LUND UNIVERSITY

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Economic Growth in Sweden, 1870-2000

Essay on Human Capital Contribution

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Abstract: In this paper, we analyze the role which human capital played in Swedish economic growth over the late nineteenth-twentieth centuries. It has been shown that Swedish development over the considered period may be divided into three sub-periods, which have particular features when it comes to interrelations between human capital and economic growth. In the first sub-period (1888-1933), the Lucasian growth regime was likely to be dominating, that is, the rate of economic growth was defined by the rate of human capital accumulation. After 1934 economic growth switched to the Romerian mode, that is, the rate of economic growth was defined by already accumulated level of human capital. When it comes to the third sub-period (1971-2000), we could not specify the dominating growth regime based on the methodology suggested in this research. Regression analyses have shown that in general over 1870-2000 human capital had the significant, positive effect on economic growth; however, size and significance of the effect are highly vulnerable to regression specification.

Keywords: economic growth, human capital, Sweden, Lucas, Romer, endogenous growth models, 'new growth theories'

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I. INTRODUCTION

The so-called 'Solow residual puzzle' (only one seventh proportion of an output growth was attributed to growth in physical capital and labor in 1957 seminal study by Solow) made it clear that economic growth may not be considered solely in terms of physical capital and labor inputs. This stimulated a great amount of empirical work aiming at diminishing the role of residual by extending theoretical framework in general, and looking for new factors of economic growth in particular.

One more often criticized feature of the neo-classical growth theory is its exogenous character – an economic growth rate in the conventional Solow-Swan model (Solow 1956, 1957; Swan 1956) is determined by a rate of technological progress which is not directly observable. Therefore, some attempts were made to endogenize economic growth in theoretical models, that is, to make a long-run growth being explained within a model rather than determined exogenously.

Both developments led to establishment of the so-called 'new growth theories' in the late 1980s–early 1990s (Lucas 1988; Romer 1990), which by introducing a new type of capital – namely, human capital – tried to model an endogenous mechanism behind economic growth. In this paper we will employ these theories in order to analyze relationships between human capital and economic growth in Sweden over almost one and a half century period, namely, between 1870 and 2000.

Swedish case is interesting in several ways.

First, in the period from 1850 onwards, Sweden demonstrated one of the highest rates of economic growth in the world with an annual rate of 2,67 per cent in 1850-2000 (Maddison 2009), and turned from a poor agrarian country on European periphery into one of the world's wealthiest nations (in 2010 Sweden had eighth highest GDP per capita according to the World Bank (2012) data).

Second, Sweden is one of the leaders in terms of human capital development – Human Development Index 2011 ranks Sweden as the world's tenth country with the highest level of human capital (UNDP 2011).

Comparing these two facts makes it possible to conclude that human capital could play an important role in Swedish growth processes. One can argue that this conclusion is rather far-fetched. However, Martynovich (2010) showed that during the period of 1870-2000 a long-term relationship was established between the levels of human capital in the economy and GDP so that one-percent increase in the level of human capital added 2,19 per cent to the GDP level[1]. Besides that, study suggested that it was the level of human capital which caused GDP increase and not vice versa.

Finally, recently developed Lund University Macroeconomic and Demographic Database (LU-MADD; Krantz and Schön 2007; Ljungberg and Nilsson 2009) provides us with the newly estimated national historical accounts as well as human capital stocks for more than one hundred year period. While current empirical research on relationships between economic growth and human capital is mostly covering processes taking place after 1960, employing the long-run historical data may help to perform further validation of theoretical models as well as lead to better understanding of the nature of relationships between human capital and economic growth.

While both models of Lucas (1988) and Romer (1990) consider human capital to be one of the major determinants of economic growth, they define two growth regimes which differ in the mechanisms underlying this determination. Particularly, while Lucas suggests an economic growth rate to be determined by a rate of human capital accumulation, Romer claims that it is determined by a level of already accumulated human capital. In this paper we will try to understand ***which mechanism – Lucasian or Romerian – was dominating at different stages of Swedish development***.

The major idea of the research is, thus, not to capture an effect of human capital on economic growth in quantitative terms (though, we provide a reader with some estimates), but rather to distinguish between several sub-periods for each of which one mechanism of human capital contribution to economic growth (defined by one of the 'new growth theories') was dominating. The latter, in general, defines the scope of this research.

The rest of the paper is organized as follows. In Section II we provide a review of empirical literature on relationships between human capital and economic growth. Section III is aimed at introducing the 'new growth theories' by Lucas (1988) and Romer (1990) which lay down a theoretical framework for the research. The data and methodological issues

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[1] Martynovich (2010) employed the Solow-Swan model augmented for human capital in which total output of the economy was produced through an application of labor, physical and human capital [$Y_t = A_t(K_t^{\alpha} * L_t^{\beta} * H_t^{\gamma})$]. Analysis suggested that during the period of 1870-2000 there was a cointegration between the levels of accumulated human capital and GDP. Using vector error correction (VEC) framework, the long-term equilibrium equation was estimated to be $\ln Y_t = 2{,}19 \ln H_t$

are discussed in Section IV. Section V reviews major trends in human capital accumulation and economic growth in Sweden, 1870-2000, as well as introduces the hypotheses for empirical analysis, which is performed in Section VI. Section VII concludes.

II. HUMAN CAPITAL AND ECONOMIC GROWTH: REVIEW OF EMPIRICAL LITERATURE

Establishment of human capital theory in the mid-twentieth century (Schultz 1961; Becker 1964) caused revolution in approaches to studying determinants of economic growth. However, it was not earlier than the early 1990s, when empirical research on relationships between human capital and economic growth exploded. Micro-level studies consistently pointed to the fact that individuals, investing in their education (and, thus, accumulating individual human capital), could expect substantial monetary returns in terms of personal income (cf. Fleischhauer (2007) for review of individual level studies). It was, therefore, assumed that benefits from individual human capital accumulation may spill over to other individuals boosting economic development of regions and nations.

Current research on relationships between human capital and economic growth is hugely dominated by two theoretical approaches, namely, the augmented Solow-Swan model and the 'new growth theories', which, in their turn, are matched by two methodological approaches: growth accounting and macro growth regressions respectively. These approaches are not directly comparable because of different aims and, therefore, different output of studies in these streams of research. Further, we will summarize basic features of both theoretical approaches as well as results from empirical studies for each of them.

II.1. Augmented Solow-Swan Model and Growth Accounting

The Solow-Swan model augmented for human capital was firstly introduced by Mankiw, Romer and Weil (1992). Production function was suggested to be a constant returns Cobb-Douglas function so that production at time t is given by:

$$Y(t) = A(t)H(t)^{\alpha}K(t)^{\beta}L(t)^{1-\alpha-\beta}$$

$$\alpha > 0;\ \beta > 0;\ \alpha + \beta < 1 \quad \text{(II.1)}$$

where $Y(t)$ – total output; $A(t)$ – level of technology (measuring exogenously given technological progress); $H(t)$ – human capital stock in the labor force; $K(t)$ – physical capital stock; $L(t)$ – labor force. Assuming $\alpha + \beta < 1$ implies that there are decreasing returns to all capital in the model[2].

[2] Assumption of decreasing returns to all capital is introduced since in case of constant returns to scale in capital factors ($\alpha + \beta = 1$) there is no steady state for the model (Mankiw, Romer, Weil 1992: 416-417).

In per capita terms production function (II.1) may be re-written as:

$$y(t) = A(t)h(t)^{\alpha}k(t)^{\beta}$$

$$\alpha > 0;\ \beta > 0;\ \alpha + \beta < 1 \qquad \text{(II.2)}$$

where $y(t)$ – GDP per worker; $h(t)$ – average human capital stock per worker; $k(t)$ – physical capital stock per worker.

Re-writing (II.2) in growth rates:

$$\frac{\dot{y}}{y} = \frac{\dot{A}}{A} + \alpha\frac{\dot{h}}{h} + \beta\frac{\dot{k}}{k} \qquad \text{(II.3)}$$

Per capita growth rate ($\dot{y}/y$) is, thus, decomposed into a contribution of factor inputs ($\dot{h}/h$ and $\dot{k}/k$) and a residual total factor productivity ($\dot{A}/A$), which accounts for the effect of technological change on economic growth.

Growth accounting exercises are aimed at assessing shares of factor inputs contribution versus total factor productivity contribution to growth in output (*growth accounting*) or cross-country differences in output per worker (*level accounting*). The output of empirical studies in this stream of research is, therefore, a percentage contribution of human capital accumulation to a rate of growth. The results from some major studies within this approach are presented in Appendix 1.

One striking conclusion from growth accounting exercises is that in the most recent studies the share of human capital contribution to the growth in output is declining in favor of total factor productivity. Besides changes in estimation methodology, samples of data (both in terms of considered countries and time periods), and proxies for human capital variable[3], this may be attributed to two factors. First, it is possible that development of economic systems makes a mechanism behind economic growth more complex, which implies inclusion of factors that are not considered in the augmented Solow-Swan model. This, in its turn, leads to an increase in total factor productivity share in output growth as the former is calculated on a residual basis. Second, output elasticities by factor inputs (α and β) are *a priori* imposed to be around 0,3 each. It may be reasonable to assume, though, that, for example, a contribution of human capital

[3] While in earlier studies literacy and enrollment rates are employed, later studies tend to use average years of schooling as a proxy for human capital(Sianesi and van Reenen 2003).

input to growth increases with time. This may lead to overestimation of a total factor productivity share in output growth in the later studies as they include datasets with extended time frames. However, since, to our best knowledge, there is no evidence for the latter claim in the literature, the issue of sensitivity testing of growth accounting results to changes in output elasticities by factor inputs may be an interesting topic for further research.

While accounting approach to decomposing growth is relatively easy to employ, it is subject to three major flows. First, it may be difficult to separately identify human capital aspect of labor inputs as the latter is often a mixed measure of various educational, demographic and labor force variables (Sianesi and van Reenen 2003: 172). Second, growth accounting does not take into consideration possible indirect effects of human capital accumulation on economic growth (e.g., increasing efficiency of physical capital investments, boosting technological development, etc.). Finally, as it was claimed by Griliches (1997) "accounting is no explanation" (cited from Sianesi and van Reenen 2003: 162). While growth accounting sheds some light on relative contribution of human capital to economic growth, it does not reveal causal relationships or mechanisms through which accumulation of human capital affects economic growth.

II.2. 'New Growth Theories' and Macro Growth Regressions

While the conventional neo-classical Solow-Swan growth model and its human capital-augmented modification discussed above underline an important role of technological change (exogenously given) in an increase of total output of the economy, the 'new growth theories' emphasize an endogenous mechanism, which plays the role of a main growth determinant instead of exogenous technological progress. This mechanism is hugely based on human capital, which is introduced into a production function in order to relax diminishing returns assumption and affects economic growth via two major processes: (a) accumulation of human capital; and, (b) technological facilitation due to already accumulated level of human capital (Sianesi and van Reenen 2003; van Leeuwen 2007). More detailed review of two major 'new growth theories', namely models of Lucas (1988) and Romer (1990), is provided in Section III of this paper.

Macro growth regressions based on the 'new growth theories' differ from growth accounting exercises in the respect that they aim at estimating rather than imposing output elasticities of an aggregate production function, thus, identifying determinants of economic growth and quantifying such correlations (Sianesi and van Reenen: 175). The results from some major studies within this approach are presented in Appendix 2.

Large variation in an estimated effect of human capital on economic growth may be explained by methodological differences between studies, namely:

1. *different dependent variables*

   While most studies concentrate on annual cross-country differences in growth rates of real GDP per capita, some other options include moving averages and interval values of real GDP per capita growth rates, growth in labor productivity (measured as GDP per worker), and first-differenced logarithm of real GDP per capita or per worker.

2. *different human capital proxies*

   There are three aspects in which studies differ when it comes to human capital proxies. First, while some studies consider an impact of the stock (level) of human capital or the flow (accumulation) of human capital, others incorporate both parameters in regression analyses. Second, in case of using educational proxies of human capital some studies use aggregated indicators, while others decompose educational variables into primary, secondary, and tertiary levels. Third, studies employ different data for the same human capital indicators – most often used data on, for example, educational indicators are provided by Kyriacou (1991), Barro and Lee (1993), and de la Fuente and Doménech (2000, 2002).

3. *different regression specifications*

   Temple (1999) underlines that growth regressions are highly sensitive to the model specifications, that is, an inclusion and/or exclusion of right-hand side variables may substantially change size and significance of human capital coefficients. For example, Topel (1999) claims that the negative coefficient for changes in average years of schooling obtained in influential paper by Benhabib and Spiegel (1994) is a result of a log-log specification of the model. As it was argued by Krueger and Lindahl (2001) such specification is incorrect given success of micro-Mincerian equation specifying human capital as an exponential function of schooling (cf. Section VI.1. for further explanation). One more specification issue is an inclusion of physical capital in growth regressions with human capital. On the one hand, presence of physical capital in a production function requires including it in regression analysis. On the other hand, possible simultaneity problem may cause an upward bias in a coefficient for physical capital (since richer countries tend to invest more in physical capital). This fact, combined with a low signal in human capital variables conditional on the other variables (Krueger and Lindahl 2001: 1113-1114; van Leeuwen 2007: 38) may lead to an insignificant and/or negative coefficient for human capital. Besides, de la Fuente and Doménech (2000) claim that during periods of decelerating economic growth physical capital investments are likely to decline. However, if human capital exhibits a non-decreasing growth rate within such periods, it may lead to an insignificant and/or negative coefficient for human capital variable. All in all, a specification of growth regressions may play an important role in estimating quantitative effect of human capital on economic growth.

4. *different samples*

   Most studies incorporate developing and developed countries in an integrated framework. However, there are studies concentrating solely on OECD countries or dividing countries into several sub-groups according to their level of development. Besides, time periods under consideration vary as well: more recent studies tend to include extended time frames. All this makes comparison of human capital effect estimates pretty difficult.

Nevertheless, the general conclusion from macro growth regressions is that human capital is positively associated with economic growth since there is a consistent evidence for positive (and significant) human capital coefficients. Some other results include (a) heterogeneous effects of different educational levels conditional on a country's stage of development (with primary education being more important for the least developed countries, secondary – for intermediate developing countries, and tertiary – for OECD countries) (Gemmell 1996; Petrakis and Stamatakis 2001); and, (b) presence of the indirect effects of human capital on economic growth (through increasing efficiency of physical capital investments, technology development facilitation, raising living standards, etc.) (Barro 1991; Barro and Lee 1994; Benhabib and Spiegel 1994; Gemmell 1996).

