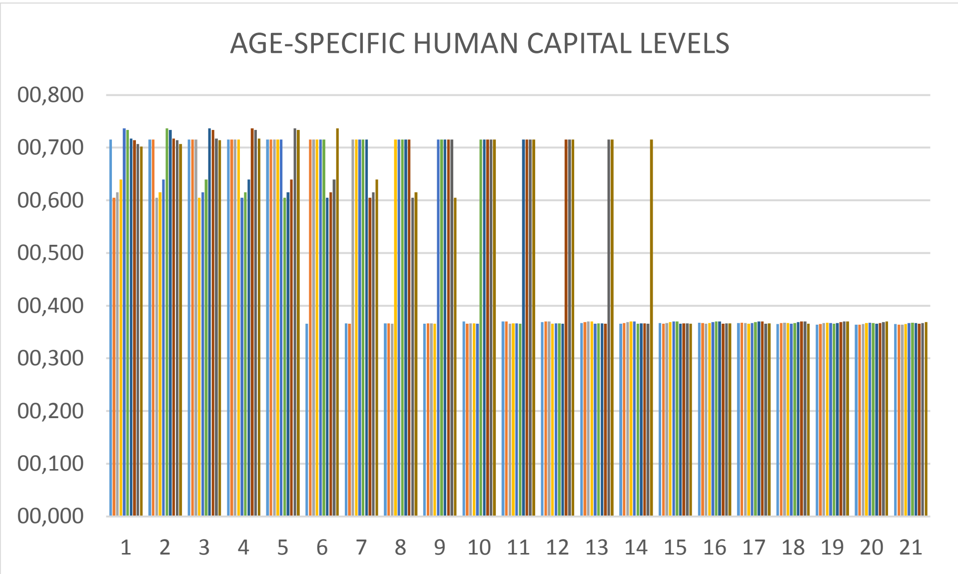


Figure 23 Age-specific human capital level across years

Impression of the trends in human capital, technology and population size on income levels is displayed in Figure 24. Through the simulation, average income level increases almost exponentially despite the declining human capital levels. Positive effect of increasing technology level surpass the negative effect of declining human capital level and increasing population size. Also, age-specific income levels get evenly distributed across age groups in parallel with the trends in age-specific human capital levels.

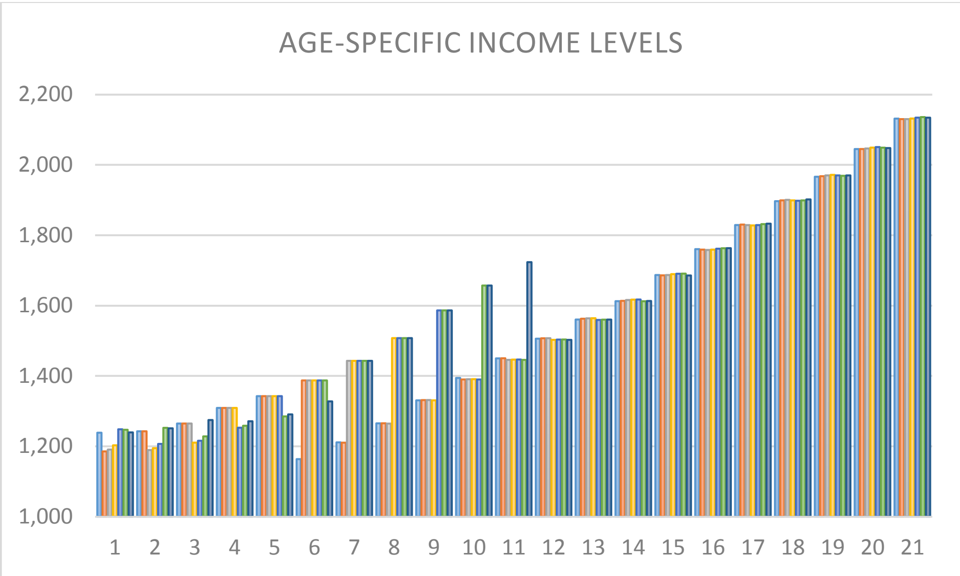


Figure 24 Age-specific income levels across years

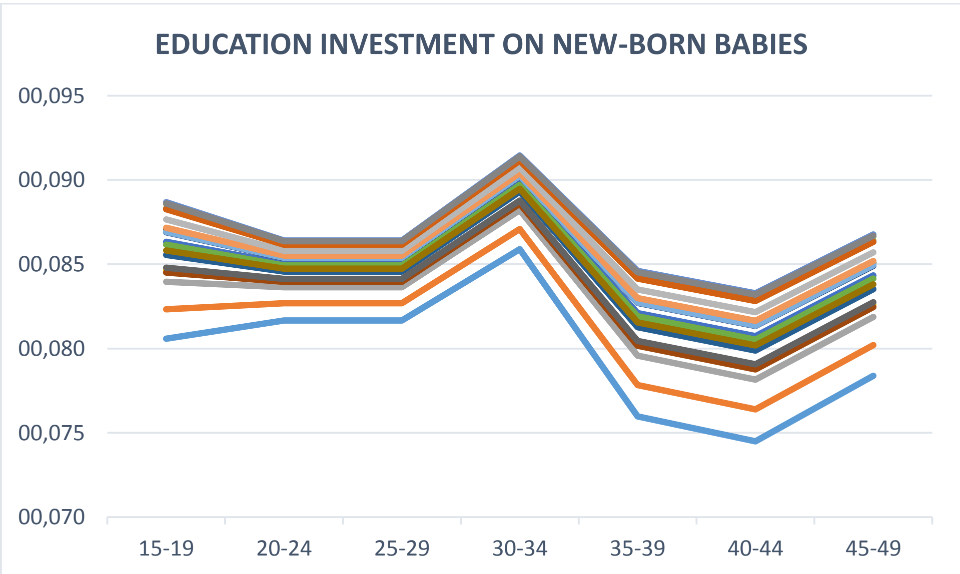


Figure 25 Age-specific education investment level on new-born babies

When we look at the education investment on new-born babies, the luckiest group is the new-born children of age group 30-34, who provide their children with the highest opportunity for education. This is the age where a breakdown is observed at fertility levels (see Figure 25) and a sharp decline begins. Accordingly, we can conclude that quantity-quality tradeoff changes dramatically in the age group of 30-34. Furthermore, the education investment levels of each age group increases with passing years with the same age distribution. Note that each line correspond to the age-specific education investment for each time step. The lowest blue one is for the first 5 years and the last highest one is for the last time period of 96-100 years.

After examining the model outcomes, we can conclude that the results display internal consistency in accordance with the causal relationships introduced in the conceptual model. Any single relationship introduced in the model can be tested empirically. Moreover, we do not face any behavior anomalies. On the contrary, the system reaches a steady state after a while. This indicates that the model outcomes will not display anomalies even in too long periods, yet, small oscillations may be observed from this point on. Shooting a steady-state and presenting small oscillations in the steady-state is actually a characteristic property of the quantitative implementation of G&W (Lagerlöf, 2006). Lagerlöf, however, states that oscillations are quite large that the empirical results are shared after some smoothing is made. In economic demography model, we do not face with such large oscillations. The results are introduced without any smoothing or further adjustment. As a result, we can conclude that the newly proposed economic demography model is a well extension of original G&W model. In addition, by preserving age and sex structure and giving age-specific results within 5 year time steps; it presents a refreshment in the demography literature integrated with the power of economic insight.

5.3. MODEL ASSESSMENT AND MODEL TESTING

A system dynamics model can be tested from two perspectives: validation and verification. Verification refers to the consistency between the conceptual model and the simulation model. It questions whether the simulation model is constructed in such a way that it perfectly reflects the conceptual model. On the other hand, validation explores whether the constructed model is an acceptable representation of the real system. There are two distinguishable model validation approaches in system dynamics: structural and behavioral. A valid system dynamics model should ensure that the internal structure of the model is a good representation of the real world. Moreover, it should also ensure that the model reveals a behavioral validity, that is, the outcomes of the model are also a reflection of the real world system. To summarize, validation stands for constructing the right model, while verification stands for doing that in the right way.

The model testing literature in system dynamics mainly focuses on model validity. Forrester and Senge (1980) defines validation as "the process of establishing confidence in the soundness and usefulness of a model" and as "the relevance to empirical environment". After discussing the concepts of model usefulness, the authors focus on how a modeler can achieve it. The authors introduce several tests to evaluate the validity of a model in three main categories. The first category is on examining the model structure, whereas the second and third categories explore the model behavior and consider policy implementation, respectively. After the study of Forrester and Senge (1980), several studies are published on model testing and validity, i.e. Barlas (1989, 1990, 1994, and 1996). Similar to Forrester and Senge (1980), Barlas also differentiated the structural validity and behavioral validity of the system dynamics models.

After all, Sterman (2000) proposed a synthesis on the literature of model testing in system dynamics. Sterman (2000) entitles the model testing as "Questions model users should ask but usually don't". The questions mentioned are grouped into four in parallel with the literature. The first group of questions is named as "Purpose, Suitability and Boundary". This group questions whether the boundary of the conceptual model is adequate and include the important relevant factors with respect to the purpose of the model. Moreover, it looks into the detail of endogenous and exogenous variables and checks whether the key factors are taken as endogenous. This first group of questions exactly explores the structural validity of the model. It asks what the purpose is and how the conceptual model reflects the reality in the scope of the given purpose.

The second group of questions is entitled as "Physical and Decision-making structure". The second group deals with the technical aspects of a system dynamics model and mainly focuses on the model verification. It examines whether the conceptual model is correctly transferred to the system dynamics simulation environment. It particularly examines whether the stock-flow structure of the model works properly without any violation of the law of matter conservation, whether the model reflects the relevant equilibrium or disequilibrium processes and whether the model accounts for the delays and distortions.

The third group of the questions is named as “Robustness and Sensitivity to Alternative Assumptions”. By means of this group of questions, the behavioral validity of the model is analyzed. Robustness is generally defined as the ability of tolerating perturbations. That is the ability to effectively perform when the variables or assumptions of the model is altered. Sensitivity, on the other hand, investigates the effect of changes in independent variables on dependent outcomes. In particular, parameters are changed systematically and outcomes are observed. A system dynamics model may expose numerical, behavioral or policy sensitivity. Numerical sensitivity accounts for the numerical changes in the model outcomes as a result of the changes in model parameters, while the behavioral sensitivity stands for the changes in behavioral patterns of the outcomes and lastly, the policy sensitivity refers to the political changes as a result of the parameter alteration.

