The long-run Relationship between Human Capital and Economic Growth in Sweden

Awel, Ahmed Mohammed

Lund University, School of Economics and Management

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Ahmed Mohammed Awel

Lund University, School of Economics and Management

Email: eut12aaw@student.lu.se / ahmi2008@gmail.com

Tel: +46703660381

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Abstract

The relationship between education and economic growth has been one of the fundamental themes of economic analysis. Despite the growing interest in the relationship between growth and education, and despite the strong theoretical foundations for a key role of education/human capital in economic growth, the empirical evidences, particularly those using causality analyses, are fragile at best. By utilizing the recently developed series of human capital, this paper examined the causal relationship between human capital and economic growth for Sweden over the period 1870-2000. The result from the Granger causality test shows that there is bidirectional causality running from human capital to output per worker and vice versa. Moreover, using vector error correction model, the paper shows that human capital has a significant positive impact on economic growth in Sweden.

Keywords: education, human capital, economic growth

1. Introduction

The relationship between education and economic growth has been one of the fundamental themes of economic analysis. The two most prominent scholars in the economics profession, the 18th century Adam Smith and the 19th century Alfred Marshall, addressed the question of how investments in education affect the wealth of nations. Throughout the 20th century, a large body of literature has been produced investigating the role of education in determining the level and growth of GDP. Much of the earlier literature is mainly theoretical and focuses on diverse growth model specifications and simultaneously their associated economic properties (Aghion and Howitt, 1998). Nevertheless, more recent work deals with empirically testing the relationship between education and economic growth using different model specifications.

Should countries invest more on human capital to ignite economic growth? Policy makers usually claim that if a country spends more on educating its people, income will increase sufficiently to more than offset the investment cost of human capital. Economists and economic historians have proposed various channels through which education can possibly affect growth. It contributes to economic growth through shaping general attitudes of the public and transferring knowledge and skills. It is also a means to create well-disciplined, literate, and flexible labour force to the labour market. Investment in education can promote growth and development through encouraging activities that can assist to catch up with the technological progress (Berthelemy and Varoudakis, 1996). In developed countries, investment on education fosters innovation thereby makes labour and capital more productive and generate income growth.

Despite the growing interest in the relationship between growth and education, and despite the strong theoretical foundations for a key role of education/human capital in economic growth, the empirical evidences, particularly those using causality analyses, are fragile at best. Barro and Sala-i-Martin (1995) and Barro (1991, 1997) found causality running from education to growth during the post-war period for a cross section of countries. Using relatively longer historical data, Ljungberg and Nilsson (2009) found that human capital has been a causal factor for economic growth since industrialisation in Sweden. Additionally, Benhabib and Spiegel (1994) showed that improved level of education promoted growth in

Chinese Taipei while Berthelemy and Varoudakis (1996) argued the other way round. Later on, Francis and Iyare (2006) came out with an evidence of bidirectional causality of income and education in Jamaica. At the same time, they found an evidence of causation which runs from income to education for Trinidad and Tobago, and Barbados. Using long term data for Germany, Diebolt and Monteils (2003) argued that the causality is from economic growth to education. Bils and Klenow (2000) used the post war data set from Barro to confirm the positive correlation between school enrolment and economic growth, but they argued that the direction of causation was not from education to economic growth. They claim that the main causations runs from economic growth to education. They argued that countries with high enrolment at the beginning, 1960, did not exhibit a faster consequent growth in human capital, and finally contributed less to economic growth.

As to the direction of causality, which one looks more plausible? This the question that should probably answered towards the end of this paper. Existing literature on the relationship between education and economic growth follow diverse methodological approaches, some follow bivariate analysis (i.e. Boldin *et al*., 2008; Dananica and Belasku, 2008; Ljungberg and Nilsson, 2009) while others use multivariate approaches (i.e. Islam *et al.,* 2007; Dauda, 2009). The other difference among the literature is on their use of proxies for education/human capital. The data that measure education or human capital are very scarce. As a result, different studies used different proxies for education and human capital. Fontvieille (1990) used material costs on public education as a measure of human capital in France. Khalifa (2008), Pradhan (2009), and Chandra and Islamia (2010) have used similar techniques (i.e. the public educational expenditures) to analyse the relationship between human capital and economic growth. Asteriou and Agiomirgiannakis (2001) and Babatunde and Adefabi (2005) used the enrolment rates at all of education levels, while Maksymenko and Rabbani (2009) utilized the average years of schooling. Most importantly, several studies that investigate the relationship between human capital and economic growth consider short span of time (post 1960 in most cases) and, as a consequence, they cannot instantaneously shed light on the long-term relation (Ljungberg and Nilsson, 2009).

Empirical analysis on the relationship between human capital and economic growth has become keen in recent literature since the outcome is increasingly becoming sensitive in most policy circles all over the world. The present study seeks to utilize the yearly historical data to determine the relationship between human capital and economic growth in Sweden. The key contribution relative to the previous studies is the utilization of longer time series to capture the possible long run relationships as well as the introduction of physical capital as explanatory factor. Therefore, the main objective of this research is to examine the long run relationship between human capital and economic growth in Sweden. In order to shed a more accurate light on the issue, the research uses well constructed growth accounting data which covers relatively long period of time, from 1870 to 2000 and uses multivariate time series analysis.