Though being convenient instrument for estimating quantitative effect of human capital on economic growth, macro growth regressions are subject to several problems. First, since most of studies include countries at different stages of development, regression analyses face the problem of parameter heterogeneity (Temple 1999). In other words, while it is reasonable to expect systematic differences in a size of human capital effect on economic growth between, for example, developing and developed countries, most studies do not account for this issue, which may lead to biased estimates. Thus, regressions assuming homogenous parameters are inappropriate way of analysis. Second, there is a significant measurement bias when it comes to proxies of human capital. Krueger and Lindahl (2001: 1134) showed that correlation between two major measures of data on average years of education – Kyriacou (1991) and Barro and Lee (1993) – is 0,86, while when it comes to changes in years of schooling it decreases to 0,34. Finally, cross-country growth regressions are subject to endogeneity bias (or, in other words, reverse causality problem). While there is a consistent evidence for positive correlation between growth and human capital, it is possible that causality is of bi-directional character. The problem is reinforced by the fact that cross-country regressions are usually concentrated on the period after 1960, which makes an explanation of long-term economic growth and a research on causality direction even more problematic.

II.3. Historical Studies

The problems of cross-country growth regressions may be partly overcome in historical studies through application of time-series and panel methods (Temple 1999). Ljungberg and Nilsson (2009) mention an emerging strand of literature on the long-term estimates of human capital. However, problems with availability of data limit such analysis to one or several countries. Besides, by now not that many attempts were made in discovering causal relationships between human capital and economic growth and estimating such relationships in quantitative terms. Couple of exceptions includes studies performed by van Leeuwen (2007) and Ljungberg and Nilsson (2009).

Van Leeuwen (2007) studied the long-term relationships between human capital and economic growth in India, Indonesia and Japan over 1890-2000 through the prism of the 'new growth theories'. It was shown that human capital was positively and significantly affecting economic growth in all countries either through its accumulation (India, Indonesia as well as Japan before 1945) or its already accumulated level (Japan after 1950). Summary of the estimated effects is provided in Appendix 3. It was also shown that institutional differences and country's development stage may influence an effectiveness of transforming human capital accumulation to economic growth as coefficients for human capital effects for Japan (developed economy) were substantially higher than those for India and Indonesia (developing economies).

Ljungberg and Nilsson (2009) by constructing the new series for average years of schooling in productive population for Sweden in 1870-2000 studied an issue of causality between human capital and labor productivity (measured by GDP per capita of productive population). With some degree of simplification it is possible to conclude that in Sweden over the indicated period it was most likely that human capital caused growth and not vice versa. However, an effect of human capital on economic growth was not directly estimated. In this paper we make a step further and try to (a) understand a mechanism through which human capital contributed to Swedish economic growth (with respect to the 'new growth theories'); and, (b) provide some quantitative estimates of this contribution.

III. THEORETICAL FRAMEWORK

As it was already pointed in Section II.2., the 'new growth theories' aim at endogenizing a process of economic growth. This is done through relaxing diminishing returns assumption made in the Solow-Swan model, though, in different ways. First generation of the 'new growth theories' is represented by two streams of research pioneered by Lucas (1988) and Romer (1990). Further, we will introduce both models and discuss their implications for empirical studies on human capital contribution to economic growth.

Both models are based on an assumption of a closed economy with competitive markets. Preferences over (per-capita) consumption are defined following Ramsey (1928), further extended by Cass (1965):

$$\int_0^\infty \frac{e^{-\rho t}}{1-\sigma}[c(t)^{1-\sigma}-1]N(t)\mathrm{d}t \tag{III.1}$$

$\rho > 0; 0 < \sigma < 1$

where $c(t)$ – per-capita consumption stream; $N(t)$ – population; ρ – discounting rate; σ – coefficient of relative risk aversion (σ^{-1} – inter-temporal elasticity of substitution).

Both models assume produced output to be fully used for final consumption and capital investment:

$$Y(t) = N(t)c(t) + \dot{K}(t) \tag{III.2}$$

where $Y(t)$ – total output, $\dot{K}(t)$ – change in physical capital $[\dot{K}(t) = K(t) - K(t-1)]$.

Both models aim at finding the *balanced social optimum growth path*, along which (a) consumption is maximized; and, (b) growth rates of (per-capita) consumption, capital and output are constant.

Now that the basic assumptions are introduced, we will turn onto a brief review of formalized models.

II.1. Lucas (1988) Growth Model with Human Capital

Lucas developed the model with two sectors: (a) production sector; and, (b) sector of human capital accumulation.

Human capital in the model is defined as a general skill level of a worker, so that an individual with a human capital level equal to $h(t)$ is same productive as two individuals with a human capital level of $0{,}5h(t)$ each. Therefore, human capital is rival and excludable and may be considered as an economic good.

Individual makes a decision about distributing his/her time between production and human capital accumulation. In that respect, decision about allocating time for production is assumed to be made first. Time for accumulation of human capital is, thus, allocated on a residual basis. Assuming that an individual with a level of human capital h devotes $u(h)$ time to production and number of such individuals is $N(h)$, effective workforce in production N^e at each moment t is equal to:

$$N^e = \int_0^\infty u(h)N(h)h \, \mathrm{d}h \qquad \text{(III.3)}$$

Total output is a function of capital and productive workforce $Y(t) = F(K; N^e)$. Human capital, thus, influences level of productivity of individual workers and, being the factor of production, total output in the economy. This is referred as an *internal effect* of human capital.

Besides, human capital affects productivity of factors of production through an *external effect*. An example of such an effect is an increase in productivity of a worker, in case he/she works next to a worker with higher level of skills. Let an average level of human capital in the economy be defined as:

$$h_a = \frac{H}{N} = \frac{\int_0^\infty hN(h)\mathrm{d}h}{\int_0^\infty N(h)\mathrm{d}h} \qquad \text{(III.4)}$$

An average level of human capital is believed to increase productivity of all factors of production. This effect is referred as external since, though everyone can benefit from it, an individual decision about allocating time between production and human capital accumulation may not have a substantial effect on h_a, so it does not influence anyone's time allocation decision.

In case of homogenous workforce, all workers have human capital level h, allocate u time to production, and an average level of human capital is equal to an individual one, that is, $h_a(t) = h(t)$.

Therefore, in the first sector, total output is produced through an application of physical and human capital, which is described by the following production function:

$$N(t)c(t) + \dot{K}(t) = AK(t)^{\beta}[u(t)h(t)N(t)]^{1-\beta}h_a(t)^{\gamma}$$

$$0 < \beta < 1;\ \gamma \geq 0 \tag{III.5}$$

where u – share of time, which individual devotes to production; h – individual level of human capital embodied in workers; h_a – average level of human capital in the economy. Here, we use a notation h_a to illustrate distinction between internal and external effects of human capital. However, in case of homogenous workforce, which is assumed further, external effect de facto just changes elasticity of output by individual human capital level.

In the second sector, a share of human capital, which is not used in production sector – 1-$u(t)$ – participates in human capital accumulation, according to the Uzawa's (1965) linear function:

$$\dot{h}(t) = h(t)\delta[1 - u(t)] \tag{III.6}$$

where $\dot{h}(t)$ – accumulation of human capital $[\dot{h}(t) = h(t) - h(t-1)]$; δ – productivity of human capital accumulation sector (defines maximum rate of human capital accumulation in case all effort is devoted to that $[u(t) = 0]$). Accumulation of human capital is, thus, subject to the constant marginal returns: a given percentage increase in $h(t)$ requires the same effort and does not depend on already attained level of human capital. These non-diminishing returns in human capital accumulation sector are believed to be the major mechanism behind the endogenous growth in the model.

An optimization task is formulated in the following way:

$$\begin{cases} \int_0^{\infty} \frac{e^{-\rho t}}{1-\sigma}[c(t)^{1-\sigma} - 1]N(t)\mathrm{d}t \rightarrow max \\ N(t)c(t) + \dot{K}(t) = AK(t)^{\beta}[u(t)h(t)N(t)]^{1-\beta}h_a(t)^{\gamma} \\ 0 < \beta < 1;\ \gamma \geq 0;\ \rho > 0; 0 < \sigma < 1 \\ g = \frac{\dot{y}}{y} = \frac{\dot{k}}{k} = \frac{\dot{c}}{c} = const \end{cases} \tag{III.7}$$

In other words, Lucas considers the balanced growth path along which *per-capita* output, capital stocks and consumption grow at a constant rate.

The current value Hamiltonian associated with the optimization task is:

$$\mathcal{H}(K,h,\theta_1,\theta_2,c,u,A,\beta,\gamma,\delta,\sigma,N)=\frac{N}{1-\sigma}[c^{1-\sigma}-1]+\theta_1\big[AK^{\beta}(uNh)^{1-\beta}h^{\gamma}-$$
$$-Nc]+\theta_2[\delta h(1-u)]\rightarrow max, \tag{III.8}$$

where θ_1 and θ_2 value increments to K and h respectively.

The first-order necessary conditions for maximization are:

$$c^{-\sigma}=\theta_1 \tag{III.9}$$

$$\theta_1(1-\beta)AK^{\beta}(uNh)^{-\beta}Nh^{1+\gamma}=\theta_2\delta h \tag{III.10}$$

These conditions actually imply that: (a) an allocation of goods should be so that their marginal value is equal for both uses – capital accumulation and consumption; and, (b) the time should have equal marginal value for both production and human capital accumulation.

Euler equations (for the rate of change in θ_1 and θ_2) are:

$$\dot{\theta}_1=\rho\theta_1-\theta_1\beta AK^{\beta-1}(uNh)^{1-\beta}h^{\gamma} \tag{III.11}$$

$$\dot{\theta}_2=\rho\theta_2-\theta_1(1-\beta+\gamma)AK^{\beta}(uN)^{1-\beta}h^{-\beta+\gamma}-\theta_2\delta(1-u) \tag{III.12}$$

Boundary (initial) conditions $K(0)$ and $h(0)$ taken together with conditions (III.5), (III.6) (III.9)-(III.12) lead to the two-parameter family of paths $[K(t),\ h(t),\ \theta_1(t),\ \theta_2(t)]$. Unique member of this family satisfying the following transversality conditions:

$$\lim_{t\to\infty}\theta_1\,Ke^{-\rho t}=0 \tag{III.13}$$

$$\lim_{t\to\infty}\theta_2\,he^{-\rho t}=0 \tag{III.14}$$

defines the balanced growth path.

If we now denote $\dot{c}(t)/c(t)$ as g (III.9) and (III.11) imply that:

$$\beta AK(t)^{\beta-1}(u(t)N(t)h(t))^{1-\beta}h(t)^{\gamma}=\rho+\sigma g \tag{III.15}$$

By differentiating (III.15) and considering (III.6) we, therefore, obtain:

$$g=\frac{\dot{y}}{y}=\frac{\dot{k}}{k}=\frac{\dot{c}}{c}=\left(\frac{1-\beta+\gamma}{1-\beta}\right)\frac{\dot{h}}{h} \tag{III.16}$$

Efficient rate of human capital accumulation along the balanced growth path is:

$$\nu^* = \sigma^{-1}\left[\delta - \frac{1-\beta}{1-\beta+\gamma}(\rho - \lambda)\right], \tag{III.17}$$

where λ – rate of population growth ($\lambda \geq 0$).

Lucas (1988) claims that for any initial levels $K(0)$ and $h(0)$ of physical capital and human capital respectively, any optimal path $[K(t);\ h(t)]$ converges to the balanced growth path. Therefore, the balanced social optimum growth path is a good approximation for any path, which an economy follows most of time.

Important implications of the Lucas growth model for our study include the following:

- along the balanced social optimum growth path a rate of per capita GDP growth is defined by a rate of human capital accumulation;
- since elasticity of output by an average level of human capital is non-negative ($\gamma \geq 0$), a rate of per capita GDP growth is either the same (in case of no external effects) or slightly higher (in case of positive external effects) than the rate of human capital accumulation. This implies that the human capital-to-GDP ratio should be either constant or slightly decreasing over time[4].

II.2. Romer (1990) Growth Model with Human Capital

Romer introduces the model with three sectors: (a) technological sector; (b) sector of

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[4] We can express (III.16) in the following way:

$$\frac{\dot{y}}{y} = \varphi\frac{\dot{h}}{h} \tag{III.16a}$$

So, if human capital grows at rate ν, then GDP grows at rate $\varphi\nu$. In that respect, φ is either equal to 1 (when there are no external effects, $\gamma = 0$), or more than 1 (when there are external effects, $\gamma > 0$).

Turning onto dynamic situation, let's assume that human capital at time t is equal to HC_t and GDP is equal to Y_t. Then, ratio of HC/Y at time $t+1$ will be equal to:

$$\frac{HC_{t+1}}{Y_{t+1}} = \frac{(1+\nu)HC_t}{(1+\varphi\nu)Y_t} \leq \frac{HC_t}{Y_t} \tag{III.16b}$$

We know that the ratio $\frac{1+\nu}{1+\varphi\nu}$ is either 1 (when $\gamma = 0$) or less than 1 (when $\gamma > 0$). Therefore, over time the human capital-to-GDP ratio is either constant or slightly decreasing.

intermediate products manufacturing; and, (c) final output sector.

In the first sector, accumulated human capital is used for production of new technologies, which is described by the following equation:

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

$$\delta > 0 \qquad \text{(III.18)}$$

where H_A – amount of human capital involved in technological sector; δ – productivity parameter.

From here we can already note some differences between Lucas and Romer models. While Lucas treats human capital as a rival and excludable good, Romer considers it as a general knowledge which is non-rival and only partly excludable (and, therefore, is neither economic nor fully public good). Besides, contrary to Lucas, allocation of human capital for the technological sector is made on a primary basis in Romer model, while residual is left for production[5]. In that respect, human capital plays the role of a technological facilitator rather than a direct production factor (Romer 1990; van Leeuwen 2007). One more important conclusion from (III.18) is that, contrary to Lucas, a level of technology is not fixed and grows over time.

In the sector of intermediate production, existing technologies are used for manufacturing of intermediate products. In that respect, it is suggested that each existing technology A_i creates a new intermediate product x_i, which taken all together account for a total amount of physical capital in the economy.

Finally, in the third sector, total output is produced through an application of residual human capital, labor and physical capital (introduced as an aggregate of intermediate products):

$$N(t)c(t) + \dot{K}(t) = H(t)_Y^{\alpha} N(t)^{\beta} \int_0^A x_i^{1-\alpha-\beta} \mathrm{d}i \qquad \text{(III.19)}$$

$$\alpha > 0;\ \beta > 0;\ \alpha + \beta < 1$$

where H_Y – level of human capital, which is involved in production (defined as a residual

[5] Thus, one can say that in Romer model human capital enters production function as an exogenous factor (van Leeuwen 2007).

function from human capital involved in research sector $H_Y = H - H_A$, where H is a total level of human capital in the economy); N – population involved in production (assumed to be constant over time).

Using physical capital decomposition into multiple individual intermediate products is done in order to underline the fact that different intermediate products have different marginal productivity. In case, all products are absolute substitutes, production function (III.19) transforms into a conventional production function in the Solow-Swan model augmented for human capital (see Section II.1).