Sterman (2000) names the last group of questions as “Pragmatics and Politics of Model Use”. This last group deals with the stage after modelling. It delves into the details about the cost of model run and model updates, examines the publication and documentation of the model and the model outcomes.

To summarize, Sterman (2000) recommends making the model assessment in four categories. First category is about the structural validity that examines the suitability and adequacy of the model boundary and the model content. Second category stands for the verification of the model that examines whether the system dynamics simulation model built reflects the conceptual model tested in the first category and whether its model dynamics work properly in the simulation run. The third model assessment category concentrates on the behavioral validity and analyzes the outcomes under changing conditions. Last category is about the period after the model run which comprises the documentation, publication and reproducibility. With respect to the categorization of Sterman (2000), first model assessment of structural validity is done implicitly throughout the text in the system dynamics representation part (see section 7.2). The structure of the model is analyzed and visualized with causal loop and stock-flow diagrams in a detailed way. The boundaries and endogenous and exogenous factors are discussed. Afterwards, the verification of the model is done through parameter calibration (see section 8) and base model run (for the results, see section 9). As a result of base model run, it is showed that the conceptual model presented in section 7.2 is successfully transferred into the computer environment with the parameters calibrated by the real life values. In the base model run, we faced neither a behavior anomaly nor an unexpected behavior and we concluded that the model run does not reveal any inconsistency with the conceptual model. Meantime, the procedures followed in the study is documented in a very detailed way. It is quite convenient to run the model on a conventional PC and anyone interested in the study can reproduce the same results provided with the documentation of the data and the details of the model structure. Moreover, if a model revision is required, it would be possible to make incremental changes upon the provided documentation. Hence, there is no doubt regarding the pragmatics and model use. Up to this point what we have not done is to analyze the behavioral validity of the model through robustness and sensitivity analysis. By this means, a detailed sensitivity analysis and extreme condition tests are conducted and they are presented in the next two sub-sections (section 10.1 and 10.2).

5.3.1. Extreme Condition Tests

In order to test the robustness of the model we first conducted extreme condition test regarding the technology sub-module. Importing technological know-how is a very common case in developing countries. In that case, technological development is not endogenous; but an external push in the technological progress is in action. From this view point, the model is subject to critics in terms of the endogenous technological development assumptions. If the model does not allow for the technology import case, which is very common in developing countries, the model would be restricted to developed countries only. However, if we numerically show that the model also works effectively in the case of technology import, we may end up with a conclusion that the proposed model has the property of generalizability. By this means, we built a test scenario in which endogenous technological development is interrupted every 4 periods and endogenous technological development progress rate is multiplied by 10 in a fictive way. The aim is to explore whether the key outputs of the model perform effectively in the case of external manipulations.

The manipulation on technological development is visualized in Figures 26 and 27.

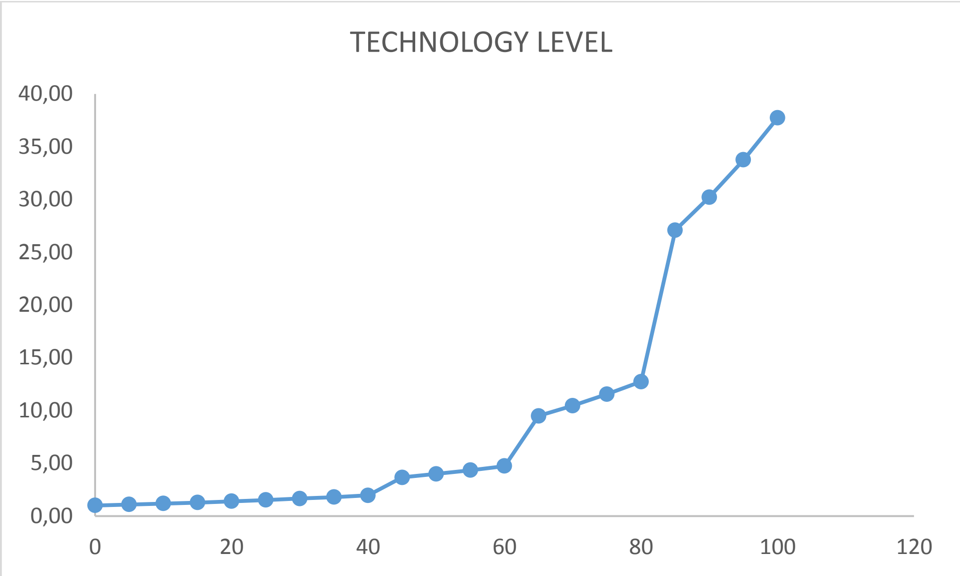


Figure 26 Technology level across years

As it is seen in the technology level graph, every 4 periods (i.e. 20 years) there is a jump in the technology level except the first 20 years, because the progress rate is so small and the effect of manipulation is negligible. Apart from the years in which technology import occurs, increase in the technological progress rate is observed to be very small relative to the imports (see Figure 10-2).

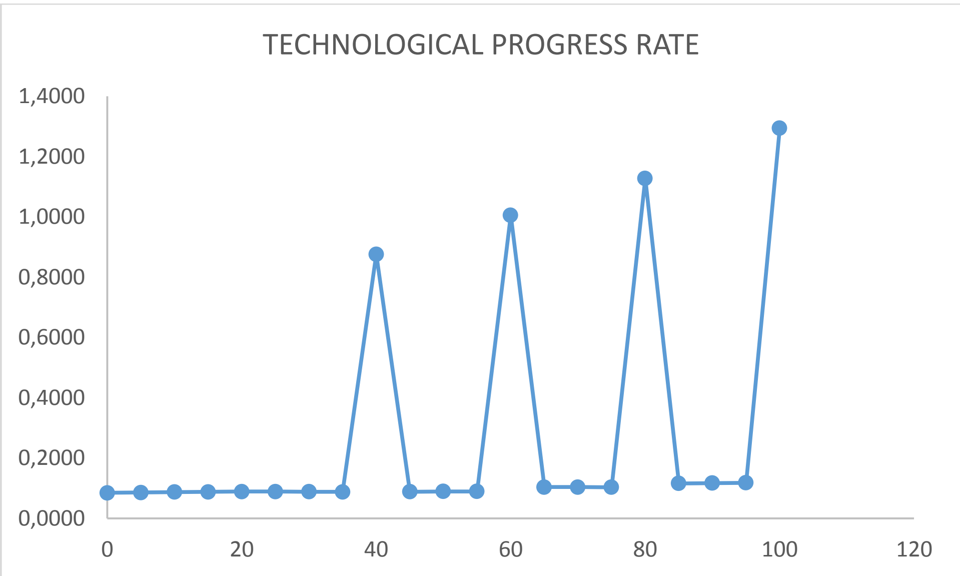


Figure 27 Technological progress rate across years

In a robust model, effects of the jumps in the technology level on fertility, population, education and human capital levels should be observable. Recall that there is a reinforcing effect of technological progress rate on education levels. Parents prefer quality over quantity in the case of high technological development and higher education levels are observed together with lower fertility rates. The outputs of the test scenario shows the expected outcome displayed in the following figures (Figure 28-29-30).