Considering that $\int_0^A x_i^{1-\alpha-\beta}\mathrm{d}i = A\bar{x}^{1-\alpha-\beta}$, $K = \eta A\bar{x}$, where η – price of an average intermediate product, and $H_Y = H - H_A$, production function (III.19) after several transformations takes the following form:

$$Nc(t) + \dot{K}(t) = [\big(H(t) - H_A(t)\big)A(t)]^{\alpha}[NA(t)]^{\beta}K^{1-\alpha-\beta}\eta^{\alpha+\beta-1}$$
$$\alpha > 0;\ \beta > 0;\ \alpha + \beta < 1 \qquad \text{(III.20)}$$

An optimization task is formulated in the following way:

$$\begin{cases} \int\limits_0^{\infty} \dfrac{e^{-\rho t}}{1-\sigma}[C(t)^{1-\sigma} - 1]\mathrm{d}t \to max \\ \dot{A} = \delta H_A A \\ C(t) + \dot{K}(t) = \left[\big(H(t) - H_A(t)\big)A(t)\right]^{\alpha}[NA(t)]^{\beta}K^{1-\alpha-\beta}\eta^{\alpha+\beta-1} \\ \alpha > 0;\ \beta > 0;\ \alpha + \beta < 1;\ \delta > 0;\ \rho > 0; 0 < \sigma < 1 \\ g = \dfrac{\dot{Y}}{Y} = \dfrac{\dot{K}}{K} = \dfrac{\dot{C}}{C} = \dfrac{\dot{A}}{A} = const \end{cases} \qquad \text{(III.21)}$$

where C is total consumption.

In other words, Romer considers the balanced growth path along which *aggregated* output, capital stocks and consumption grow at a constant rate. However, under an assumption of constant population this is equivalent to a constant growth of per-capita measures. We will, nevertheless, follow Romerian formulation. Besides, a constant growth rate of technology is assumed.

Since along the balanced growth path capital, output, consumption and technology grow with the same rate g it follows directly from (III.18) that:

$$g = \frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{C}}{C} = \frac{\dot{A}}{A} = \delta H_A \qquad \text{(III.22)}$$

Therefore, growth of the economy is dependent on the amount of human capital involved in the technological sector. However, what about a relationship between economic growth and level of *total* accumulated human capital? This will be shown further.

The current value Hamiltonian associated with the optimization task is:

$$\mathcal{H}(K, H, H_A, \theta_1, \theta_2, C, A) = \frac{C^{1-\sigma}-1}{1-\sigma} + \theta_1\left[\eta^{\alpha+\beta-1}A^{\alpha+\beta}(H - H_A)^{\alpha}N^{\beta}K^{1-\alpha-\beta} - C\right] + \\ +\theta_2[\delta H_A A] \rightarrow max, \quad \text{(III.23)}$$

where θ_1 and θ_2 value increments to K and A respectively.

The first-order necessary conditions for maximization are:

$$C^{-\sigma}=\theta_1 \quad \text{(III.24)}$$

$$\theta_1 \alpha \eta^{\alpha+\beta-1}A^{\alpha+\beta}(H - H_A)^{\alpha-1}N^{\beta}K^{1-\alpha-\beta} = \theta_2 \delta A \quad \text{(III.25)}$$

These conditions actually imply that: (a) an allocation of goods should be so that their marginal value is equal for both uses – capital accumulation and consumption; and, (b) human capital should have equal marginal value for both production and research sectors.

Euler equations (for the rate of change in θ_1 and θ_2) are:

$$\dot{\theta}_1 = \rho\theta_1 - \theta_1(1 - \alpha - \beta)\eta^{\alpha+\beta-1}A^{\alpha+\beta}(H - H_A)^{\alpha}N^{\beta}K^{-\alpha-\beta} \quad \text{(III.26)}$$

$$\dot{\theta}_2 = \rho\theta_2 - \theta_1(\alpha + \beta)\eta^{\alpha+\beta-1}A^{\alpha+\beta-1}(H - H_A)^{\alpha}N^{\beta}K^{1-\alpha-\beta} - \theta_2\delta H_A \quad \text{(III.27)}$$

Boundary (initial) conditions $K(0)$ and $A(0)$ taken together with conditions (III.18), (III.20), (III.24)-(III.27) lead to the two-parameter family of paths $[K(t), A(t), \theta_1(t), \theta_2(t)]$. Unique member of this family satisfying the following transversality conditions:

$$\lim_{t\to\infty} \theta_1 K e^{-\rho t} = 0 \quad \text{(III.28)}$$

$$\lim_{t\to\infty} \theta_2 A e^{-\rho t} = 0 \quad \text{(III.29)}$$

defines the balanced growth path.

From (III.25) and (III.27) we can derive:

$$-\sigma\delta H_A = \rho - \delta\left(\frac{\alpha + \beta}{\alpha}H - \frac{\beta}{\alpha}H_A\right) \quad \text{(III.30)}$$

Solving this equation for H_A and remembering that $g = \delta H_A$, we obtain an economic growth rate expressed as a function of total accumulated human capital and fundamentals of the model:

$$g = \frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} = \frac{\delta H - \frac{\alpha}{\alpha+\beta}\rho}{\frac{\alpha}{\alpha+\beta}\sigma + \frac{\beta}{\alpha+\beta}} = \pi_1 H - \pi_2 \tag{III.31}$$

where $\pi_1 = \frac{\delta(\alpha+\beta)}{\alpha\sigma+\beta}$ and $\pi_2 = \frac{\alpha\rho}{\alpha\sigma+\beta}$.

Important implications of Romer growth model for our study include the following:

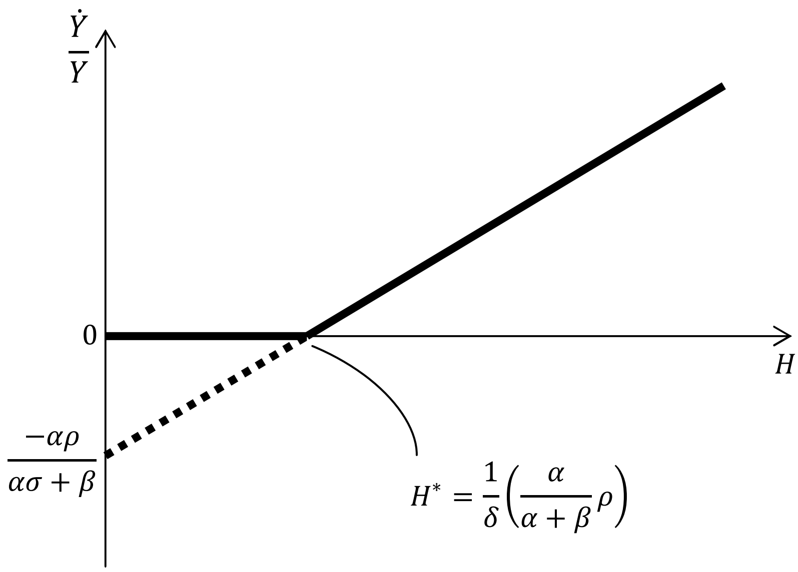
- along the balanced path a rate of GDP growth is defined by a level of already accumulated human capital;
- since productivity in technological sector is always positive ($\delta > 0$), the human capital-to-GDP ratio should obviously be decreasing over time.

One more conclusion is that Romerian growth starts only when particular level of human capital is accumulated in the economy. Indeed, from (III.31) it follows:

$$\frac{\dot{Y}}{Y} = \frac{\delta H - \frac{\alpha}{\alpha+\beta}\rho}{\frac{\alpha}{\alpha+\beta}\sigma + \left(1 - \frac{\alpha}{\alpha+\beta}\right)} \geq 0 \quad \Leftrightarrow \quad H \geq \frac{1}{\delta}\left(\frac{\alpha}{\alpha+\beta}\rho\right) > 0 \tag{III.32}$$

Graphically this could be interpreted in the way depicted in Figure III.1.

Figure III.1. Conditions for Romerian Growth



This corresponds to van Leeuwen's (2007) notion that Romerian growth is a feature of economies which have passed particular technological frontier.

III.3. Summary of Theoretical Findings and Practical Implications

Based on seminal articles from Lucas (1988) and Romer (1990), some other theoretical and empirical contributions (Aghion and Howitt 1999, 2009; Barro, Sala-i-Martin 2004; van Leeuwen 2007) as well as discussion above, it is possible to distinguish between several aspects (in models' inputs, theoretical conclusions and practical implications) in which models of Lucas and Romer differ (Table III.1).

Table III.1. Comparing Lucas and Romer Models

	Lucas (1988)	**Romer (1990)**
Main Inputs		
Human capital (HC) is defined as	skills embodied in workers (rival and excludable)	general knowledge (non-rival and only partly excludable)
HC mainly plays a role of	factor of production	technological facilitator
HC enters production	on a primary basis	on a residual basis
HC is involved in technological/HC accumulation sector	on a residual basis	on a primary basis
Endogenous growth happens through	accumulation of skills with non-diminishing returns	development of technologies
Main Results		
Growth rate is defined by	rate of human capital accumulation	level of accumulated human capital
Growth starts	at any point as long as accumulation of human capital takes place	when economy reaches particular technological frontier (defined by level of accumulated human capital)
HC-to-GDP ratio	remains constant or slightly decreases over time	decreases over time

It may be concluded from the discussion in the table that models of Lucas and Romer define two growth regimes, which are different both in terms of growth determinants and mechanisms through which an endogenous growth takes place. Further we will employ theoretical framework elaborated in this section for studying economic growth of Sweden over the period 1870-2000.

IV. DATA AND METHODOLOGY

IV.1. Human Capital Proxy

Average standard years of schooling (adjusted to changes in a length of a schooling year over time) are chosen as a proxy for human capital variable in this research. This is not entirely correct since this indicator does not fully reflect the nature of human capital. However, in terms of this particular study such operationalization seems to be reasonable since it covers (though, partly) features of human capital, which are defined in both Lucas and Romer models.

On the one hand, average years of schooling have positive effect on average worker skills and, therefore, reflect the human capital definition employed by Lucas (1988). However, limitation of this indicator is that it does not account for (a) skills acquired through on-the-job training, experience and learning-by-doing; (b) possible depreciation of human capital; and, (c) quality of one year of schooling, which is likely to increase with time.

On the other hand, the more years of schooling are accumulated in the economy – the more knowledge and ideas are likely to be generated. Thus, average years of schooling may be a suitable proxy for the Romer's definition of human capital. The limitation here is that this indicator does not account for possible flows of knowledge coming from outside an economic system in the form of knowledge exchange between international units of multinational companies, inflow of high-skilled labor from the other countries, etc. However, as processes of globalization put forward an issue of international human capital migration (in different forms) it is important to consider that factor.

One more possible problem, which may be caused by using average years of schooling as a proxy for human capital, was mentioned by Földvári and van Leeuwen who claimed in their recent article that it should be interpreted not as a level of human capital but as its accumulation (Földvári and van Leeuwen 2009). This may significantly influence results obtained by empirical analysis, especially when it comes to comparison of growth models. In this paper, however, we stick to the traditional interpretation of average years of schooling as a proxy for a *level* of human capital.

Using average years of schooling has an important implication for specification of growth regressions. Following micro-Mincerian studies results, Topel (1999) and Soto (2002) argued that human capital is an exponential function of schooling. In other words, with some degree of simplification an individual profit from human capital in year t is defined according to exponential equation:

$$h_t = h_o(1+\rho)^{sch} \ , \qquad \text{(IV.1)}$$

where h_t – individual profit from human capital in year t; ρ – discounting rate; sch - number of individual's years of schooling.

By aggregating this equation across all individuals within a studied sample we obtain:

$$\bar{h}_t = \bar{h}_o(1+\rho)^{ays} \ , \qquad \text{(IV.2)}$$

where $\bar{h}_t$ – average profit from per capita human capital in year t; ays – average years of schooling.

By taking logarithm and assuming $ln\,\bar{h}_0 = \alpha$ and $\ln(1+\rho) = \beta$ we get:

$$\ln \bar{h}_t = \alpha + \beta * ays \qquad \text{(IV.3)}$$

Thus, if we want to estimate a log-log model in which a rate of per capita GDP growth is explained by a level of per capita human capital, namely:

$$\Delta\ln y_t = \gamma_1 + \gamma_2 \ln \bar{h}_t + \delta X_t + u_t \qquad \text{(IV.4)}$$

[where X_t – vector of control variables (in our case, all variables that we would like to include into a growth regression along with human capital); u_t – stochastic error term] and use average years of schooling as a proxy for human capital we should actually estimate the following equation:

$$\Delta\ln y_t = \gamma_1 + \gamma_2(\alpha + \beta * ays) + \delta X_t + u_t = (\gamma_1 + \alpha\gamma_2) + \beta\gamma_2 * ays + \delta X_t + u_t \qquad \text{(IV.5)}$$

Therefore, average years of schooling should enter growth regressions linearly.

IV.2. Data and Variables

The data are from the Lund University Macroeconomic and Demographic Database (LU-MADD). The dataset includes GDP, government and private consumption, investment, population and educational variables. The data are annual and cover the period of 1850-2000 for national accounts and 1870-2000 for educational indicators. Detailed summary of employed variables is presented in Appendix 4.

When it comes to per capita terms we use GDP, human capital, physical capital and investments per capita of productive population (aged 15-65). Such indicators capture more welfare aspect than indicators per hour worked and more efficiency aspect than standard per capita indicators. This allows such variables to be more sensitive to spillovers and external economies, which makes them particularly convenient when studying a human capital effect on economic growth.

IV.3. Distinguishing between Lucas and Romer Growth Regimes

Although theoretical differences between the models of Lucas and Romer are quite pronounced, it may be not that easy to distinguish between them empirically. First of all, we already claimed that average years of schooling are not the best human capital proxy when it comes to comparing different models. Second, the models of Lucas and Romer are not mutually exclusive, but rather complementary. While human capital plays the role of a technological facilitator in the model of Romer, it still enters production function on a residual basis. Therefore, finding relationship between growth in output and human capital accumulation is not sufficient condition for rejecting the Romerian growth regime. Besides, most likely it is possible to find some evidence for both Lucasian and Romerian growth at any moment of time. Taking this into consideration, we limit ourselves to determining regime which is *dominating* over the particular period. There are three possible ways to do that.

The first way to distinguish between the models is to look at a development of the human capital-to-GDP and/or human capital-to-physical capital ratios. As it was discussed in Section III, over time these ratios should remain almost constant in case there is the Lucasian growth, while they should decline substantially in case of the Romerian growth. Therefore, ocular inspection of a graphical representation of these ratios allows making primary conclusions about dominating growth regimes for different periods. Further statistical analysis, including testing for unit root in series representing the human capital-to-GDP ratio and/or human capital-to-physical capital ratios[6] and testing for breakpoints helps to make further inferences. We will limit ourselves to analyzing the human capital-

[6] Since in the periods of Lucasian growth we expect the human capital-to-GDP and/or human capital-to-physical capital ratios to be almost constant, in these periods the series representing these ratios should be stationary. In case of Romerian growth these ratios may be either trend-stationary with negative trend or not stationary at all.

to-GDP ratio since we are more interested in relationship between them. Results of this test are presented in Section V.3.