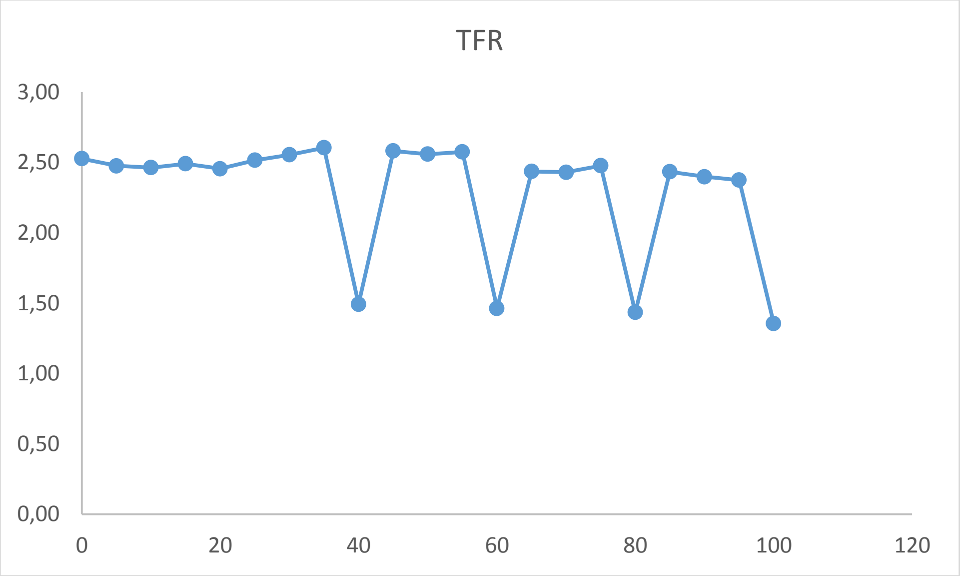


Figure 28 TFR across years

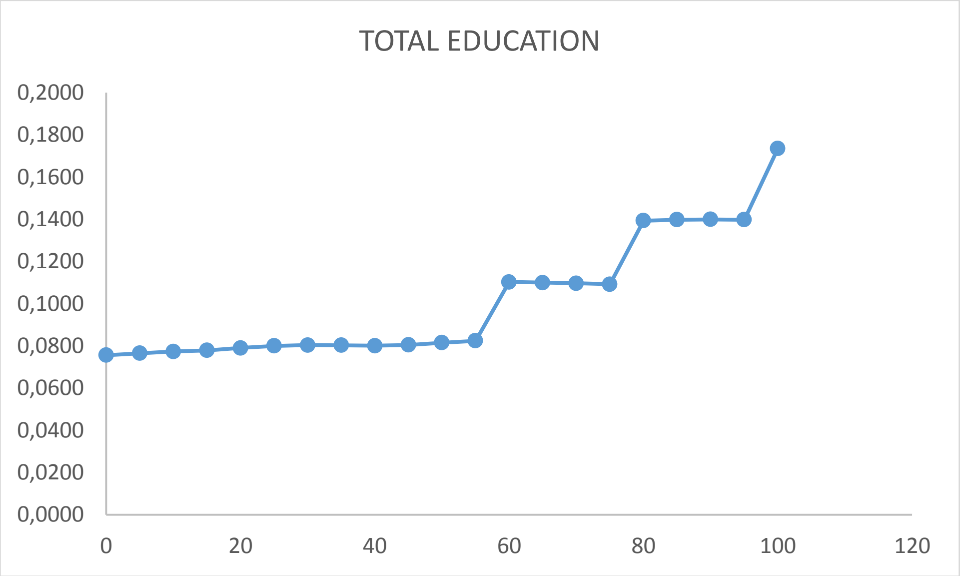


Figure 29 Total education level across years

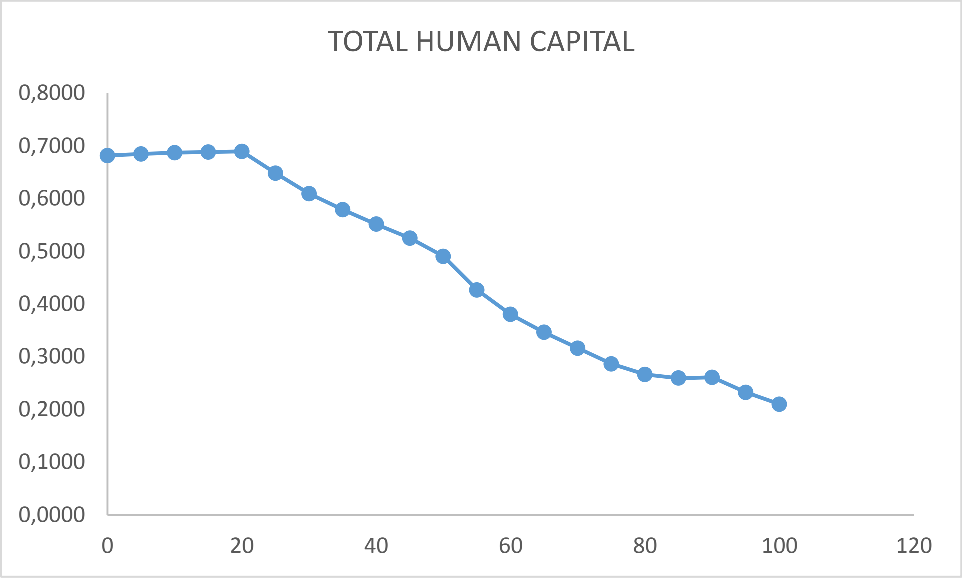


Figure 30 Total human capital level across years

As expected, jumps in the technological development are reflected as the sharp declines in total fertility rate and they result in a piece-wise function of total education level. The behavioral pattern of TFR observed in the original model run stay the same except the points of jumps and falls at manipulation years. On the other hand, age-specific education and human capital levels display changes in behavioral patterns with respect to the manipulations in technological development. In the base model, age-specific differences in levels of education and human capital disappear after a while and they got an even distribution across the age groups. However, in the test case of technology import, the cohorts born at the time of the import have higher levels of education and higher levels of human capital.

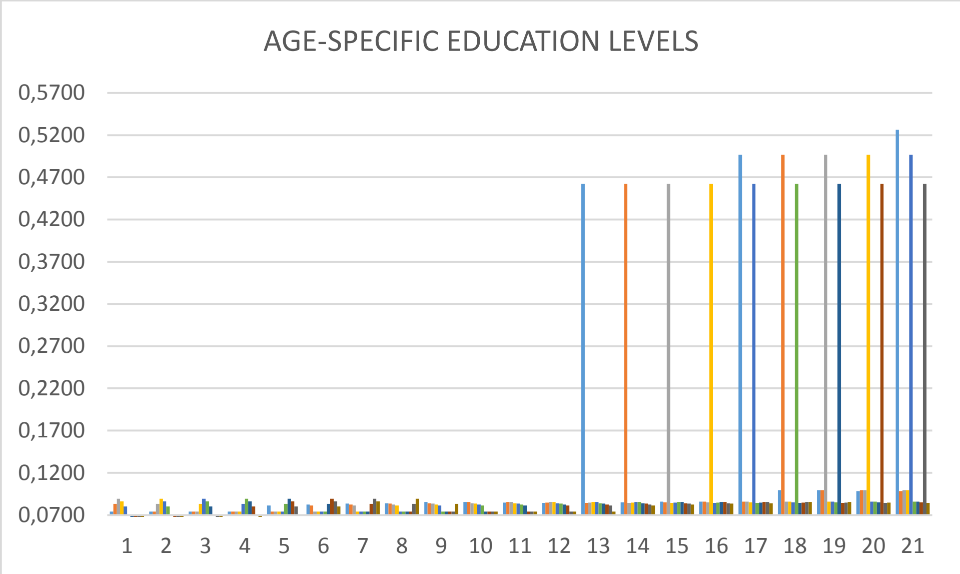


Figure 31 Age-specific education level across years

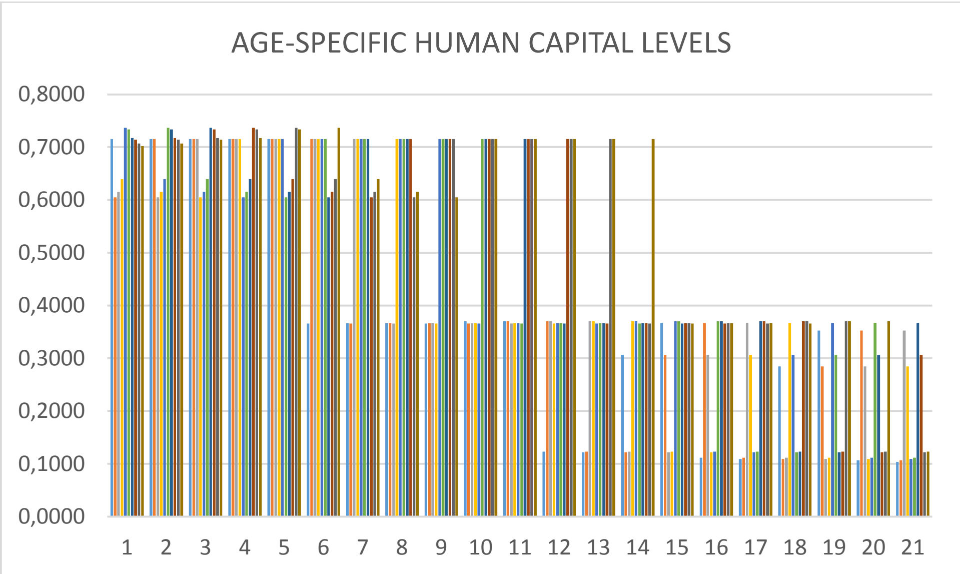
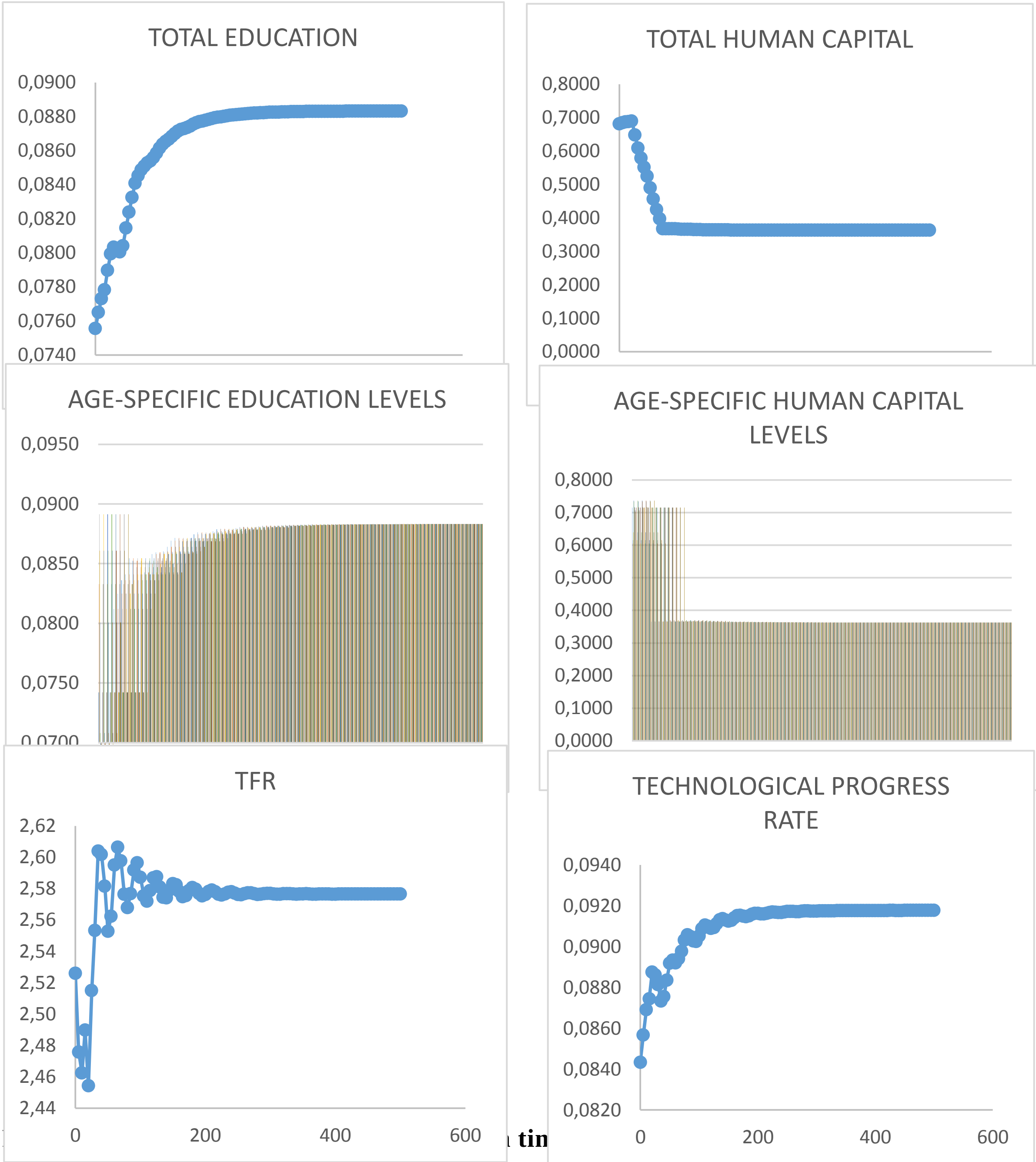


Figure 32 Age-specific human capital level across years

To summarize, the economic demography model reacts effectively in the case of technology import. There is no unexpected behavior observed in the key outputs of the model. Moreover, the behavior patterns of the key outputs do not change except for the specific manipulation instants. So, it can be concluded that the prosed model is quite robust against the external changes in technological development process. Hence, the economic demography model is said to be generalizable even for the developing countries as well as the developed countries.

Besides technology import scenario, we have also tested the model by running it on a very long time period of 500 years, i.e. 100 time steps of 5 years each. We observed that the model outputs apart from the increasing levels of population, income and technology, all reached a stable steady-state point around 100 years (see Figure 33). This fact can be interpreted in a way that the model loses its effectiveness at long time periods. In order to keep the effectiveness of the model sustainable, adopting dynamic parameter setting instead of static one would be a solution if and only if the model outputs are sensitive to parameter changes. By this means, the sensitivity analysis done for behavioral validity would also be beneficial to explore the usefulness of the idea of dynamic parameter setting.



5.3.2. Sensitivity Analysis

For the sake of behavioral validity we conducted a univariate sensitivity analysis. Univariate means that the sensitivity is done separately for each parameter. Varying alternatives of parameter combinations are not considered. For each parameter that is subject to the analysis, we defined a minimum and maximum value and observed the model outcomes by systematically changing the values of each parameter in between the determined range. Starting from the minimum value, base model is run for each parameter value that is increased by an increment till the maximum value.

Sensitivity analysis is done for the parameters of **labor share (α)**, **weight on fertility in the utility function (γ)** and **educational part of τ (ρ)**. Parameter values used in the base model run are taken as the mean values and minimum and maximum values of the sensitivity ranges are determined around the mean values by ∓50% change. The systematic parameter change increment is determined as 0.01. Moreover, **subsistence level of consumption ($\tilde{c}$)** is also subject to the analysis. Since it is an age-specific parameter, there is not a single range traced in the parameter values; but a unified percentage range between 0% and 200% is determined for all age-groups. Accordingly, systematic change of age groups' subsistence level of consumption is assumed to start from 0% of the value used in the base model run and continue till the 200% of that value with an increment of 5% in each run. The sensitivity design is summarized in Table 8 with the detail of specific numerical values.

Parameter	Value in base model	Percent change	Minimum value	Maximum value	Change increment	Number of run cases
α	0.2620	∓50%	0.13	0.39	0.01	27
γ	0.6708	∓50%	0.34	0.99*	0.01	66
ρ	0.1946	∓50%	0.10	0.29	0.01	20
$\tilde{c}_1$	0.3849	(0%-200%)	0	0.7698	5%	41
$\tilde{c}_2$	0.4299	(0%-200%)	0	0.8598	5%	41
$\tilde{c}_3$	0.4265	(0%-200%)	0	0.8531	5%	41
$\tilde{c}_4$	0.4551	(0%-200%)	0	0.9102	5%	41
$\tilde{c}_5$	0.4582	(0%-200%)	0	0.9163	5%	41
$\tilde{c}_6$	0.5064	(0%-200%)	0	1.0127	5%	41
$\tilde{c}_7$	0.5469	(0%-200%)	0	1.0938	5%	41

Table 8 Design of sensitivity analysis

*(*Maximum value is restricted by the maximum allowable value of the parameter.)*

The results of the sensitivity analysis is presented in the upcoming sections. Numerical results are displayed in the succeeding figures (Figure 34-48). The solid black lines in the graphs correspond to the simulation outcome of the minimum parameter value that is subject to sensitivity analysis, whereas the solid red lines stand for the simulation outcomes of the maximum parameter value.

5.3.2.1. Sensitivity Analysis w.r.t Labor Share (α)

First-hand dependent variable of **labor share (α)** is the income level (see the equation 6.10). According to the equation 6.10, human capital and technology levels have positive effects on income level, whereas the population size has a negative effect. Any increase in the labor share (α) reinforces the positive effect of human capital level, whereas it weakens the positive effect of technology level and negative effect of population size. Theoretically it is impossible to come up with a conclusion whether the income level will increase or decrease with increasing level of labor share (α). Experimental results show that as labor share (α) increases, income levels shift downwards (Figure 34). Note that the simulation outcomes for the minimum value of (α) is showed with the solid black line, whereas the simulation outcome for the maximum value of (α) is displayed by the solid red line. With diminishing income levels, total fertility rates also decrease with a declining rate till 15^{th} period and display no sensitivity afterwards, because income levels increase continuously through the horizon and after it reaches a threshold value, the equation of number of children per person (6.11) dictates that the number of children per person is equal to the constant γ. This fact means that total fertility rate is not effected by the income level after a threshold value (Figure 35). In parallel with declining TFR values, total population size also declines (Figure 36). Both the TFR values and the total population size are less sensitive to the values below the mean value of (α). Below figures demonstrate the sensitivity results of average income level, total fertility rate and total population size with respect to the changes in labor share. Each line in the graphs represent a test run of one alternative parameter value of labor share. Any parameter apart from this is assumed to be constant at the level that is used in the base model run. Converging lines denote the diminishing sensitivity, whereas diverging ones show the increasing sensitivity.