Second test was suggested by van Leeuwen (2007) and van Leeuwen and Földvári (2008). They assumed that if there is a long-run relationship between economic growth and human capital (in terms of its level or growth rate), variables representing these indicators (in our case GDP per capita of productive population and average years of schooling) should be cointegrated. There are two options.

First, both variables are integrated of the same order, most likely I(1). In this case, if they are also cointegrated, we can estimate a cointegrating equation:

$$\ln y_t = \alpha_0 + \alpha_1 sch_t + u_t \tag{IV.6}$$

If there are no breakpoints, this is equivalent to:

$$\Delta \ln y_t = \alpha_0 + \alpha_1 \Delta sch_t + u_t \tag{IV.7}$$

In other words, there is a long-run relationship between a growth rate of output and an increase in average years of schooling, hence, Lucasian growth.

Second, level of GDP per capita of productive population is one order more integrated than average years of schooling. Let's say that sch_t is I(1) and $\ln y_t$ is I(2). In that case, $\Delta \ln y_t$ is I(1). Therefore, we can estimate the following cointegrating equation:

$$\Delta \ln y_t = \beta_0 + \beta_1 sch_t + u_t \tag{IV.8}$$

In other words, there is a long-run relationship between growth rate of output and average years of schooling, hence, Romerian growth.

This method is summarized in Table IV.1.

Table IV.1. Cointegration Approach to Distinguishing between Growth Regimes

Variable	Order of integration	
$\ln y_t$	I(d[7])	I(d+1)
Sch_t	I(d)	I(d)
	Lucasian growth	Romerian growth

[7] d is an arbitrary non-negative integer.

Results of the second test are presented in Section VI.1.

The third way to evaluate dominating growth regime is to perform regression analysis and look at significance of coefficients for average years of schooling and change in this variable.

IV.4. Regression Analysis

Departing point for regression analysis is the intertemporal Macro-Mincer equation suggested by Heckman and Klenow (1997) in the form presented by van Leeuwen (2007):

$$\Delta \ln y_t = \alpha_0 + \alpha_1 t + \alpha_2 \Delta \ln y_{t-1} + \alpha_3 \ln y_{t-1} + \alpha_4 \Delta sch_{t-1} + \alpha_5 sch_{t-1} + u_t \qquad \text{(IV.9)}$$

Couple of comments should be made here. First, using independent variables with one period lag is motivated by trying to avoid the problem of simultaneity (or, reverse causality). This, however, puts an additional assumption on our analysis: independent variables should be intertemporally correlated. Second, including initial log-level of GDP per capita of productive population ($\ln y_{t-1}$) is done since being the most aggregated economic indicator it incorporates most of changes happening within an economic system. Therefore, we use it in order to account for major economic trends.

In order to serve the needs of this research, equation (IV.9) requires some transformations. We distinguish between two classes of models: Lucas- and Romer-type specifications.

Lucasian growth is modeled in the following way:

$$\Delta \ln y_t = \beta_0 + \beta_1 t + \beta_2 \Delta \ln y_{t-1} + \beta_3 \ln y_{t-1} + \beta_4 \Delta Sch_{t-1} + \beta_5 imb_{t-1} + \beta_6 imb_{t-1}^2 + u_t \qquad \text{(IV.10)}$$

Here, imb_{t-1} is supposed to capture the so-called imbalance effect[8].

---

[8] The basic notion behind an imbalance effect is that when economy develops along the balanced growth path, the human capital-to-physical capital ratio is supposed to develop along some kind of an equilibrium path. Since economy is supposed to develop along the balanced growth path most of time (Lucas 1990), in the long run there should be no such effect. However, in relatively short run, any deviations from this equilibrium may affect an output growth rate. Generally, it may be assumed that an excess of both human and physical capital increases growth rate of output (van Leeuwen 2007: 180). However, as Barro and Sala-i-Martin (2004: 246) claim, excess of physical capital may actually lead to a growth slow-down. In order to account for this, we should model it as the imbalance effect as a U-curve by introducing a second polynomial of the imbalance effect variable. ***(Continued on the next page)***

Romerian growth is modeled as:

$$\Delta \ln y_t = \gamma_0 + \gamma_1 t + \gamma_2 \Delta \ln y_{t-1} + \gamma_3 \ln y_{t-1} + \gamma_4 sch_{t-1} + u_t \qquad \text{(IV.11)}$$

The imbalance effect is not present in the Romer-type regressions since the Romer theory does not model formation of human capital. Indeed, while Lucas (1988) specifies particular human capital accumulation sector, Romer does not consider any mechanisms through which level of human capital in the economy is increased. Thus, it appears that human capital is entering the Romer model at no cost, implying that the imbalance effect should not be considered. This notion is quite doubtful, though[9].

Given the discussion on an inclusion of physical capital variables into growth regressions (see Section II.2), besides specifications given by (IV.10) and (IV.11) we also estimate equations in which physical capital is introduced as a growth and/or level variable. This is done in order to check for a robustness of human capital coefficients between different specifications. More detailed information about employed regression specifications is provided in Appendix 5.

Results of regression analyses are presented in Section VI.2., where we employ it for distinguishing between growth regimes in different sub-periods[10], and in Section VI.4., where we use it for modeling effects of human capital on economic growth over the whole considered period.

(Continued) The imbalance effect is usually modeled as a logged ratio between human and physical capital: $imb_t = ln\left(\frac{h}{k}\right)_t$. Right-hand side of this equation may be rewritten as $\ln\left(\frac{h}{k}\right)_t = \ln h_t - \ln k_t$. As it was shown in Section IV.1., when we use average years of schooling as a proxy for human capital, a log-function of human capital should be approximated with a linear function of years of schooling. Therefore, in this research we use the following specification of the imbalance effect: $imb_t = Sch_t - \ln k_t$.

[9] However, in our particular specification of the imbalance effect, it is highly correlated with average years of schooling ($r_{sch_t/imb_t} = 0{,}9999$). Therefore, including the imbalance effect in the Romer-type regressions would lead to biased estimates, which would make an inference about (a) dominating growth regime; and, (b) size of human capital effect on growth inconclusive. Therefore, we should exclude the imbalance effect from the Romer-type regressions in our case. Nevertheless, an importance of the imbalance effect for the Romer-type regressions may be a fruitful issue for further research.

[10] Estimated models are ranked, first, by significance of human capital variable, and, second, by general fit of the model as suggested by the adjusted coefficient of determination and information criteria. The top-ranked model is believed to point to dominating growth regime in particular sub-period.

V. HUMAN CAPITAL ACCUMULATION AND ECONOMIC GROWTH IN SWEDEN, 1870-2000

V.1. Educational System of Sweden, 1800-2000

In this section we will briefly outline the main developments in Swedish educational system in the nineteenth-twentieth centuries. Ljungberg and Nilsson (2009) distinguish between three periods during which the educational system of Sweden was characterized by relatively stable structure and distinctive features.

Educational system in the first period (until the 1840s) may be referred as early modern. Primary education at this period was mainly home-based and limited at achieving an ability to read and understand religious texts. Formal schooling was available in some parishes; however, in the 1820s the share of children actually going to school was about 10 per cent. Nevertheless, around 90 per cent of Swedish population had some kind of reading ability on the edge of nineteenth-twentieth centuries (Ljungberg and Nilsson 2009). Secondary education was mainly established in the form of grammar schools *(läroverk)*, which included classes at both primary and secondary levels and, thus, were an alternative to the primary education sector. Vocational education was hardly integrated into the formal schooling system and remained mostly apprenticeship-based before the mid-nineteenth century. Tertiary education was provided by two universities (Lund and Uppsala) and Medical College in Stockholm.

With the adoption of 1842 Act, which required establishment of at least one primary school (*folkskola*) in each parish of the country and introduced compulsory education, the era of mass education started. However, since funding of those schools was in responsibility of parishes, accessibility and quality of educational programs differed significantly. In 1870 compulsory education was extended from four to six years, which marked breakthrough of primary schooling both in terms of enrollment rates and a share of spending on primary schooling in GDP (Ljungberg 2002; Ljungberg and Nilsson 2009).

Secondary education was reformed in 1849, when all previously existing forms were merged into grammar schools (*läroverk)*, which were available separately for boys and girls and, as before, represented an alternative rather than a complement for primary schooling. In the beginning of the twentieth century, formal exam concluding lower secondary education given at grammar schools was introduced. One more important milestone was opening of state secondary schools for women in 1927, which substantially increased a number of female students graduating from upper secondary education.

Tertiary education expanded during the second half of the nineteenth century due to establishment of specialized (technical, dentist, agricultural, economic) and more general colleges, mainly in Stockholm and Gothenburg.

The second half of the nineteenth century marked expansion of vocational education in the school-based forms, which happened through opening of farm schools (*lantbruksskolor*), agricultural colleges (*lantmannaskolor*) and technical upper secondary schools. However, if in the former two education took place on a full-time basis, the latter remained mostly Sunday and evening schools with more general courses than applied ones. Thus, even though the formal apprenticeship system was dismantled around 1864, in 1972 the number of students in technical schools was still three times lower than the number of apprentices (Ljungberg and Nilsson 2009). In the early 1920s vocational sector became a bit more organized with schools becoming specialized on one of three fields – technical, commercial and domestic work – and courses taking more applied character.

In general, educational system established after the 1840s was of parallel-type and remained dominant until the mid-twentieth century.

The third period (from the 1950s onwards) brought dramatic changes to the educational system. In general, this period may be characterized as a transition from parallel to uniform system. By the end of the 1960s, primary and lower secondary educational levels were merged so that nine year compulsory schools (*grundskolor*) were established. In the beginning of the 1970s traditional upper secondary and vocational schools were merged into integrated upper secondary schools (*gymnasieskolor*) with the length of both theoretical and vocational programs currently being equal to three years[11]. Finally, restructuring of higher education in 1977 upgraded several programs (such as nurses and pre-school teachers training and education in the fine arts) to a tertiary level provided on the basis of universities and colleges (*högskolor*). With some minor exceptions, the 1977 reform of tertiary education completed shaping modern educational system of Sweden.

V.2. Trends in Human Capital Accumulation and Economic Growth

Table V.1. summarizes developments in average years of schooling per capita of productive population. Over 1870-2000 average time spent by a person of productive population in school increased by 10,5 years, of which major share of increase (7,4 years) fell on primary education (Ljungberg and Nilsson 2009: 83). However, while in the period

[11] Vocational training length was prolonged from two to three years in the early 1990s.

before 1950 growth in primary education accounted for about 94 percent of total increase, after 1950 its share in total increase fell to 50 percent indicating rising importance of voluntary education[12].

Table V.1. Average Years of Schooling, 1870-2000

	Primary	*Secondary*	*Tertiary*	*Vocational*	*Total*
1870	0,99	0,01	0,02	0,01	1,03
1880	1,43	0,02	0,03	0,01	1,49
1890	2,01	0,02	0,04	0,02	2,08
1900	2,58	0,03	0,04	0,02	2,67
1910	3,13	0,03	0,05	0,02	3,24
1920	3,69	0,04	0,06	0,03	3,82
1930	4,25	0,05	0,07	0,03	4,40
1940	4,75	0,06	0,08	0,06	4,95
1950	5,30	0,09	0,11	0,10	5,60
1960	6,17	0,14	0,15	0,19	6,66
1970	6,64	0,34	0,27	0,35	7,60
1980	7,31	0,60	0,50	0,48	8,89
1990	7,94	0,93	0,75	0,62	10,24
2000	8,40	1,20	1,14	0,79	11,52

Note: Constructed by author on the basis of the LU-MADD and Ljungberg and Nilsson (2009) data

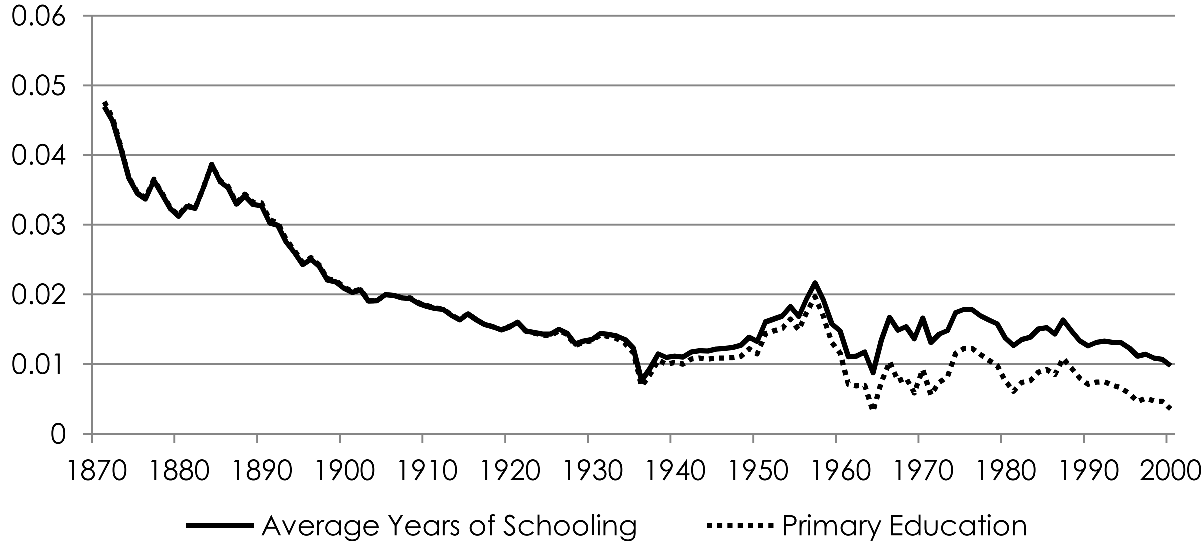
Other interesting conclusions from Table V.1. include (a) eightfold increase in contribution of secondary and tertiary education after 1960; and, (b) reduction of relative importance of vocational education when compared to secondary education around the same period. Both developments may be related to the Third Industrial Revolution, which brought dramatic changes to the labor market and the industrial structure of the economy putting an additional pressure on necessity of tertiary education expansion.

Looking at the rate of change in average years of schooling (Figures V.1. and V.2.) supports conclusions made above. Figure V.1. shows the change in total average years

[12] It is worth mentioning that we use modified classification between the educational levels when compared to the LU-MADD and Ljungberg and Nilsson (2009). The authors of the database distinguish between five levels: primary, lower secondary, upper secondary, tertiary and vocational. As it was pointed in Section V.1., lower secondary education was merged with primary education to form compulsory schooling. In order to make our analysis more comprehensible we, therefore, decided to consider lower secondary education as a part of primary education over the whole period. Secondary education in this paper refers to upper secondary education in the LU-MADD and Ljungberg and Nilsson (2009). Tertiary and vocational educational levels are considered as they appear in the database.