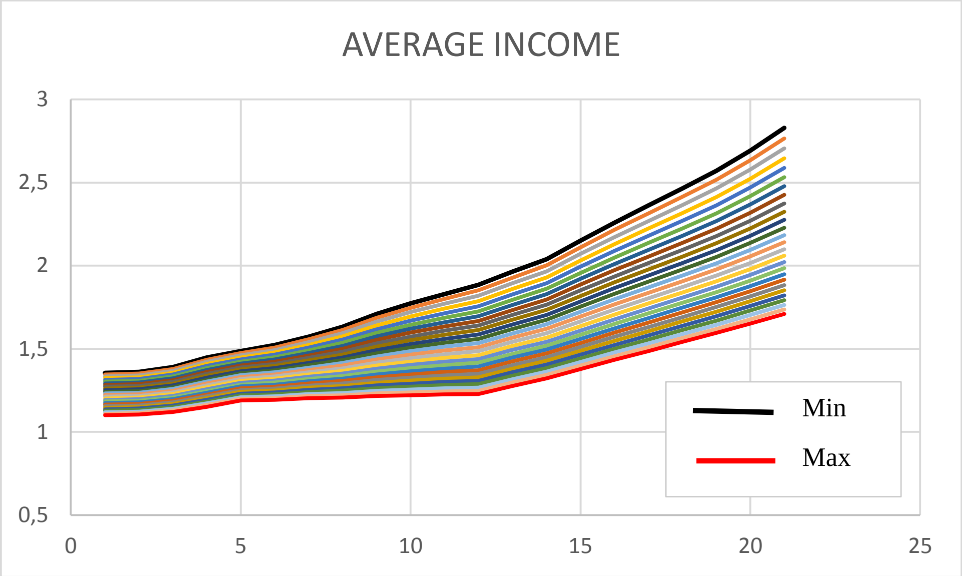


Figure 34 Sensitivity of average income w.r.t α

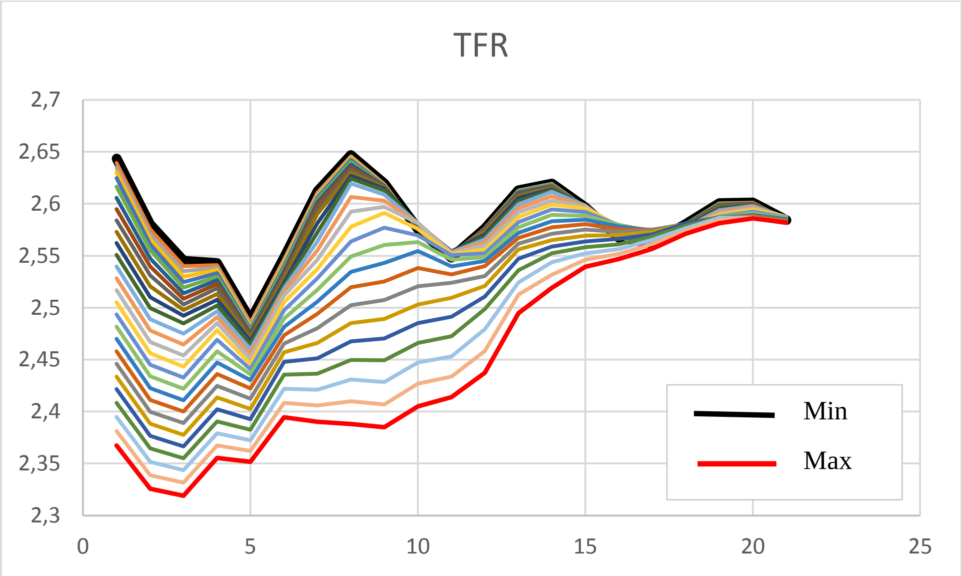


Figure 35 Sensitivity of TFR w.r.t α

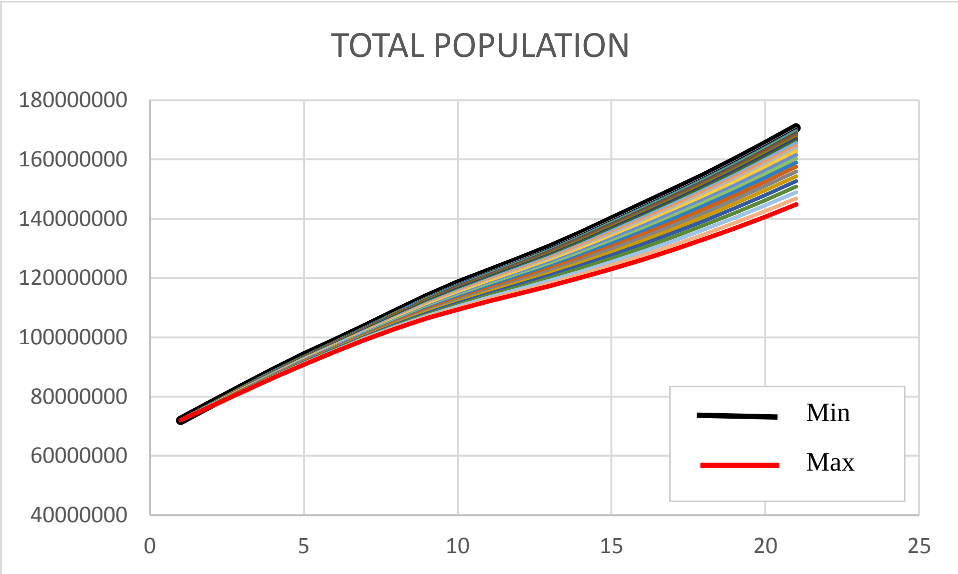


Figure 36 Sensitivity of total population size w.r.t α

5.3.2.2. Sensitivity Analysis w.r.t Weight on Fertility in the Utility Function ($\boldsymbol{\gamma}$)

The second parameter that is subject to the sensitivity analysis is **weight on fertility in the utility function ($\boldsymbol{\gamma}$)**. It has a direct effect on the decision maker's utility function which is a positive function of number of children, human capital level of the children and the consumption of the decision maker beyond the children (equation 6.1). An increase in weight on fertility in the utility function (γ) results in a reinforcement in the positive effect of number of children and human capital level of children, while it has a dampening effect on the positive effect of own consumption on the utility function. Conceptually, rising γ level means that utility gathered from children is appreciated more. Experimental results show that the rising level of γ results in higher TFR values as expected (Figure 37). Total fertility rate is sensitive to the parameter change in each period and at each value of γ. On the other hand, when we look at the sensitivity of education, we observe that it is insensitive at the beginning of the horizon, i.e. between the 1st and 5th period, but it gets affected afterwards (Figure 38). Till the 13th period education level increases with the increasing level of γ and this pattern changes in the opposite way starting from 13th period. This results can be interpreted as the change in the quantity-quality tradeoff. After 13th period, they prefer to increase the utility gathered from children in a cheaper way and they compensate quality with quantity. Reflections of the aggregate effect of the changes in fertility and education are also visible in human capital and average income levels. While human capital level is insensitive to the rise in γ for the periods between 0-5 and 15-20, it displays a downward shift in between (Figure 39). Meantime, average income levels go down and flatten with increasing γ (Figure 40). The change in the quantity-quality tradeoff of parents may be associated with the fact that the human capital is insensitive to change in γ after a certain time frame. Lastly, total population is also affected with an increasing sensitivity especially towards the end of horizon (Figure 41). The population size diminishes at low levels of γ as a result of TFR values below the replacement level (i.e. 2.1). It keeps the upward trend for the values of γ higher than the mean value.

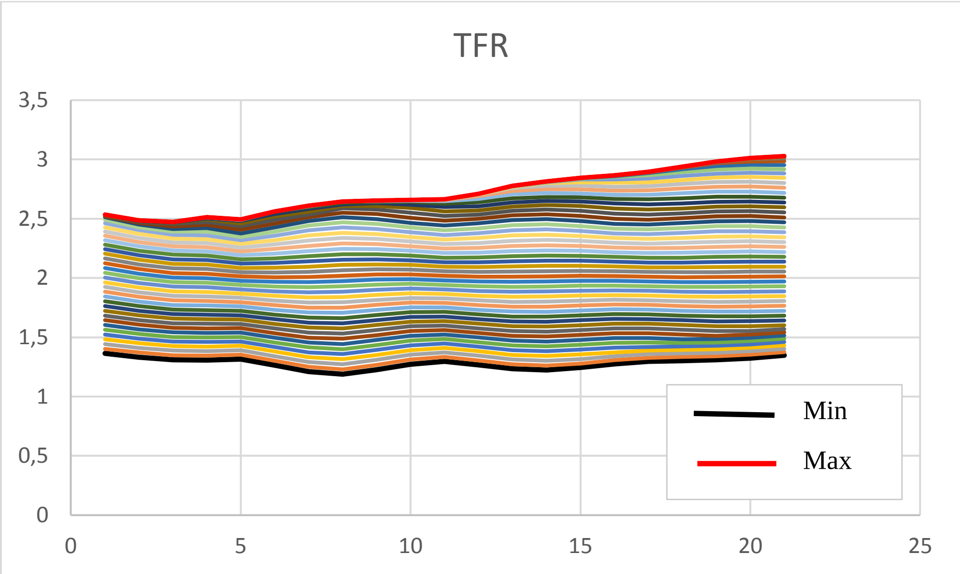


Figure 37 Sensitivity of TFR w.r.t γ

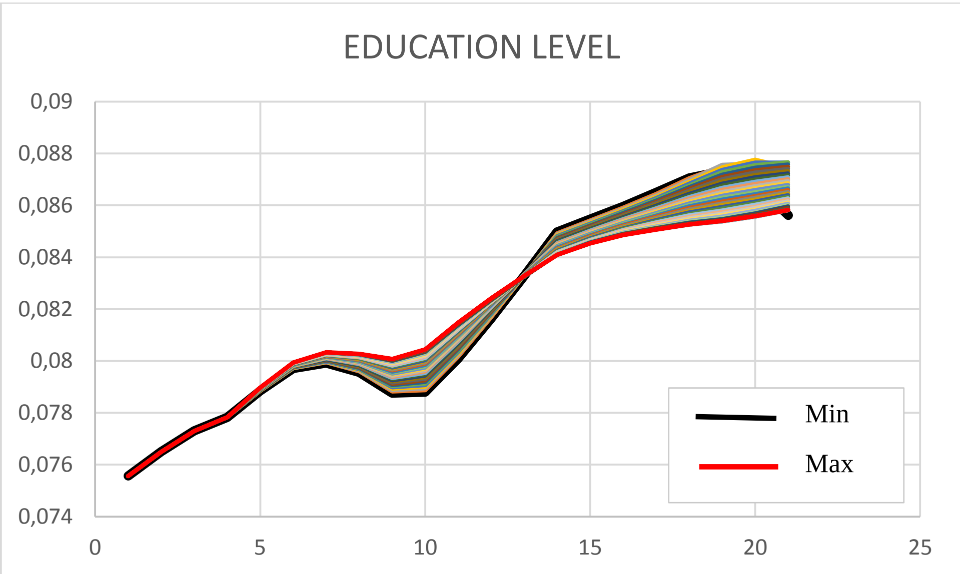


Figure 38 Sensitivity of education level w.r.t γ

Consequently, it is observed that key outputs are quite sensitive to the changes in the parameter of weight on fertility in the utility function, γ. However, they do not show any behavioral sensitivity except the total population size and they keep the original behavioral patterns.

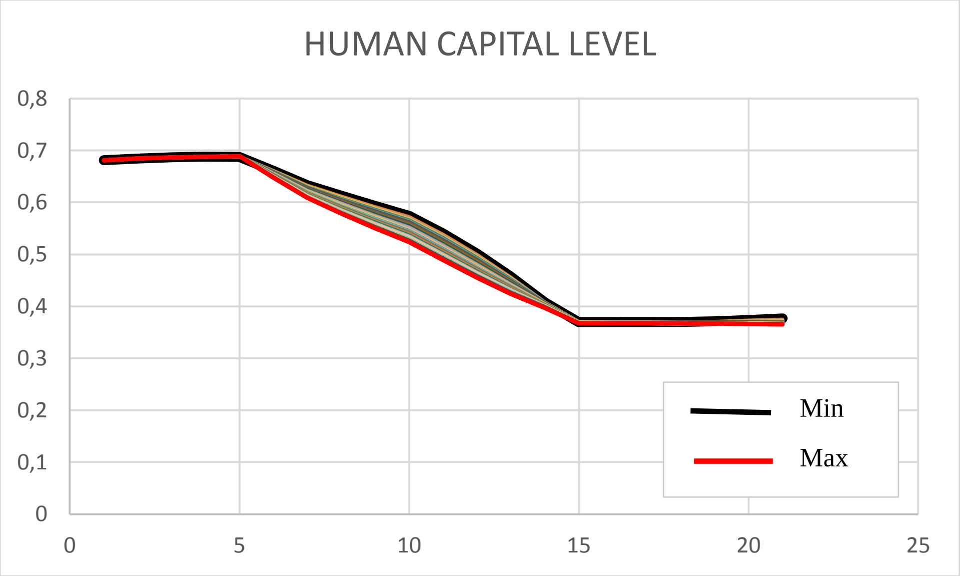


Figure 39 Sensitivity of human capital level w.r.t γ

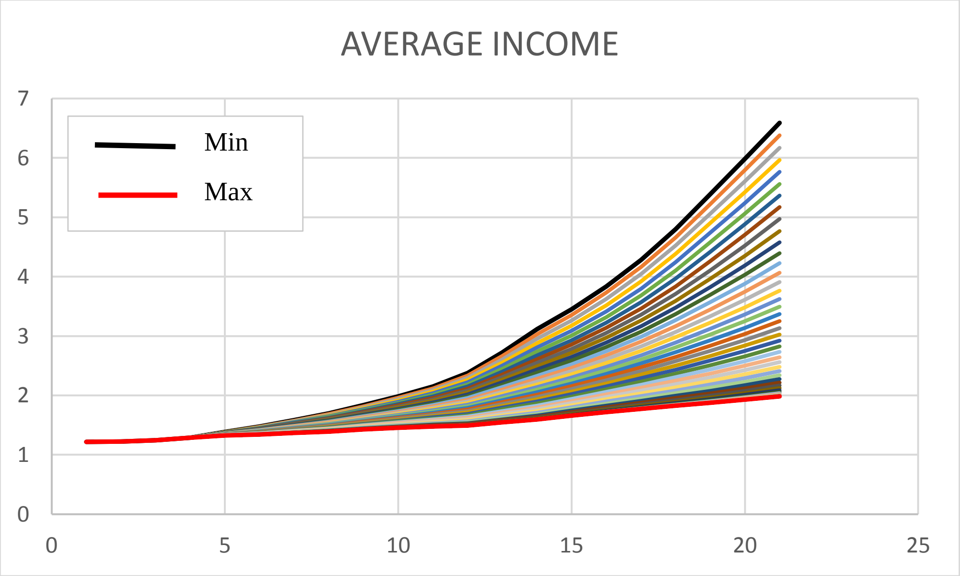


Figure 40 Sensitivity of average income level w.r.t γ

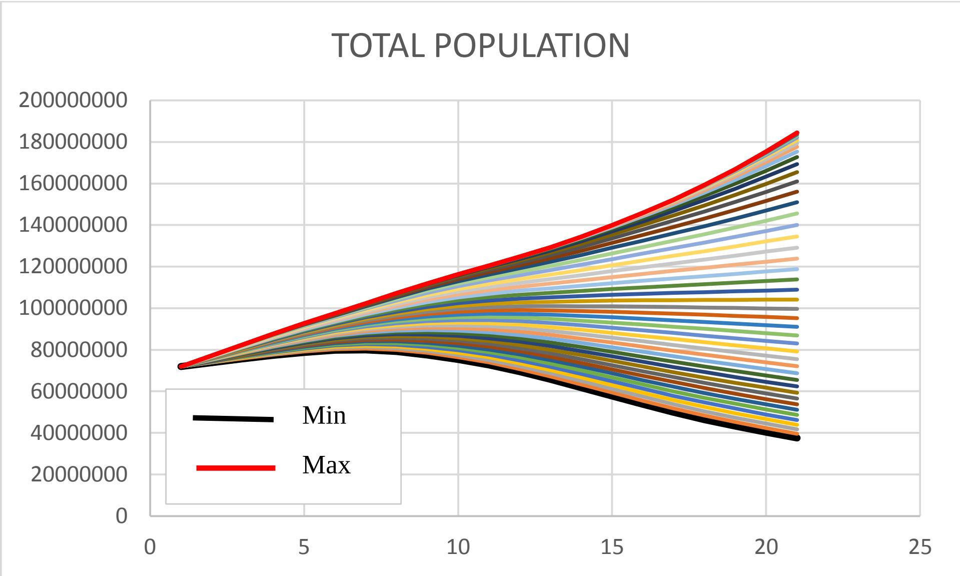


Figure 41 Sensitivity of total population size w.r.t γ

5.3.2.3. Sensitivity Analysis w.r.t Educational Part of $\boldsymbol{\tau}$ ($\boldsymbol{\rho}$)

Another parameter that is subject to sensitivity analysis is **the educational part of $\boldsymbol{\tau}$ ($\boldsymbol{\rho}$)**. This parameter has a direct relationship with the human capital level, education level and the technological progress rate. Theoretical framework strictly tells that the human capital level and technological progress rate are a positive function of ρ (equations 6.5 and 6.8 respectively), while education level attributed to the child has an inverse relationship with ρ (equation 6.6). Experimental results reveal a high sensitivity for total education level starting at 5th period (Figure 42). Increasing ρ values results in a downward shift in education level and also a trend change from upward to downward after the parameter value of 0.15. Moreover, total education level displays a behavioral pattern change with respect to the changes in parameter ρ compared to the base model run. Due to declining education levels, technological progress rates also decline despite the positive effect of increasing ρ (Figure 43). Combined effect of education and technological progress rate on human capital is observed in a way that human capital level shifts upward with increasing ρ value (Figure 44). Although the education level shifts downward, lower technological progress rates dampens the deterioration effect and shifts the human capital upward. The sensitivity of human capital level is observed to be more sensitive in periods 0-5 and 15-20.

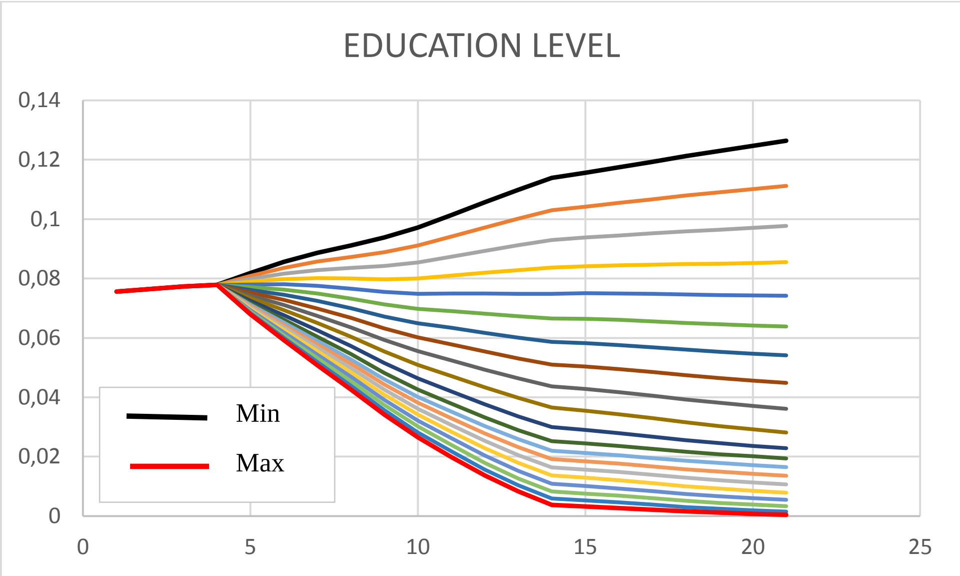


Figure 42 Sensitivity of education level w.r.t ρ

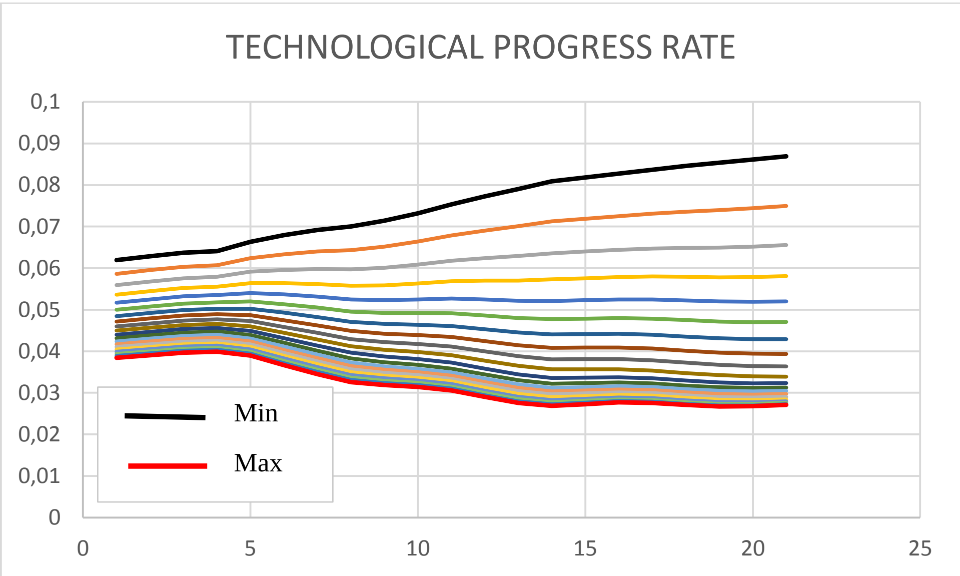


Figure 43 Sensitivity of technological progress rate w.r.t ρ

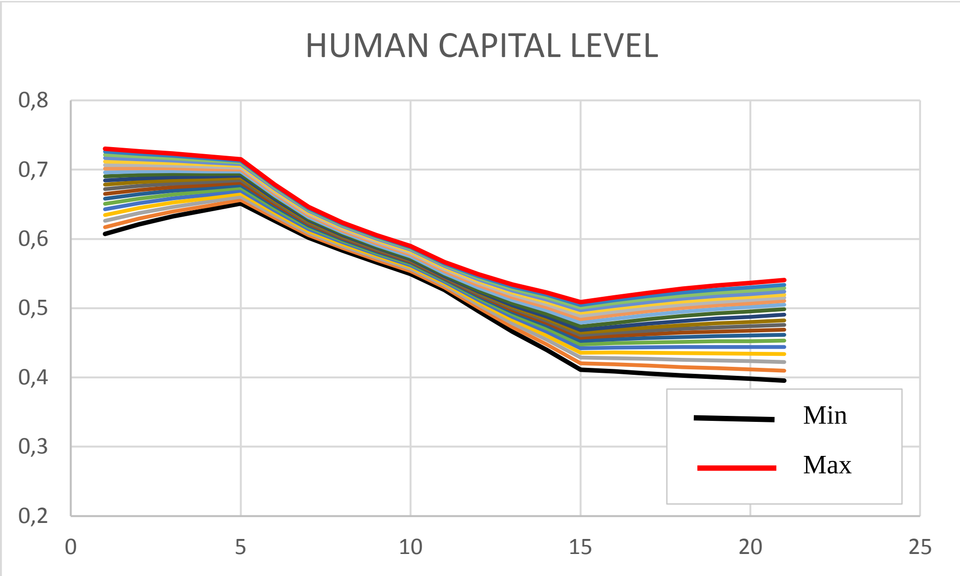


Figure 44 Sensitivity of human capital level w.r.t ρ

As a consequence of the diminishing education levels for increasing values of ρ, TFR values shift upward with increasing ρ (Figure 45). However, this pattern changes after the 13th period where the graph of the education level flattens.

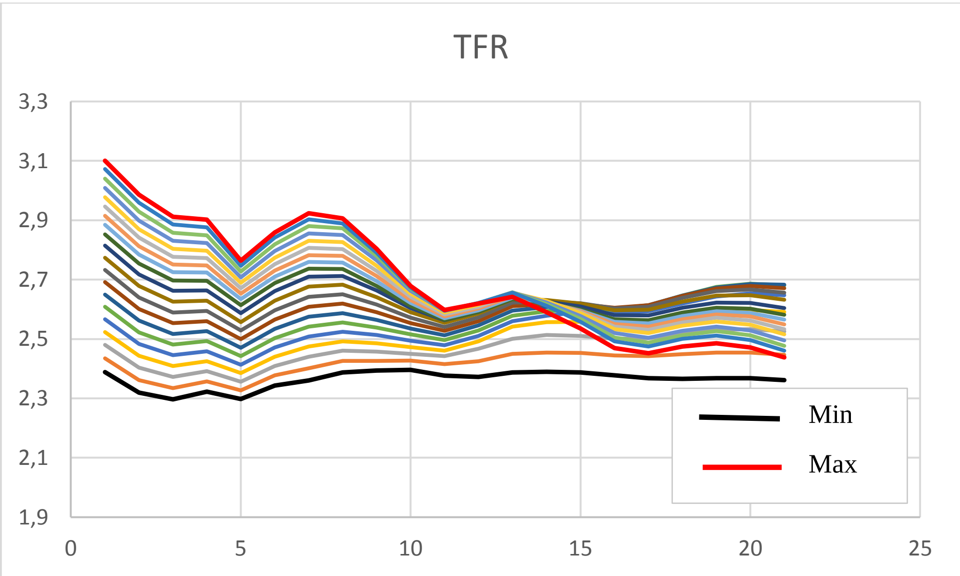


Figure 45 Sensitivity of TFR w.r.t ρ

Last remarkable point in the sensitivity of ρ is that the average income levels shift downward with increasing ρ despite the increasing human capital levels. The equation of income (equation 6.10) dictates that the income is a positive function of human capital but it is a negative function of total population. As the experimental results show, the negative effect of total population surpasses the positive effect of human capital on income levels (Figure 46).