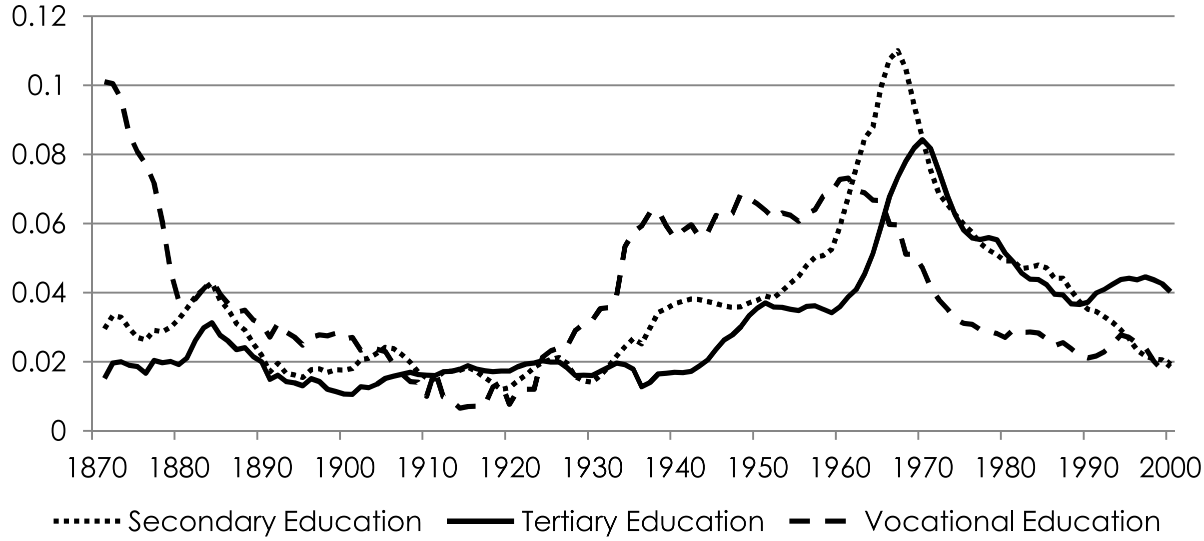
of schooling and those at the primary level. It suggests that the falling rate of human capital accumulation due to primary schooling determined a slow-down in growth of total average years of education. However, after the World War II trends diverge, which may be explained by a rapid expansion of voluntary education (Figure V.2). Growth in total average years of schooling stabilized around 1,5 per cent per year with a next slow-down starting in the late 1980s.

Figure V.1. Rate of Change of Average Years of Schooling due to Primary, and due to All Education, 1870-2000



Note: Constructed by author on the basis of the LU-MADD and Ljungberg and Nilsson (2009) data

Figure V.2. Rate of Change of Average Years of Schooling due to Secondary, Tertiary and Vocational Education, 1870-2000

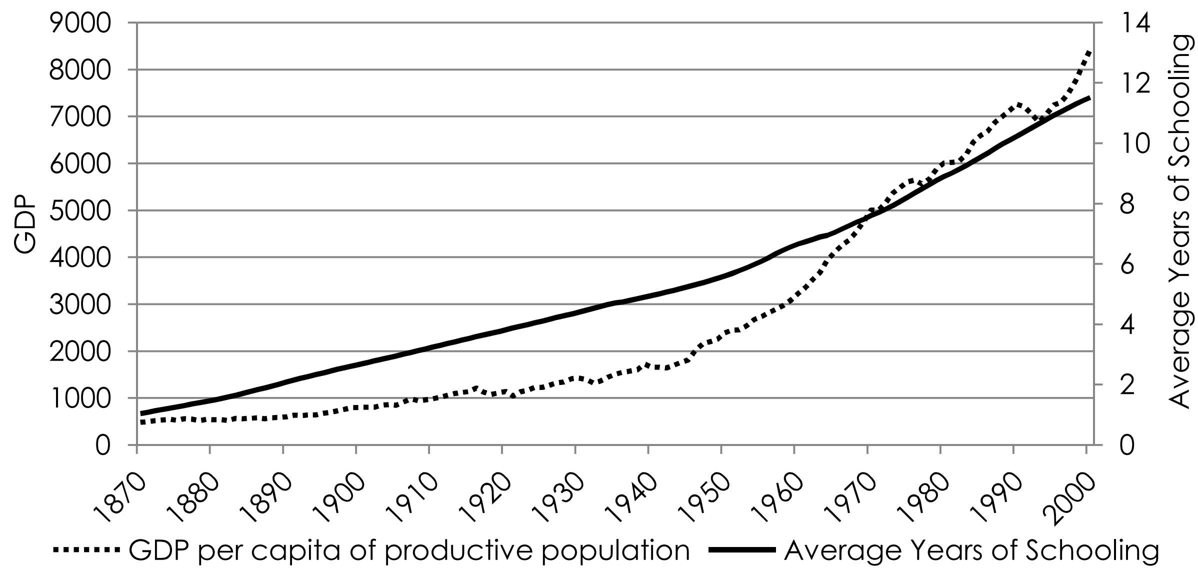


Note: Constructed by author on the basis of the LU-MADD and Ljungberg and Nilsson (2009) data

The boost in voluntary education growth, however, did not last for long with a vocational education growth rate peaking around 1960, secondary education – around 1967, and tertiary education – around 1970. Therefore, the transition to the uniform educational system after 1950 had a strong effect on human capital accumulation only for a limited period of time, which may be an indication of reaching some kind of the 'steady state' in which all citizens were able to get as much schooling as they wanted. In other words, increase in accessibility and uniformity of education was not enough to offset a decelerating rate of human capital accumulation (Ljungberg and Nilsson 2009: 87).

Figure V.3. relates average years of schooling to GDP per capita of productive population.

Figure V.3. Human Capital Accumulation and Economic Growth, 1870-2000



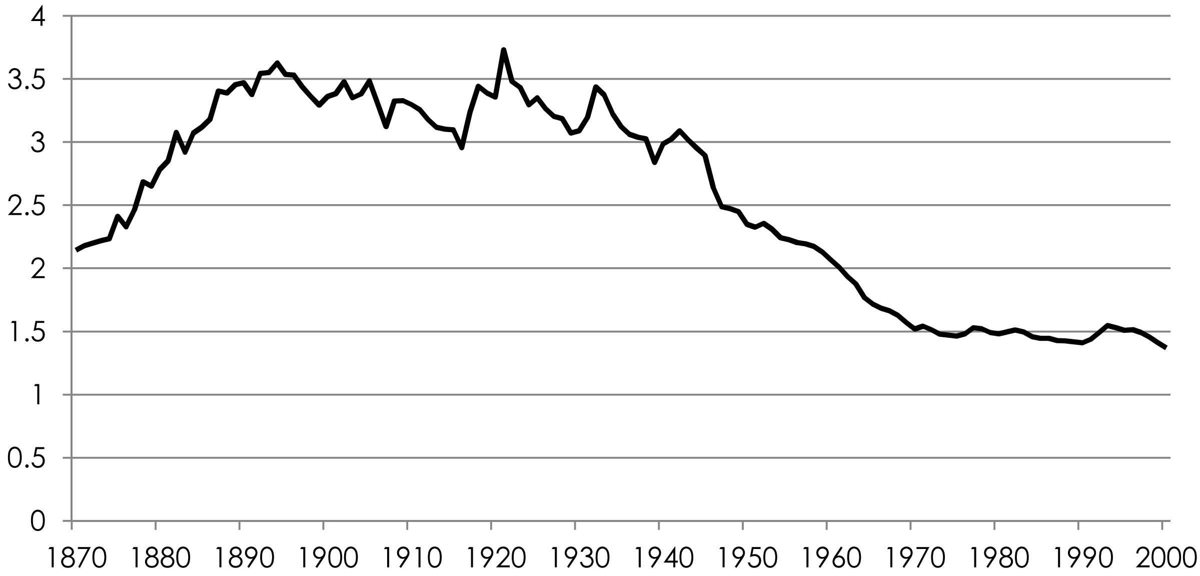
Note: Constructed by author on the basis of the LU-MADD, Krantz and Schön (2007) and Ljungberg and Nilsson (2009) data

It may be implied from Figure V.3. that average years of schooling were growing with about the same rate as GDP per capita of productive population (to be more certain, 1,87 per cent and 2,22 per cent annual growth rates respectively). However, while the former grows along an almost monotonous curve, the latter demonstrates some kind of a cyclic behavior. Thus, in order to make conclusions about contribution of human capital to economic growth we need to perform some deeper analysis of interrelations between them.

V.3. Interrelations between Human Capital and Economic Growth: Formulating the Hypotheses

We start our analysis of interrelations between human capital and economic growth by looking at a development of the human capital-to-GDP ratio over time (Figure V.4.).

Figure V.4. Human Capital-to-GDP Ratio, 1870-2000



Note: Constructed by author on the basis of the LU-MADD, Krantz and Schön (2007) and Ljungberg and Nilsson (2009) data. Human capital in thousands of standard years of schooling in population aged 15-65. GDP in millions Swedish Crowns in constant 1910/1912 market prices.

As follows from Figure V.4., the human capital-to-GDP ratio followed four distinctive patterns over time. It was rapidly increasing in the period before the mid-1880s, remained relatively constant between the mid-1880s and mid-1930s, declined substantially between the mid-1930s and early 1970s and turned constant again afterwards.

We employed Quandt-Andrews test in order to specify breakpoints in the data. 1888, 1934 and 1971 were the most robust suggestions, which appeared consistently in-between different test specifications. Chow test for joint significance of these breakpoints suggests that they are chosen correctly[13]. So, now we have four exactly identified sub-

[13] To perform Chow test we specified the following regression $\Delta\left(\frac{H}{Y}\right)_t = \alpha + \beta\left(\frac{H}{Y}\right)_{t-1} + \gamma t + u_t$ so that current developments in the series is explained by its past evolution. Chow test for joint significance of breakpoints in 1888, 1934 and 1971 returned zero probability of rejection of hypothesis about no breaks at specified periods.

periods: 1870-1887, 1888-1933, 1934-1970, 1971-2000.

In the period between 1870 and 1887, the human capital-to-GDP ratio was rapidly increasing, which may not be implied from the models of Lucas and Romer (see Table III.1). This may be attributed to three different factors. First, the amount of accumulated human capital was so small that neither its level nor its accumulation could launch and sustain a mechanism of endogenous growth and, thus, the models of Lucas and Romer models may not be applied *a priori*. Second, as it was already claimed in Section V.1. expansion of formal education in Sweden took place after the overall increase in literacy. As a consequence, an outrunning growth in the level of average years of schooling (when compared to GDP) could be misleading. Third, one can put under doubt an assumption that early industrialization required skills acquired through formal schooling. Goldin and Katz (1998) claimed that a complementarity between human capital and technology appeared in the times of the Second Industrial Revolution. Earlier industrialization was mainly based on traditional skills, and only with a transition to the modern economic growth pattern schooling became crucial. The fact that Second Industrial Revolution in Sweden started around 1890, which almost coincides with defined breakpoint in the human capital-to GDP ratio, gives support to the idea put forward by Goldin and Katz. Anyway, we should exclude this sub-period from further analysis since neither Lucas nor Romer model may be applied because of increasing human capital-to-GDP ratio.

In the other three sub-periods, however, the 'new growth theories' may be applied since the human capital-to-GDP ratio remained relatively constant or declined. As it was suggested in Section IV.3. in case of the Lucasian growth regime a series representing the human capital-to-GDP ratio should be stationary, while this does not hold in case of the Romerian growth. Results of Ng-Perron unit root test for this ratio are presented in Table V.2. on the next page.

As follows from the Table V.2., the human capital-to-GDP ratio series is stationary in the sub-periods 1888-1933 and 1971-2000. This implies that ratio fluctuates around constant mean, which in its turn means that the Lucasian growth regime is more likely to be dominating. In the sub-period 1934-1970, however, the human capital-to-GDP ratio series is not even trend-stationary, which suggests that growth is more of a Romerian nature[14].

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[14] As we exclude the period of 1870-1887 from our analysis, in the further parts of the paper we refer to 1888-1933 as to the first sub-period, 1934-1970 – the second sub-period, and, 1971-2000 – the third sub-period.

Table V.2. Unit Root Tests of Human Capital-to-GDP ratio

	α	MZa	MZt	MSB	MPT
Test statistics		-11,5$^{\perp}$	-2,40$^{\perp}$	0,209$^{\perp}$	2,14$^{\perp}$
	1%	-13,8	-2,58	0,174	1,78
1888-1933*	5%	-8,1	-1,98	0,233	3,17
	10%	-5,7	-1,62	0,275	4,45
Test statistics		-8,3	-2,03	0,246	11,02
	1%	-23,8	-3,42	0,143	4,03
1934-1970**	5%	-17,3	-2,91	0,168	5,48
	10%	-14,2	-2,62	0,185	6,67
Test statistics		-40,3$^{\perp}$	-4,26$^{\perp}$	0,106$^{\perp}$	1,22$^{\perp}$
	1%	-13,8	-2,58	0,174	1,78
1971-2000*	5%	-8,1	-1,98	0,233	3,17
	10%	-5,7	-1,62	0,275	4,45

Notes:

$^{\perp}$ Rejection of a unit-root hypothesis at 5% level and better

* Specification included only constant

** Specification included constant and trend

Critical values based on Ng-Perron (2001)

The first regime switch (from Lucasian to Romerian) around 1934 could mean that Sweden reached particular technological threshold after which human capital was not anymore contributing to economic growth just as a factor of production as it is suggested by model of Lucas, but rather became a technological facilitator which is a feature of Romerian growth. This is in line with previous studies (e.g., van Leeuwen 2007).

Transition from Romerian to Lucasian growth later in the twentieth century is, however, something less expected from a theoretical point of view. As follows from (III.32), after reaching particular level of accumulated human capital the Romerian growth is supposed to take place. It is also interesting that this transition coincides with the Third Industrial revolution. There are three possible explanations to this.

First, even in the situation with falling rates of human capital accumulation (see above), the general slow-down in Swedish economic growth in this period was too strong. Thus, the human capital-to-GDP ratio returned to a constant level.

Second, as it was pointed earlier, the Third Industrial Revolution put an additional pressure on necessity of higher education expansion, which could lead to the situation, when even large amounts of accumulated human capital due to primary and secondary education could not create enough impetus for economic growth and, therefore, it was only accumulation of human capital in the tertiary educational sector that was driving growth. Thus, economic growth switched to the Lucasian mode in its underlying mechanism, but of a different character than the Lucasian growth in the first sub-period.

Finally, this may be caused by the features of Romerian growth. If we come back to equation (III.31), we must conclude that economic growth should always accelerate as the level of human capital in the economy always increases, and that the human capital-to-GDP ratio should always decline. However, in reality both conclusions are doubtful. Economic growth rate increases in some periods and declines in the others. The human capital-to-GDP ratio cannot decline forever. Therefore, it is possible that at some moment in time the Romerian growth is replaced by Lucasian, because parameters of the economy's production function are changing and the economy needs to reach new human capital threshold in order to switch to Romerian growth again (in other words, as parameters of the economy may change over time, this may lead to an increase in the minimum level of accumulated human capital required for the Romerian growth in equation (III.32), thus, forcing the economy to switch to the Lucasian mode of growth). Therefore, the mechanism of human capital contribution to economic growth may be subject to some kind of a cyclic pattern in which over time the Lucasian mode of growth is replaced by the Romerian one and backward.

Despite some contradictory evidence when it comes to theoretical terms, the first test for distinguishing between the models suggested the following hypotheses about the mechanism of human capital contribution to economic growth.

H_1: *Economic growth in Sweden followed Lucasian pattern in the period between 1888 and 1933*

H_2: *Economic growth in Sweden followed Romerian pattern in the period between 1934 and 1970*

H_3: *After 1971 Swedish economic growth switched to a new Lucasian period*

These hypotheses lay the basis for the further empirical study.

VI. EMPIRICAL RESULTS

VI.1. Distinguishing between Growth Regimes: Cointegration Approach

Now that we have applied the first test for distinguishing between Lucasian and Romerian growth regimes and divided our sample into three sub-periods, we can proceed to a more detailed analysis of interrelations between human capital and economic growth. The next approach for defining dominating growth regime is a cointegration testing procedure discussed in Section IV.3.

First step is to test average years of schooling and GDP per capita of productive population series for presence of a unit root. For this purpose, we employ Ng-Perron test. Results are presented in Table VI.1.

Table VI.1. Unit Root Tests for Three Sub-Periods (Level Variables)

	α	MZa		MZt		MSB		MPT	
		sch_t	$\ln y_t$	sch_t	$\ln y_t$	sch_t	$\ln y_t$	sch_t	$\ln y_t$
Test statistics		-15,0	-8,12	-2,68	-1,88	0,178	0,232	6,43	11,59
1888-1933	1%	-23,8	-23,8	-3,42	-3,42	0,143	0,143	4,03	4,03
	5%	-17,3	-17,3	-2,91	-2,91	0,168	0,168	5,48	5,48
	10%	-14,2	-14,2	-2,62	-2,62	0,185	0,185	6,67	6,67
Test statistics		-19,3$^{\perp}$	-3,9	-3,01$^{\perp}$	-1,26	0,157$^{\perp}$	0,321	5,24$^{\perp}$	21,48
1934-1970	1%	-23,8	-23,8	-3,42	-3,42	0,143	0,143	4,03	4,03
	5%	-17,3	-17,3	-2,91	-2,91	0,168	0,168	5,48	5,48
	10%	-14,2	-14,2	-2,62	-2,62	0,185	0,185	6,67	6,67
Test statistics		-36,2$^{\perp}$	-24,7$^{\perp}$	-4,15$^{\perp}$	-3,47$^{\perp}$	0,115$^{\perp}$	0,141$^{\perp}$	3,06$^{\perp}$	3,92$^{\perp}$
1971-2000	1%	-23,8	-23,8	-3,42	-3,42	0,143	0,143	4,03	4,03
	5%	-17,3	-17,3	-2,91	-2,91	0,168	0,168	5,48	5,48
	10%	-14,2	-14,2	-2,62	-2,62	0,185	0,185	6,67	6,67

Notes:
$^{\perp}$ Rejection of a unit-root hypothesis at 5% level and better.
All specifications included constant and trend.
Critical values based on Ng-Perron (2001).

Ng-Perron test for stationarity reveals that in the first sub-period (1888-1933) neither average years of schooling nor GDP per capita of productive population are stationary. In the second sub-period (1934-1970) the former appears to be trend-stationary, while the latter is still suggested to have a unit root. Finally, for the third sub-period (1971-2000) test suggests that both series are trend-stationary. The fact that GDP per capita of productive population is trend-stationary in the third sub-period is a bit strange as macroeconomic variables are usually I(1).

This could be caused by relatively small size of the third sub-sample. However, since we stick to periodization defined in Section V.3., we will trust the obtained result[15].

In order to determine an order of integration for those variables, which were not stationary in levels we also perform unit root tests for first differences. Results are presented in Table VI.2.

Table VI.2. Unit Root Tests for Three Sub-Periods (First-Differenced Variables)

	α	MZa		MZt		MSB		MPT	
		Δsch_t	Δy_t	Δsch_t	Δy_t	Δsch_t	Δy_t	Δsch_t	Δy_t
Test statistics		-9,4$^{\perp}$	-17,0$^{\perp}$	-2,09$^{\perp}$	-2,89$^{\perp}$	0,223$^{\perp}$	0,170$^{\perp}$	2,92$^{\perp}$	1,55$^{\perp}$
1888-1933	1%	-13,8	-13,8	-2,58	-2,58	0,174	0,174	1,78	1,78
	5%	-8,1	-8,1	-1,98	-1,98	0,233	0,233	3,17	3,17
	10%	-5,7	-5,7	-1,62	-1,62	0,275	0,275	4,45	4,45
Test statistics		n.a.	-18,7$^{\perp}$	n.a.	-3,04$^{\perp}$	n.a.	0,163$^{\perp}$	n.a.	1,36$^{\perp}$
1934-1970	1%	n.a.	-13,8	n.a.	-2,58	n.a.	0,174	n.a.	1,78
	5%	n.a.	-8,1	n.a.	-1,98	n.a.	0,233	n.a.	3,17
	10%	n.a.	-5,7	n.a.	-1,62	n.a.	0,275	n.a.	4,45
Test statistics		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1971-2000	1%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	5%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	10%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Notes:
$^{\perp}$ Rejection of a unit-root hypothesis at 5% level and better.
All specifications included only constant.
Critical values based on Ng-Perron (2001).

As follows from Table VI.2, those variables which were not stationary in levels are all stationary in first differences. Therefore, based on Tables VI.1. and VI.2. we can make conclusions about the order of integration of average years of schooling and GDP per capita of productive population series (Table VI.3.).

These findings suggest that if there are long-run relationships between human capital and economic growth, they may exist between growth in average years of schooling

[15] Besides, GDP per capita of productive population series is also suggested to be stationary in the third sub-period by KPSS and Elliott-Rothenberg-Stock unit root tests.

Table VI.3. Order of Integration for Human Capital and Economic Growth Series for Three Sub-Periods

	1888-1933	1934-1970	1971-2000
$\ln y_t$	I(1)	I(1)	I(0)
sch_t	I(1)	I(0)	I(0)

and growth of GDP per capita of productive population, hence Lucasian growth, in the first and the third sub-periods (see equation IV.6.), and between level of average years of schooling and growth in GDP per capita of productive population, hence Romerian growth, in the second sub-period (equation IV.8.). To test whether these long-run relationships actually exist we have to test for cointegration between the variables. For this purpose we apply the two-step Engle-Granger procedure. In the first step, cointegration equations are estimated and residuals from these equations are saved. In the second step, residuals are tested for stationarity. Results are presented in Table VI.4.

Table VI.4. Unit Root Tests for Residuals from Cointegrating Equations

	α	Tested variable - ε_t			
		MZa	MZt	MSB	MPT
Test statistics		-6,3	-1,76	0,279	3,95
1888-1933*	1%	-13,8	-2,58	0,174	1,78
	5%	-8,1	-1,98	0,233	3,17
	10%	-5,7	-1,62	0,275	4,45
Test statistics		-16,1$^{\perp}$	-2,84$^{\perp}$	0,176$^{\perp}$	1,53$^{\perp}$
1934-1970**	1%	-13,8	-2,58	0,174	1,78
	5%	-8,1	-1,98	0,233	3,17
	10%	-5,7	-1,62	0,275	4,45
Test statistics		-19,7$^{\perp}$	-3,11$^{\perp}$	0,158$^{\perp}$	1,35$^{\perp}$
1971-2000*[16]	1%	-13,8	-2,58	0,174	1,78
	5%	-8,1	-1,98	0,233	3,17
	10%	-5,7	-1,62	0,275	4,45

Notes:
$^{\perp}$ Rejection of a unit-root hypothesis at 5% level and better.
All specifications included only constant.
* Residuals are saved from cointegrating equation $lny_t = \alpha_0 + \alpha_1 sch_t + \gamma trend + \varepsilon_t$
** Residuals are saved from cointegrating equation $\Delta lny_t = \alpha_0 + \alpha_1 sch_t + \gamma trend + \varepsilon_t$
Critical values based on Ng-Perron (2001).

[16] From the strict statistical point of view is it not reasonable to test for cointegration between growth in average years of schooling and growth in GDP per capita of productive population in the third sub-period as both variables are I(0). However, since this is just one of the tests for determining dominating growth regime we will leave the results as they are.

It follows from Table VI.4. that while residual for cointegration equation is stationary only at 10 per cent significance level for the first sub-period, it is strictly significant for the second and the third sub-periods. We, therefore, get some support for all three hypotheses, though, stronger one for *H2* and *H3*.

Further, by performing regression analyses, we will continue testing our hypotheses as well as will try to quantify an effect that human capital had on economic growth.

VI.2. Distinguishing between Growth Regimes: Regression Approach

In this section we apply regression models specified in Appendix 5 in order to perform the third test for dominating growth regime in each of earlier defined sub-periods. It should be noted that since those regressions cover limited time periods they are ignoring longer economic trends which may influence coefficients for human capital variable. Therefore, in this section we do not aim to make any final conclusions about the size of human capital effect on economic growth. This will be done further in Section VI.4, where we model economic growth over the whole considered period.

Results of estimations for the first sub-period are presented in Table VI.5 (see page 43). According to it, we can make the following conclusions:

(1) average years of schooling do not have a significant effect on economic growth in the first sub-period neither in growth nor in level specification;

(2) coefficients for human capital variable are highly sensitive to different regression specifications: they vary not only in the size of an effect, but also in the sign (except for positive coefficients in the models where a log-level of physical capital is included, the effect of average years of schooling on growth is suggested to be negative);

(3) nevertheless, adjusted coefficient of determination and information criteria signal that the Lucasian growth is more likely which is in accordance with previous analysis.

Table VI.6. (page 44) summarizes results of second sub-period regressions. In the second sub-period coefficients for average years of schooling are more robust (both in size and sign) when compared to the first one. However, while the Lucas-type models return negative and insignificant coefficients, the level of average years of schooling in Romer-type specifications tends to have positive and significant effect on economic growth (with the exception of (R2) regression where physical capital is introduced only in growth specification – in this specification coefficient for average years of schooling is positive but insignificant). Though general fit of the Romer-type models is somewhat lower, significance of human capital coefficients makes us conclude that the Romerian growth regime is a better approximation for human capital contribution to economic growth in the second sub-period.

Table VI.5. Regression Test for Dominating Growth Regime, 1888-1933

	Dependent Variable - $\Delta\, ln\, y_t$*						
		Lucas-type models			*Romer-type models*		
	(M)	(L1)	(L2)	(L3)	(R1)	(R2)	(R3)
Constant	4,6542 (0,0009)**	4,4695 (0,0001)	4,7582 (0,0002)	5,4040 (0,0001)	3,6591 (0,0027)	3,7168 (0,0034)	3,4131 (0,0200)
Trend	0,0359 (0,3515)	0,0235 (0,3387)	0,0227 (0,3606)	0,0977 (0,1511)	0,0254 (0,5091)	0,0238 (0,5492)	0,0098 (0,8501)
ΔSch_{t-1}	-2,9496 (0,1293)	-1,2733 (0,5839)	-1,0528 (0,6205)	1,3827 (0,6570)			
imb_{t-1}		-0,0545 (0,9000)	-0,0156 (0,9719)	-1,1920 (0,2709)			
imb_{t-1}^2		-0,0215 (0,2067)	-0,0241 (0,1759)	-0,0501 (0,0780)			
Sch_{t-1}	-0,3294 (0,6100)				-0,1929 (0,7668)	-0,1600 (0,8137)	0,0740 (0,9335)
$\Delta \ln y_{t-1}$	0,0481 (0,7379)	0,0872 (0,5535)	0,1143 (0,4634)	0,0077 (0,9655)	0,0409 (0,5091)	0,0494 (0,7488)	0,0850 (0,6329)
$\ln y_{t-1}$	-0,7046 (0,0002)	-0,7582 (0,0001)	-0,8049 (0,0002)	-0,6583 (0,0069)	-0,5871 (0,0005)	-0,6020 (0,0014)	-0,6506 (0,0038)
$\Delta \ln k_{t-1}$			0,3157 (0,5634)	-0,0416 (0,9463)		0,1110 (0,8433)	0,2217 (0,7236)
$\ln k_{t-1}$				-0,4564 (0,2342)			0,0612 (0,6771)
Obs.	46	46	46	46	46	46	46
Adjusted R^2	0,2422	0,2594	0,2463	0,2556	0,2143	0,1949	0,1776
AIC	-3,8561	-3,8617	-3,8273	-3,8237	-3,8382	-3,7957	-3,7568
SIC	-3,5779	-3,5436	-3,4695	-3,4262	-3,5996	-3,5174	-3,4388

Notes:

* Dummies are not reported

** P-Values are reported

Table VI.6. Regression Test for Dominating Growth Regime, 1934-1970

	*Dependent Variable - $\Delta\, ln\, y_t$**						
		Lucasian models			*Romerian models*		
	(M)	(L1)	(L2)	(L3)	(R1)	(R2)	(R3)
Constant	3,4704 (0,0000)**	3,7910 (0,0000)	3,6988 (0,0000)	3,8524 (0,0000)	3,4636 (0,0000)	3,5653 (0,0000)	4,0358 (0,0000)
Trend	0,0144 (0,0029)	0,0271 (0,0001)	0,0270 (0,0000)	0,0209 (0,0015)	0,0148 (0,0030)	0,0146 (0,0053)	0,0177 (0,0042)
ΔSch_{t-1}	-0,2660 (0,0782)	-0,2317 (0,1146)	-0,2305 (0,1234)	-0,2684 (0,1018)			
imb_{t-1}		-0,3779 (0,0008)	-0,3777 (0,0010)	-0,2514 (0,0951)			
imb_{t-1}^2		0,0420 (0,0000)	0,0413 (0,0002)	0,0308 (0,0149)			
Sch_{t-1}	0,0771 (0,0771)				0,0660 (0,0374)	0,0667 (0,1258)	0,1043 (0,0282)
$\Delta \ln y_{t-1}$	0,1321 (0,2072)	0,1617 (0,1164)	0,1575 (0,1409)	0,2002 (0,0812)	0,1772 (0,0966)	0,1822 (0,1014)	0,1245 (0,3107)
$\ln y_{t-1}$	-0,6480 (0,0002)	-0,6607 (0,0000)	-0,6473 (0,0000)	-0,7928 (0,0000)	-0,6461 (0,0000)	-0,6635 (0,0000)	-0,5953 (0,0001)
$\Delta \ln k_{t-1}$			-0,0752 (0,8449)	0,3638 (0,4115)		0,0918 (0,8346)	-0,0752 (0,8722)
$\ln k_{t-1}$				0,1354 (0,4430)			-0,1696 (0,3013)
Obs.	37	37	37	37	37	37	37
Adjusted R^2	0,7394	0,7542	0,7455	0,7724	0,7183	0,7087	0,7099
AIC	-5,6866	-5,7453	-5,6927	-5,7733	-5,7279	-5,6754	-5,6617
SIC	-5,2948	-5,3535	-5,2573	-5,2509	-5,3796	-5,2836	-5,2263

Notes:

* Dummies are not reported

** P-Values are reported

Finally, regression analysis for the third sub-period is summarized in Table VI.7 (see next page).