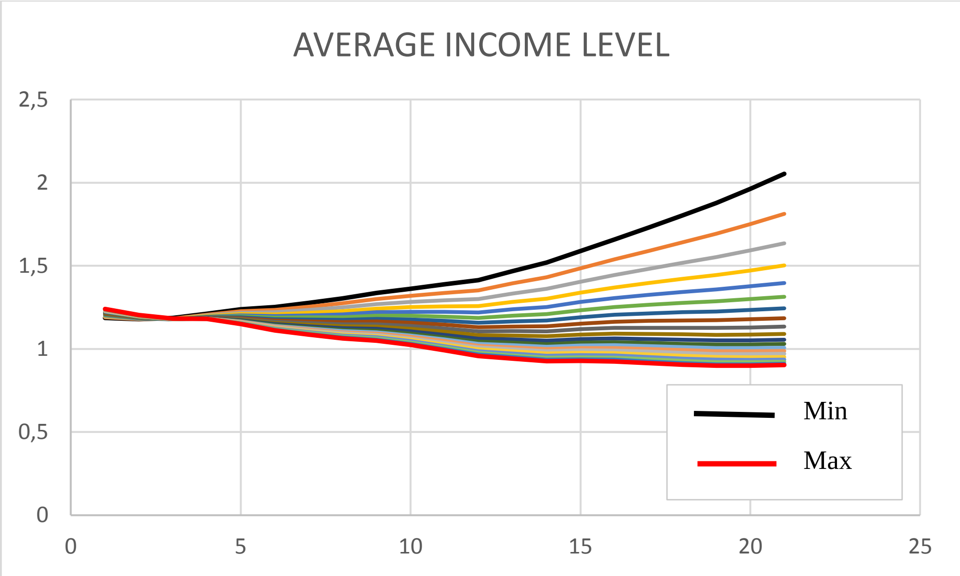


Figure 46 Sensitivity of average income level w.r.t ρ

5.3.2.4. Sensitivity Analysis w.r.t Subsistence Level of Consumption ($\tilde{c}$)

Lastly, the model sensitivity is investigated with respect to **subsistence level of consumption ($\tilde{c}$)**. The most notable effect is observed in fertility. According to the equation of number of children per person (equation 6.11), subsistence level of consumption effects the choice of fertility by determining whether the consumption constraint is binding or not. Below the mean value of $\tilde{c}$, subsistence level of consumption has no effect on the TFR value (Figure 47). Above the mean value, on the other hand, TFR values shift downward with increasing level of $\tilde{c}$. After 12th period the TFR values at different levels of $\tilde{c}$ converges and fertility loses the sensitivity with respect to $\tilde{c}$. Besides lowering TFR values, decision makers also lower education level with increasing $\tilde{c}$, because they have to allocate more resources on satisfying the higher level of subsistence (Figure 48). Nevertheless, after 12th period the trend changes just in the opposite way. It is not a coincidence that both the convergence of TFR and the trend change in the education level occur in the same period. This can be explained by the fact that the average income in the model increases throughout the horizon and it reaches an adequate value to afford both for higher education and higher fertility levels.

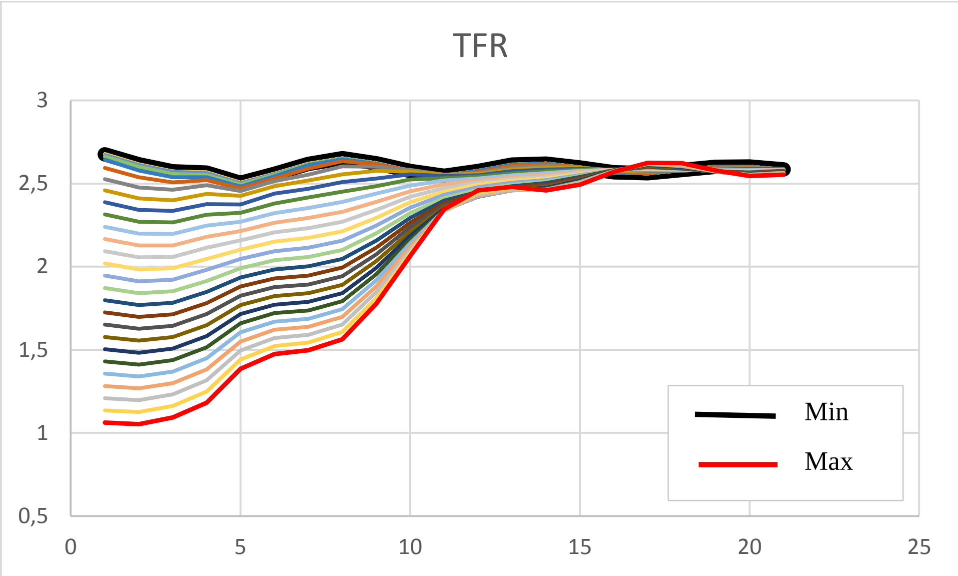


Figure 47 Sensitivity of TFR w.r.t $\tilde{c}$

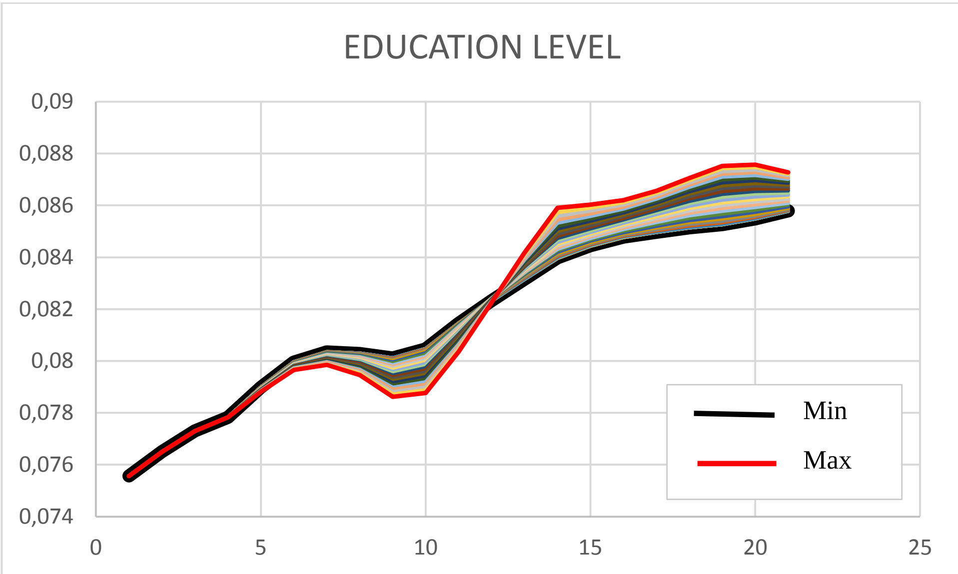


Figure 48 Sensitivity of education level w.r.t $\tilde{c}$

In the light of the sensitivity results, we can conclude that the model dynamics move in coherence under different parameter settings. The behavioral patterns are either preserved as in the base model run or can be explained in consistency with the model dynamics. Hence, the model is said to pass the test of behavioral validity. Furthermore, by means of showing that the model is highly sensitive to parameter changes, we can conclude that working with dynamic parameter setting would increase the effectiveness of the model for the long planning periods.

CONCLUSION

In this thesis, we developed an economic demography model that assumes endogenous fertility, education, human capital and technology. The model is based on the ground breaking study of Galor and Weil's (2000) unified growth model. Unified growth model proposes an economic growth model that is able to explain the history of humanity starting from Malthusian era till the sustained economic growth period. However, covering such a long time span, it has certain limitations. In the unified growth model, individuals are assumed to live for two periods, each of which has a length of approximately 20 years. It is assumed that each individual in the first age group survives to the next age group; and each individual in the second age group dies out to the next period. This model ignores the realistic mortality assumptions of age-specific survivorship and also the life spans longer than 40 years. On the other hand, the model also neglects the population age and sex structure. As it is mentioned earlier in the document, last stage of the demographic transition is population aging and it is impossible to make a comment on the population age structure with the unified growth theory. The economic demography model is developed to tackle those limitations of the unified growth model.

Economic demography model is developed in such a way that it works out in integration with the conventional demographic tool of cohort component modelling. Thus, it keeps the population age and sex structure under the assumption of the age-specific survival rates. The individuals are assumed to decide on the number of children they will have and the education level of the children as well as their own consumption level so as to maximize their utility subject to a budget constraint. The choices of individuals triggers the conceptual model dynamics and make up the country level macro indicators of fertility, education and human capital levels in interaction with the endogenous technology. The economic development model is further tested experimentally with system dynamics methodology upon the parametric form of the unified growth model proposed by Lagerlöf (2006). The experimental results and the model assessment demonstrate that our economic demography model works out in coherence.

Providing a deep insight on the economic and demographic conditions over the short to medium term, our model proposal presents a professional decision support tool for the public policy makers. On the other hand, this model also paves the way for future development.

A remarkable critic about the model is about the endogenous technology. The model ignores the external effects on technology level and the experimental results yield almost a smooth and continuous development in technology. However, in developing countries it is very common to experience jumps in technology level by technology import. Also, according to the economic conditions, it is possible to observe a technology downscale by factory close downs. In order to catch up with these real life technology dynamics, any attempt to improve the conceptual model and/or the parameter setting may be a contribution.

Another criticism may be about the fact that the model reaches a steady state after a while and loses its effectiveness. The results of the sensitivity analysis reveal that the model is highly parameter sensitive. Hence implementing a dynamic parameter setting instead of the stationary setting would be a good solution for the sake of long-term efficacy.

Lastly, the model calibration is done based on various data sources and the data used belongs to neither a single country nor a single year. Moreover, we performed parameter optimization in the case that we could not find a reliable data source. So, the population simulated is a representative fictive population rather than a population of a real world country. As a consequence, the model is said to have no prospective power; but it rather explores the causal relationships among the variables. In that sense, it would be a valuable contribution to enhance the data sources and test the prospective power and the historical replicability of the proposed model as a future work.