Regression specifications for the third sub-period are a bit different when compared to the previous two: getting rid of residual autocorrelation problem made us include more lags for some variables. Possible explanation for facing this problem is that as economy develops it becomes more inert and, thus, less able to transform signals from particular sources of growth (in our case, capital investments and changes in average years of schooling) into growth at an aggregated level.

Table VI.7. Regression Test for Dominating Growth Regime, 1971-2000

	Dependent Variable - $\Delta \ln y_t$*						
		Lucasian models			*Romerian models*		
	(M)	(L1)	(L2)	(L3)	(R1)	(R2)	(R3)
Constant	0,0316 (0,9726)**	-0,8462 (0,4109)	1,7747 (0,3620)	1,6658 (0,4355)	0,9270 (0,3437)	2,5782 (0,0169)	2,7775 (0,0114)
Trend	0,0578 (0,0037)	0,0527 (0,0038)	0,0645 (0,0028)	0,0654 (0,0049)	0,0359 (0,0539)	0,0482 (0,0069)	0,0481 (0,0068)
ΔSch_{t-1}	-0,4646 (0,0645)	-0,4388 (0,0663)	-0,4671 (0,0457)	-0,4636 (0,0554)			
ΔSch_{t-2}	0,7659 (0,0157)	0,6754 (0,0225)	0,5198 (0,0740)	0,5540 (0,1458)			
imb_{t-1}		-0,45853 (0,0024)	-0,3320 (0,0335)	-0,3408 (0,0480)			
imb_{t-1}^2		0,0073 (0,0499)	-0,0023 (0,7605)	-0,0022 (0,7726)			
Sch_{t-1}	-0,3754 (0,0088)				-0,4163 (0,0908)	-0,5240 (0,0185)	-0,6100 (0,0103)
Sch_{t-2}	0,1639 (0,2401)				0,2061 (0,4098)	0,2761 (0,2036)	0,3652 (0,1136)
$\Delta \ln y_{t-1}$	0,4958 (0,0454)	0,3779 (0,0175)	0,7749 (0,0079)	0,7463 (0,0365)	0,34392 (0,0232)	0,6231 (0,0010)	0,8240 (0,0020)
$\Delta \ln y_{t-2}$	-0,3449 (0,0273)	-0,4300 (0,0087)	-0,2050 (0,2806)	-0,2305 (0,3791)	-0,2539 (0,1262)	-0,1796 (0,2413)	-0,0505 (0,7832)
$\ln y_{t-1}$	-0,3578 (0,0024)	-0,2633 (0,0316)	-0,7675 (0,0442)	-0,7186 (0,1611)	-0,3427 (0,0079)	-0,6575 (0,0003)	-0,9505 (0,0034)
$\Delta \ln k_{t-1}$			-0,4727 (0,6459)	-0,5190 (0,6392)		-0,8785 (0,3820)	-0,4913 (0,6359)
$\Delta \ln k_{t-2}$			2,1104 (0,0751)	2,0328 (0,1257)		2,2821 (0,0251)	2,5847 (0,0149)
$\ln k_{t-1}$				-0,0376 (0,8829)			0,2404 (0,2386)
Obs.	30	30	30	30	30	30	30
Adjusted R^2	0,6545	0,6903	0,7157	0,6983	0,5563	0,6791	0,6871
AIC	-5,9825	-6,0765	-6,1400	-6,0747	-5,7504	-6,0412	-6,0539
SIC	-5,5155	-5,5628	-5,5328	-5,4208	-5,3301	-5,5274	-5,4934

Notes:
* Dummies are not reported
** P-Values are reported

Table VI.7. suggests the following:

(1) in case of the Lucas-type models negative effect in one-period lag is outweighed by positive effect from two-period lagged variable totaling in positive effect of

growth in average years of schooling. However, coefficients are sensitive to model specification (cumulative two-periods effect is varying in size; besides, second lag is not significant in case of including log-level of physical capital);

(2) on the contrary, in case of the Romer-type models, significance of coefficients improves when we account for physical capital variables. Cumulative effect, however, is negative, though a bit mitigated when second lag of schooling variable is included. Variation in the size of coefficient is quite large making us conclude that the effect of human capital on growth is unstable in Romer-type regressions;

(3) obtaining more or less significant coefficients in both Lucas- and Romer-type models makes it difficult to decide on dominating growth regime in the third sub-period. Adjusted coefficient of determination and information criteria, however, suggest that the Lucas-type models tend to explain economic growth a bit better.

At this point we are done with performing tests on dominating growth regime for three sub-periods, and can now proceed to making some conclusions.

VI.3. Distinguishing between Growth Regimes: Summarizing Results

Results from three tests for dominating growth regimes are summarized in Table VI.8.

Table VI.8. Dominating Growth Regimes: Tests Summary

Test	Sub-Periods		
	1888-1933	1934-1970	1971-2000
Human Capital-to-GDP Ratio	Lucasian	Romerian	Lucasian
Cointegration Approach	Lucasian	Romerian	Lucasian
Regression Approach	Lucasian	Romerian	Ambiguous

In general, all three tests yield similar results for the first and the second sub-periods, which makes it possible to conclude that hypotheses *H1* and *H2* formulated in Section V.3. are fully supported by our analysis. It implies that mechanism behind human capital contribution to economic growth has undergone transition from Lucasian to Romerian growth regime after 1934.

When it comes to the third sub-period, deciding on a dominating growth regime is a bit tricky. On the one hand, two out of three tests suggest that growth in 1971-2000 was likely to be of a Lucasian character. On the other hand, ambiguous results of the regression test for distinguishing between the models made us look at the results of the first two tests more carefully.

When it comes to the human capital-to-GDP ratio test, the results could not be any clearer – graphical representation as an almost horizontal line coupled with stationarity of series representing this ratio (meaning that it fluctuates around constant mean) imply that the Lucasian growth regime dominated in the third sub-period.

However, as human capital enters the Romerian production function (though, on a residual basis) finding long-term relationship between growth in human capital and GDP growth is not sufficient condition to reject the Romerian growth. In that respect, the results of the cointegration test may be misleading.

All in all, for the third sub-period we have one test with clear results and two tests with results being rather ambiguous. Therefore, when modeling human capital contribution to economic growth over the whole period, we will consider both possible options, namely, Lucasian and Romerian growth in the third sub-period.

VI.4. The Effect of Human Capital on Economic Growth: Some Estimates

Now that we have defined dominating growth regime for each of the sub-periods, we will try to estimate an effect of human capital on economic growth over the whole period 1888-2000. In order to control for switches in growth modes we use dummy variables. The results of estimation are presented in Table VI.9.

Column (1) of Table VI.9. provides report of an estimation of Macro-Mincer equation corrected for our periodization (with the Lucasian growth assumed for the third sub-period). As we can see, human capital had a positive and significant effect on economic growth in the first two sub-periods so that in 1888-1933 an acceleration of *growth* in average years of schooling by one year per year would boost economic growth by 220 per cent, while in 1934-1970 an increase in *level* of already achieved years of schooling by one year would lead to 12 per cent speed-up in economic growth. For the third period increase in schooling is suggested to slow-down output growth. Though, insignificance of a coefficient does not allow making any serious conclusions about the nature of human capital contribution to economic growth in that sub-period. In column (2), we tried to include second lag for changes in schooling in the third sub-period (as it was done before in Section VI.2.), however, this did not lead to significantly different results. It is interesting to point here, that in both Lucasian periods we obtain negative (and significant) coefficient for a second polynomial of an imbalance effect variable, which implies that the imbalance effect has a form of an inverted U-curve. This may be interpreted in the following way: any deviation of the human capital-to-physical capital ratio from its equilibrium value leads to deceleration of economic growth.

Table VI.9. The Effect of Human Capital on Economic Growth, 1888-2000

	Dependent Variable - $\Delta\, ln\, y_t$*					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	2,9243 (0,0000)**	2,9239 (0,0000)	2,8676 (0,0000)	2,8085 (0,0000)	2,4429 (0,0000)	2,3188 (0,0000)
Trend	0,0025 (0,5424)	0,0025 (0,5460)	0,0028 (0,5251)	0,0008 (0,8795)	0,0029 (0,4997)	0,0035 (0,4218)
$D_{1888-1933} * \Delta Sch_{t-1}$	2,2038 (0,0190)	2,2024 (0,0198)	2,1146 (0,0443)	1,1166 (0,5090)	1,2479 (0,1113)	1,0868 (0,1798)
$D_{1888-1933} * imb_{t-1}$	0,2354 (0,0040)	0,2355 (0,0042)	0,2258 (0,0189)	0,2344 (0,0159)	0,1734 (0,0124)	0,1521 (0,0407)
$D_{1888-1933} * imb_{t-1}^2$	-0,0303 (0,0076)	-0,0303 (0,0080)	-0,0296 (0,0139)	-0,0219 (0,1661)	-0,0228 (0,0315)	-0,0215 (0,0460)
$D_{1934-1970} * Sch_{t-1}$	0,1203 (0,0077)	0,1203 (0,0080)	0,1148 (0,0313)	0,1174 (0,0285)	0,0839 (0,0249)	0,0722 (0,0721)
$D_{1971-2000} * \Delta Sch_{t-1}$	-0,4063 (0,6164)	-0,3976 (0,4331)	-0,3998 (0,3605)	-0,4385 (0,3206)		
$D_{1971-2000} * \Delta Sch_{t-2}$		-0,0175 (0,9733)				
$D_{1971-2000} * imb_{t-1}$	0,2390 (0,0054)	0,2394 (0,0059)	0,2285 (0,0254)	0,2287 (0,02569)		
$D_{1971-2000} * imb_{t-1}^2$	-0,0116 (0,0052)	-0,0116 (0,0057)	-0,0111 (0,0240)	-0,0103 (0,0393)		
$D_{1971-2000} * Sch_{t-1}$					0,0819 (0,0257)	0,0701 (0,0763)
$\Delta \ln y_{t-1}$	0,0718 (0,4298)	0,0714 (0,4375)	0,0665 (0,4851)	0,0979 (0,3484)	0,0164 (0,8544)	0,0005 (0,9500)
$\ln y_{t-1}$	-0,4892 (0,0000)	-0,4891 (0,0000)	-0,4797 (0,0000)	-0,5350 (0,0000)	-0,4039 (0,0000)	-0,3835 (0,0000)
$\Delta \ln k_{t-1}$			-0,0655 (0,8481)	0,0275 (0,9399)		-0,2450 (0,4321)
$\ln k_{t-1}$				0,0755 (0,4531)		
Obs.	113	113	113	113	113	113
Adjusted R^2	0,3133	0,3062	0,3064	0,3032	0,3054	0,3027
AIC	-4,4019	-4,3842	-4,3846	-4,3729	-4,3979	-4,3866
SIC	-4,0157	-3,9739	-3,9743	-3,9384	-4,0359	-4,0004

Notes:
* Dummies are not reported
** P-Values are reported

Accounting for growth in physical capital, which is done in column (3), does not substantially influence the results – the size of most coefficients remains almost unchanged. However, the significance of coefficients for human capital variables falls a little bit (though, coefficients are still significant at 5 per cent level).

If we include a log-level of physical capital along with growth in this variable [column (4)], results change considerably. The effect of growth in years of schooling in the first sub-period loses half of its magnitude and becomes insignificant. In the second Lucasian sub-period (1971-2000), coefficients become 10% more negative (though, still remaining insignificant). On the other hand, the effect of level of average years of schooling in the second sub-period keeps the same value. It should be pointed, however, that due to strong collinearity between a log-level of GDP per capita of productive population and a log-level of physical capital ($r_{\ln y_t/\ln k_t}$ =0,9978) estimates for individual regressors may be biased. Therefore, we should not trust column (4) model too much.

Results of estimating the same equations but assuming the Romerian growth in the third sub-period are reported in columns (5) and (6)[17]. The major improvement in those models is that now we obtain positive coefficients for human capital variables in all three sub-periods. However, when it comes to the first sub-period, coefficient loses its significance. Besides, for the first two sub-periods coefficients are significantly lower when compared to models in which the Lucasian growth was assumed for the third sub-period. What is also interesting, coefficients for human capital variables become less robust conditional on an inclusion of growth in physical capital – they lose more in size and significance than in case of the Lucasian growth in the third sub-period. So, when we assume the Romer model to explain growth in the third sub-period, we obtain somewhat less robust specifications.

All in all, our models suggest that human capital (in growth and level specifications) had the positive effect on economic growth in the first two sub-periods. However, when it comes to the third sub-period, situation is quite uncertain. Possible explanations for that include:

(1) *incorrect specification of human capital variable* – this could work in two ways. First, since years of schooling ignore some aspects of human capital (e.g. experience), it is possible that coefficients we obtain are misleading. Besides, it

[17] We do not present results for the model for which log-level of physical capital is included since problem of multicollinearity leads to biased estimates anyway.

may be reasonable to assume that skills due to formal schooling could become of less importance than, for example, skills acquired through learning-by-doing in the third sub-period. Second, we already pointed that the Third Industrial Revolution put an additional pressure on necessity of higher education. Thus, we may assume that it was only growth in average years of schooling due to tertiary education which actually was driving growth, while levels of primary and secondary education were just necessary conditions for growth to happen. Therefore, including aggregated years of schooling for the third sub-period could lead to the biased results.

(2) reverse causality in the third sub-period – as Ljungberg and Nilsson (2009) suggest, while for the period 1870-1970 increase in average years of schooling caused economic growth, after 1970 there is some evidence for bi-directional or even reverse causality (from economic growth to more education), depending on the educational level. If the latter is true, it is possible that the whole idea of estimating an effect of total (including all educational levels) average years of schooling on growth in the third sub-period is not correct.

What follows from discussion above, looking at an effect of average years of schooling due to different educational levels may be a fruitful topic for future research. However, because of limited character of this paper we are not able to perform it right now.

This completes our analysis, so we are now ready to proceed to some conclusions.

VII. CONCLUSION

In this paper we tried to perform an assessment of human capital contribution to economic growth in Sweden over the period of 1870-2000 with relation to the 'new growth theories' developed by Lucas (1988) and Romer (1990).