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APPENDIX I: Sample Model Life Table

(It displays the survival rates for the age groups starting from birth to 85^+ according to the values of life expectancy at birth between 89 and 100 with 1 year increments. The original table includes the age groups till 130^+ and values of life expectancy at birth starting from 20. This table represents a part of the original one.)

Age specific probabilities of dying by sex, model life table and level of life expectancy

United Nations Population Division, *World Population Prospects: The 2010 Revision.*

(Type: CD West Sex: Female)

Sum of q(x,n)	E(0)											
age	89	90	91	92	93	94	95	96	97	98	99	100
0	0.00349042	0.00303526	0.00262551	0.00225833	0.00193088	0.00164034	0.00138396	0.00115904	0.00096295	0.00079315	0.00064718	0.00052270
1	0.00070051	0.00060893	0.00052656	0.00045278	0.00038703	0.00032871	0.00027728	0.00023217	0.00019286	0.00015883	0.00012959	0.00010465
5	0.00032155	0.00027776	0.00023862	0.00020380	0.00017298	0.00014585	0.00012209	0.00010142	0.00008355	0.00006821	0.00005515	0.00004411
10	0.00024603	0.00021120	0.00018026	0.00015292	0.00012889	0.00010788	0.00008962	0.00007386	0.00006034	0.00004884	0.00003913	0.00003100
15	0.00038925	0.00033206	0.00028158	0.00023727	0.00019858	0.00016500	0.00013604	0.00011123	0.00009012	0.00007231	0.00005741	0.00004505
20	0.00055580	0.00047414	0.00040207	0.00033880	0.00028356	0.00023561	0.00019426	0.00015883	0.00012869	0.00010326	0.00008198	0.00006433
25	0.00068056	0.00058057	0.00049233	0.00041486	0.00034722	0.00028851	0.00023787	0.00019449	0.00015759	0.00012644	0.00010038	0.00007877
30	0.00083993	0.00071654	0.00060764	0.00051203	0.00042855	0.00035609	0.00029359	0.00024005	0.00019450	0.00015606	0.00012390	0.00009723
35	0.00112598	0.00096058	0.00081460	0.00068644	0.00057453	0.00047740	0.00039361	0.00032183	0.00026077	0.00020923	0.00016611	0.00013035
40	0.00163307	0.00139323	0.00118154	0.00099567	0.00083337	0.00069249	0.00057096	0.00046684	0.00037827	0.00030352	0.00024096	0.00018910
45	0.00259339	0.00221266	0.00187657	0.00158144	0.00132371	0.00109998	0.00090697	0.00074160	0.00060092	0.00048218	0.00038281	0.00030041
50	0.00398063	0.00339656	0.00288088	0.00242798	0.00203242	0.00168900	0.00139271	0.00113881	0.00092281	0.00074049	0.00058790	0.00046137
55	0.00624587	0.00533024	0.00452159	0.00381120	0.00319063	0.00265174	0.00218673	0.00178820	0.00144911	0.00116286	0.00092327	0.00072459

APPENDIX I (CONTINUED)

Sum of q(x,n)	E(0)											
age	89	90	91	92	93	94	95	96	97	98	99	100
60	0.01004212	0.00857207	0.00727317	0.00613163	0.00513406	0.00426752	0.00351959	0.00287843	0.00233280	0.00187212	0.00148649	0.00116666
65	0.01979329	0.01709811	0.01468647	0.01253936	0.01063789	0.00896334	0.00749738	0.00622211	0.00512023	0.00417509	0.00337077	0.00269214
70	0.03904623	0.03414993	0.02970882	0.02569978	0.02209885	0.01888146	0.01602269	0.01349752	0.01128102	0.00934856	0.00767596	0.00623969
75	0.07610113	0.06744413	0.05947114	0.05216204	0.04549377	0.03944070	0.03397501	0.02906714	0.02468613	0.02080001	0.01737612	0.01438148
80	0.14573184	0.13106793	0.11731173	0.10446707	0.09253108	0.08149456	0.07134244	0.06205425	0.05360471	0.04596423	0.03909949	0.03297398
85	0.25707285	0.23506696	0.21394905	0.19378126	0.17461613	0.15649630	0.13945437	0.12351303	0.10868525	0.09497464	0.08237588	0.07087519

APPENDIX II: DISSERTATION ORIGINALITY REPORT

HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
THESIS/DISSERTATION ORIGINALITY REPORT

HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
TO THE DEPARTMENT OF BUSINESS ADMINISTRATION

Date: 30/06/2015

Thesis Title / Topic: A System Dynamics Approach to Economic Growth Model from a Demographic Perspective: An Economic Demography Model Proposal

According to the originality report obtained by my thesis advisor by using the Turnitin plagiarism detection software and by applying the filtering options stated below on **30/06/2015** for the total of **106** pages including the a) Title Page, b) Introduction, c) Main Chapters, and d) Conclusion sections of my thesis entitled as above, the similarity index of my thesis is **6%**.

Filtering options applied:

1. Approval and Decleration sections excluded
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3. Quotes included
4. Match size up to 5 words excluded

I declare that I have carefully read Hacettepe University Graduate School of Social Sciences Guidelines for Obtaining and Using Thesis Originality Reports; that according to the maximum similarity index values specified in the Guidelines, my thesis does not include any form of plagiarism; that in any future detection of possible infringement of the regulations I accept all legal responsibility; and that all the information I have provided is correct to the best of my knowledge.

I respectfully submit this for approval.

30.06.2015
Date and Signature

Name Surname:	Gözdem DURAL SELÇUK
Student No:	N10143819
Department:	Department of Business Administration
Program:	Business Administration Ph. D. program
Status:	☐ Masters ☒ Ph.D. ☐ Integrated Ph.D.

ADVISOR APPROVAL

APPROVED.

Assist. Prof. Dr. Hüseyin TUNÇ

HACETTEPE ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
YÜKSEK LİSANS/DOKTORA TEZ ÇALIŞMASI ORJİNALLİK RAPORU

HACETTEPE ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İŞLETME ANABİLİM DALI BAŞKANLIĞI'NA

Tarih: 30/06/2015

Tez Başlığı / Konusu: Ekonomik Büyüme Modeline Demografik Bakış Açısı ile Bir Sistem Dinamiği Yaklaşımı: Bir Ekonomik Demografi Modeli Önerisi

Yukarıda başlığı/konusu gösterilen tez çalışmamın a) Kapak sayfası, b) Giriş, c) Ana bölümler ve d) Sonuç kısımlarından oluşan toplam **106** sayfalık kısmına ilişkin, **30/06/2015** tarihinde tez danışmanım tarafından Turnitin adlı intihal tespit programından aşağıda belirtilen filtrelemeler uygulanarak alınmış olan orijinallik raporuna göre, tezimin benzerlik oranı **%6**'dır.

Uygulanan filtrelemeler:

1- Kabul/Onay ve Bildirim sayfaları hariç,
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Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Çalışması Orjinallik Raporu Alınması ve Kullanılması Uygulama Esasları'nı inceledim ve bu Uygulama Esasları'nda belirtilen azami benzerlik oranlarına göre tez çalışmamın herhangi bir intihal içermediğini; aksinin tespit edileceği muhtemel durumda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim.

Gereğini saygılarımla arz ederim.

30.06.2015

Tarih ve İmza

Adı Soyadı:	Gözdem DURAL SELÇUK
Öğrenci No:	N10143819
Anabilim Dalı:	İşletme
Programı:	İşletme doktora programı
Statüsü:	☐ Y.Lisans ☒ Doktora ☐ Bütünleşik Dr.

DANIŞMAN ONAYI

UYGUNDUR.

Yrd. Doç. Dr. Hüseyin TUNÇ

APPENDIX III: ETHICS BOARD WAIVER FORM FOR THESIS WORK

HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
ETHICS BOARD WAIVER FORM FOR THESIS WORK

HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF BUSINESS ADMINISTRATION TO THE DEPARTMENT PRESIDENCY

Date: 26/06/2015

Thesis Title / Topic: A System Dynamics Approach to Economic Growth Model from a Demographic Perspective: An Economic Demography Model Proposal

My thesis work related to the title/topic above:

1. Does not perform experimentation on animals or people.
2. Does not necessitate the use of biological material (blood, urine, biological fluids and samples, etc.).
3. Does not involve any interference of the body's integrity.
4. Is not based on observational and descriptive research (survey, measures/scales, data scanning, system-model development).

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I respectfully submit this for approval.

26.06.2015
Date and Signature

Name Surname:	Gözdem DURAL SELÇUK
Student No:	N10143819
Department:	Department of Business Administration
Program:	Business Administration Ph. D. program
Status:	☐ Masters ☒ Ph.D. ☐ Integrated Ph.D.

ADVISER COMMENTS AND APPROVAL

Assist. Prof. Dr. Hüseyin TUNÇ

HACETTEPE ÜNİVERSİTESİ
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HACETTEPE ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İŞLETME ANABİLİM DALI BAŞKANLIĞI'NA

Tarih: 26/06/2015

Tez Başlığı / Konusu: Ekonomik Büyüme Modeline Demografik Bakış Açısı ile Bir Sistem Dinamiği Yaklaşımı: Bir Ekonomik Demografi Modeli Önerisi

Yukarıda başlığı/konusu gösterilen tez çalışmam:

1. İnsan ve hayvan üzerinde deney niteliği taşımamaktadır,
2. Biyolojik materyal (kan, idrar vb. biyolojik sıvılar ve numuneler) kullanılmasını gerektirmemektedir.
3. Beden bütünlüğüne müdahale içermemektedir.
4. Gözlemsel ve betimsel araştırma (anket, ölçek/skala çalışmaları, dosya taramaları, veri kaynakları taraması, sistem-model geliştirme çalışmaları) niteliğinde değildir.

Hacettepe Üniversitesi Etik Kurullar ve Komisyonlarının Yönergelerini inceledim ve bunlara göre tez çalışmamın yürütülebilmesi için herhangi bir Etik Kuruldan izin alınmasına gerek olmadığını; aksi durumda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim.

Gereğini saygılarımla arz ederim.

26.06.2015
Tarih ve İmza

Adı Soyadı:	Gözdem DURAL SELÇUK
Öğrenci No:	N10143819
Anabilim Dalı:	İşletme
Programı:	İşletme doktora programı
Statüsü:	☐ Y.Lisans ☒ Doktora ☐ Bütünleşik Dr.

DANIŞMAN GÖRÜŞÜ VE ONAYI

Yrd. Doç. Dr. Hüseyin TUNÇ

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