It has been shown that Swedish development over considered period could be divided into several sub-periods, which have particular features when it comes to interrelations between human capital and economic growth. The period of 1870-1887 was skipped in the analysis since neither Lucas nor Romer model could be applied to it. In the first of analyzed sub-periods (1888-1933), the Lucasian growth regime was likely to be dominating, that is, the rate of economic growth was defined by the rate of human capital accumulation $(\Delta \ln y_t \propto \Delta \ln h_t)$. After 1934, economic growth switched to the Romerian mode, that is the rate of economic growth was defined by already accumulated level of human capital $(\Delta \ln y_t \propto \ln h_t)$. When it comes to the third sub-period (1971-2000), the results of tests for distinguishing between growth regimes were in most cases ambiguous, meaning that we could not define dominating growth regime based on the methodology suggested in this research.

Conditional on the defined sub-periods, we performed regression analyses in order to provide some quantitative estimates of the effect that human capital had on economic growth over considered period. Given the third sub-period growth regime uncertainty, we estimated two types of models: (a) assuming the Lucasian growth after 1970; and, (b) assuming the Romerian growth for the same period.

It has been shown that if we assume the Lucasian growth regime to be dominating in the third sub-period, there are positive and significant relationships between human capital and economic growth in the first two sub-periods, while for the third one such correlation is not found (see Table VII.1). An increase in the growth of average years of schooling by one year per year would lead to more than trebling of growth rate in the first sub-period. In the second sub-period, an increase in the level of average years of schooling by one year would lead to 12 per cent increase in an annual growth rate. In the third sub-period, the coefficient for the growth in average years of schooling was negative, though insignificant.

In case of assuming the Romerian growth for the third sub-period, results are somewhat different. We obtain positive coefficients for human capital variables in all three sub-periods; however, coefficient for the first one is not significant (see Table VII.1). In the second and the third sub-periods, increase in average years of schooling by one year would lead to eight per cent increase in an annual growth rate.

Table VII.1. Summary of Regression Analyses

	Dependent variable – $\Delta \ln y_t$		
	(a) Lucasian growth after 1970		
Sub-Period	1888-1933	1934-1970	1971-2000
Δsch_t	2,2*		-0,4
sch_t		0,12*	
	(b) Romerian growth after 1970		
Sub-Period	1888-1933	1934-1970	1971-2000
Δsch_t	1,3		
sch_t		0,08*	0,08*

Note:
* Variables are significant at 5% level

Note: Based on Table VI.9.

In general, therefore, our results correspond to previous growth regression studies since they suggest positive correlation between human capital and economic growth (see Appendix 2 for review of growth regressions).

We have also supported idea put forward by Temple (1999) that growth regressions incorporating human capital as an independent variable are very sensitive to different specifications. For example, including growth in physical capital in regressions where the Romer-type relationships between human capital and growth were assumed for the third sub-period reduced both size and significance of human capital coefficients (Table VI.9). One more example here, when we assumed the Romerian growth for the third sub-period, coefficient for growth in average years of schooling in the first sub-period lost almost half of its magnitude and became insignificant when compared to the models with the Lucasian growth assumed for the third sub-period. It would be reasonable to expect, however, that changing growth mode for the third sub-period should not affect results obtained for the first one. All in all, we may conclude that specification issues matter in growth regressions with human capital.

It was suggested that possible reasons for ambiguous results for the third sub-period include:

(a) *possible reverse causality direction* - Ljungberg and Nilsson (2009) suggest that after 1970 there is evidence for bi-directional or even reverse causality (from economic growth to more education);

(b) *using average years of schooling as a proxy for human* capital – being one-sided representation of human capital concept, average years of schooling could lead to biased estimates of the effect of human capital on growth (and, more generally, incorrect specification of the sub-periods). Complex nature of human capital, in that respect, requires employing not one single indicator, but rather system of indicators and/or an index indicator which would cover not only human capital due to formal education, but also experience, learning-by-doing, as well as costs and monetary outcomes of attaining particular level of human capital. This would help to (1) better capture the indirect effects of human capital on economic growth; (2) better understand an importance of particular areas of human capital at different stages of economic development; (3) develop a wider framework for studies of interrelations between human capital and economic growth;

(c) *employing aggregated years of schooling variable (not considering different educational levels)* – as previous research on relationships between education and economic growth suggests, different levels of education may play different role as country goes through the development process (Gemmell 1996; Petrakis and Stamatakis 2001). Therefore, using aggregate years of education may hinder some processes taking place in the economy. For example, it was hypothesized in this research that as the Third Industrial Revolution expanded it put some additional pressure on necessity of higher education, making lower educational levels necessary but not sufficient conditions for growth. Therefore, it is possible that studying effects of primary, secondary and tertiary education on economic growth separately will help to get some better knowledge on their relationships.

These fields may constitute the agenda for further research on relationships between human capital and economic growth in Sweden.

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APPENDIX 1. THE EFFECT OF HUMAN CAPITAL ON ECONOMIC GROWTH: RESULTS FROM GROWTH ACCOUNTING

	Output measure	TFP	Physical capital	Human capital	Elasticities for inputs
Jorgenson-Fraumeni (1992)	Growth accounting: output growth rates, US, 1948-1986	17%	22%	61% (labor input) of which 42% accounted by labor quality	Shares of the inputs in aggregated value added
Mankiw, Romer and Weil (1992)	Level accounting, cross-country differences in output per worker, 98 countries, 1985	22%	29%	49%	For K=0,31 For H=0,28
Bosworth, Collins and Chen (1995)	Growth accounting, cross-country differences in growth in output per worker, industrial countries, 1960-1992	44%	43%	13%	For K=0,3 For H=0,7
Bosworth, Collins and Chen (1995)	Growth accounting, cross-country differences in growth in output per worker, Asian countries (excluding China), 1960-1992	26%	62%	12%	For K=0,4 For H=0,6
Klenow and Rodriquez (1997)	Level accounting, cross-country differences in output per worker, 98 countries, 1985	67%	29%	4%	For K=0,3 For H=0,28
Klenow and Rodriquez (1997)	Growth accounting, cross-country differences in growth in output per worker, 98 countries, 1960-1985	85-90%	3%	6-12%	For K=0,3 For H=0,28
Hall and Jones (1999)	Level accounting, cross-country differences in output per worker, 127 countries, 1988	61%	17%	22% (educational attainment for the population aged 25 and older)	For K=0,3 For H, piecewise linear in years of education according to Psacharopoulos (1994): =0,134 for 1-4 years =0,101% for 5-8 years =0,068 for over 8 years

***Sources**: Sianesi and van Reenen (2003); van Leeuwen (2007); own research*

APPENDIX 2. THE EFFECT OF HUMAN CAPITAL ON ECONOMIC GROWTH: RESULTS FROM GROWTH REGRESSIONS

	Output measure	Human capital proxy	Flow/Stock	Estimated coefficient
Barro (1991)	Annual growth rate of real per capita GDP, 98 countries, 1960-1985	School enrollment rate in primary and secondary education in 1960	Initial flow	Primary = 0,025 Secondary = 0,03
Murphy, Shleifer and Vishny (1991)	Annual growth rate of real per capita GDP, 91 countries, 1970-1985	Primary school enrollment rate in 1960	Initial flow	0,022
Levine and Renelt (1992)	Annual growth rate of real per capita GDP, 119 countries, 1960-1989	Secondary school enrollment rate in 1960	Initial flow	0,032 (base estimate)
Barro and Lee (1994)	Annual $\Delta \ln(\text{GDP per worker})$, 116 countries, 1965-1985	Average years of secondary schooling of adult male population in 1965	Initial stock	0,014
Benhabib and Spiegel (1994)	Annual $\Delta \ln(\text{GDP per capita})$, 116 countries, 1965-1985	Log Kyriacou (1991) average years of schooling Log change in Kyriacou (1991) average years of schooling	Average stock Average flow	Average stock = 0,12-0,17 Average flow = -0,072
Hanushek and Kimko (1995)	Annual growth rate of real per capita GDP, 150 countries, 1960-1990	Average years of secondary schooling of adult male population in 1960	Initial stock	0,36
Gemmell (1996)	Annual growth rate of real per capita GDP, 98 countries, 1960-1985	Constructed human capital stock in 1960 and annual human capital growth rates at primary, secondary and tertiary levels	Initial stock Annual flows	*Full sample*: Primary stock = 0,008 Primary flow = 0,027 *Poorest LDCs*: Primary stock = 0,009 Primary flow = 0,042 *OECD*: Tertiary stock = 0,011 Tertiary flow = 0,059

	Output measure	Human capital proxy	Flow/Stock	Estimated coefficient
Barro (1997)	Annual growth rate of real per capita GDP, up to 87 countries, 1965-1975, 1975-1985, 1985-1990	Average years of attainment for males aged 25 and older in secondary and higher schools at the beginning of each period	Initial stocks	0,012
Judson (1998)	Five-year average growth rate of real per capita GDP, 138 countries, 1960-1990	Growth of constructed micro-based human capital stock	Period flows	*Full sample:* 0,11 *Low-efficient economies:* 0,03 *High-efficient economies:* 0,129
Krueger and Lindahl (2001)	Annual $\Delta \ln(\text{GDP per capita})$, 42 countries, 1965-1985	Kyriacou (1991) average years of schooling in 1965 Change in Kyriacou (1991) average years of schooling	Initial stock Annual flow	Initial stock=0,003 Annual flow=0,012 (insignificant)
Portela, Alessie, Teulings (2004)	Five-year interval $\Delta \ln(\text{GDP per worker})$, 95 countries, 1960-2000	Average years of schooling	Annual stock Annual flow	Annual stock=0,004 Annual flow=0,049
De la Fuente and Doménech (2006)	Annual growth rate of real per capita GDP, 21 OECD countries, 1960-1990	Average years of schooling by: - Barro and Lee (1993) - Kyriacou (2001) - De la Fuente and Doménech (2002)	Annual stock	*Barro and Lee data:* 0,089 *Kyriacou data:* 0,009 (insignificant) *De la Fuente and Doménech data:* 0,744
Cohen and Soto (2007)	Annual $\Delta \ln(\text{GDP})$, 78 countries, 1970-1990	Average years of schooling in 1965 and annual growth in average years of schooling for population aged 25 and above	Initial stock Annual flow	Initial stock=0,002 Annual flow=0,123

Sources: *Sianesi and van Reenen (2003); van Leeuwen (2007); own research*

APPENDIX 3. THE EFFECT OF HUMAN CAPITAL ON ECONOMIC GROWTH IN INDIA, INDONESIA AND JAPAN 1890-2000

	Dependent Varible - $\Delta \ln y_t$*		
		India	
	1892-1920	1920-1942	1950-1990
$\Delta \ln h_t$**	1,964***	1,906***	4,289***
		Indonesia	
	1892-1920	1920-1960	1960-1992
$\Delta \ln h_t$	1,455***	1,552***	1,483
		Japan	
	1896-1945		1950-1990
$\Delta \ln h_t$	4,601***		
$\ln h_t$			1,243***

* $y_t -$ GDP per capita at time t

** h_t –per capita human capital at time t

*** Coefficient is significant at 10% level

Source: *Van Leeuwen (2007: 196-197)*

Note: Van Leeuwen used individually constructed stock of human capital which incorporated both costs and monetary outcomes of acquiring human capital

APPENDIX 4. HISTORICAL NATIONAL ACCOUNTS AND EDUCATIONAL INDICATORS FOR SWEDEN, 1870-2000: DESCRIPTIVE STATISTICS

	Description	Obs.	Mean	Max	Min	Std. Dev.
pop_t	productive population (population aged 15-65)	131	4186869	5737876	2527605	1053675
Y_t	GDP in constant 1910/1912 market prices (million SEK)	131	13440,1	48302,7	1218,22	13868,2
y_t	GDP per capita of productive population in constant 1910/1912 prices (SEK)	131	2680,29	8418,22	481,97	2363,34
H_t	total years of schooling in the population aged 15-65 (thousand)	131	24853,3	66108,5	2610,82	18555,3
Sch_t	average years of schooling per person of productive population	131	5,23	11,52	1,03	2,95
K_t	capital stocks in constant 1910/1912 prices (million SEK)	131	31896,1	129749	1209,87	39068,9
k_t	capital stocks per capita of productive population in constant 1910/1912 prices (SEK)	131	6165,96	22612,6	478,66	6813,18

Note: For further information on the variables refer to the LU-MADD, Krantz and Schön (2007), Ljungberg and Nilsson (2009)

APPENDIX 5. REGRESSION SPECIFICATIONS

Class of a Model	Label	Equation Specification
Macro-Mincer model	(M)	$\Delta \ln y_t = \alpha_0 + \alpha_1 t + \alpha_2 \Delta \ln y_{t-1} + \alpha_3 \ln y_{t-1} + \alpha_4 \Delta sch_{t-1} + \alpha_5 sch_{t-1} + u_t$
Lucas-type models	(L1)	$\Delta \ln y_t = \beta_0 + \beta_1 t + \beta_2 \Delta \ln y_{t-1} + \beta_3 \ln y_{t-1} + \beta_4 \Delta Sch_{t-1} + \beta_5 imb_{t-1} + \beta_6 imb_{t-1}^2 + u_t$
	(L2)	$\Delta \ln y_t = \delta_0 + \delta_1 t + \delta_2 \Delta \ln y_{t-1} + \delta_3 \ln y_{t-1} + \delta_4 \Delta Sch_{t-1} + \delta_5 imb_{t-1} + \delta_6 imb_{t-1}^2 + \delta_7 \Delta \ln k_{t-1} + u_t$
	(L3)	$\Delta \ln y_t = \varphi_0 + \varphi_1 t + \varphi_2 \Delta \ln y_{t-1} + \varphi_3 \ln y_{t-1} + \varphi_4 \Delta Sch_{t-1} + \varphi_5 imb_{t-1} + \varphi_6 imb_{t-1}^2 + \varphi_7 \Delta \ln k_{t-1} + \varphi_8 \ln k_{t-1} + u_t$
Romer-type models	(R1)	$\Delta \ln y_t = \gamma_0 + \gamma_1 t + \gamma_2 \Delta \ln y_{t-1} + \gamma_3 \ln y_{t-1} + \gamma_4 sch_{t-1} + u_t$
	(R2)	$\Delta \ln y_t = \mu_0 + \mu_1 t + \mu_2 \Delta \ln y_{t-1} + \mu_3 \ln y_{t-1} + \mu_4 sch_{t-1} + \mu_5 \Delta \ln k_{t-1} + u_t$
	(R3)	$\Delta \ln y_t = \pi_0 + \pi_1 t + \pi_2 \Delta \ln y_{t-1} + \pi_3 \ln y_{t-1} + \pi_4 sch_{t-1} + \pi_5 \Delta \ln k_{t-1} + \pi_6 \ln k_{t-1} + u_t$