2. Theory

Although explanations of economic growth and its correlates dates back to 18th century at the time of Adam Smith and David Ricardo, the formalization of growth theories started later, after 1950s and 1960s. Generally, growth theory advocates that economic growth relies on the accumulation of economic assets(including human), the return on these assets, the efficiency with which these assets are being used, and which in turn rely on technological progress (Blackden et al., 2007). The neoclassical growth model, which is also known as the Solow-Swan model developed by the contribution of Robert Solow and Trevor Swan, considers capital and labour as the sole determinant of economic growth. It is an extension of the Harrod-Domar growth model by including productivity growth in the model. This model treats technology as exogenous and completely ignores human capital. During the last decades, incorporating human capital as a single factor determining growth has become very important. In 1980s, a new growth model known as "Endogenous Growth Models" is developed by economists like Paul Romer and Robert Lucas. This model considers that investments in innovation, knowledge and human capital are important contributors to economic growth.

Therefore, the theoretical foundation for the impact of education on economic growth first takes its root with the endogenous growth theory, which underlines the role of human capital for technological progress and innovation (Gundlach et al., 2001). This theory gives much emphasis to human capital development and the production of new technologies. The pioneer work in this aspect is the contribution of Lucas (1988) which revealed that the level of output is a function of the stock of human capital. According to his model, sustained growth is only possible in the long run provided that human capital can grow without bound.

Afterwards, Rebelo (1991) extended the model by including physical capital as an additional factor in the human capital accumulation function. However, an alternative class of models gives more importance for modelling the incentives that different firms have to generate new ideas. The landmark contribution in this regard is by Romer (1990) that assumes the creation of new ideas is a direct function of human capital. Consequently, investment in human capital increases the stock of physical capital which in turn fosters economic growth. Other studies that considered human capital accumulation as a source of growth include (Romer, 1991; Barro and Lee, 1993; Benhabib and Spiegel, 1994). Some studies have examined different ways through human capital can affect economic growth. The models of the endogenous growth theory are important since it consider human capital accumulation as the main input in the creation of new ideas. Besides, it provides reasonable justification for taking education as a fundamental determinant of economic growth.

Finally, this paper follows Mankiw, Romer and Weil (1992) who have augmented a production function to include human capital. Therefore, I consider the growth theory to model economic growth as a function of physical and human capital accumulation. By considering human capital as an independent factor of production, the Cobb-Douglas production function I am assuming takes the following form:

$$Y = AK^{\alpha}H^{\beta}L^{(1-\alpha-\beta)} \text{ ....(1)}$$

Where Y is total output, K is physical capital, H is human capital, L is labour or employment, and A is total factor productivity. By dividing both sides of equation (1) by L and after some mathematical computations I will arrive at:

$$\frac{Y}{L} = A\left(\frac{K}{L}\right)^{\alpha}\left(\frac{H}{L}\right)^{\beta} \text{ ....(2)}$$

Or $$y = Ak^{\alpha}h^{\beta} \text{ ....(3)}$$

Where $\frac{Y}{L}$ is output per worker or economy wide labour productivity, $\frac{K}{L}$ is capital per worker and $\frac{H}{L}$ is average human capital. Finally, the natural logarithm of equation (3) above yields the structural form of the production function as:

$$\ln(y) = \ln(A) + \alpha \ln(k) + \beta \ln(h) \;............(4)$$

Based on theories and empirical evidences I have a priori expectation that human capital and output per worker have unilateral causality, i.e. human capital predicts output per worker but not the other way round. I also expect that, in the long run, human capital positively affects output per worker in Sweden.

3. Data

For this study, I use the annual time series data of Gross Domestic Product (GDP), capital stock, employment and accumulated years of schooling for post industrialization period, 1870 to 2000, in Sweden. The national account data (GDP, capital stock, and employment) is taken from Krantz and Schön (2007), while the data for accumulated years of schooling is from Ljungberg and Nilsson (2009).

The GDP data I am using is measured annually in local currency (Swedish Kroner). It is in million Swedish kroner at constant 1910/1912 prices. Physical capital is generally defined as manufactured resources such as buildings and machines. The capital stock in the dataset is the sum of building stock and machinery stock. Therefore, it will be a good proxy for physical capital. It is in thousand Swedish kroner at constant 1910/1912 prices. The employment data is in thousands and constitutes all employments in agriculture, manufacturing industry and handicrafts, building and construction, transport and communication, private services, and public services. Accumulated years of schooling (in thousands) is the product of average years of schooling and the population in productive age; which gives a more comprehensive measure of human capital (Ljungberg and Nilsson 2009). I divided the GDP data with employment to get output per worker (y), the capital stock with employment to get capital per worker (k), and human capital with employment to get average human capital (h). Finally, the series are transformed in to natural logarithms.

As shown in Figures 1, 3 and 5 below, all variables have increasing trend throughout the period under consideration. Moreover, the series does not show clear structural breaks. The pairwise correlations of variables show strong and significant correlations (see Appendix for summary statistics and pairwise correlations). A stationary data series has the property that the mean, variance and autocorrelation structure (covariance) do not depend on time or do not change over time. However, by ocular inspection, all the data series I am considering do not seem to fulfil the stationarity properties at levels. In order to avoid the spurious regression problem, the time series properties of the variables specified in equation (4) should be verified before all estimations are done. Thus, in the first step of the estimation procedure, the unit root test is carried out so as to check the stationarity of the variables.

Fig. 1 Time series graph for ln(y)

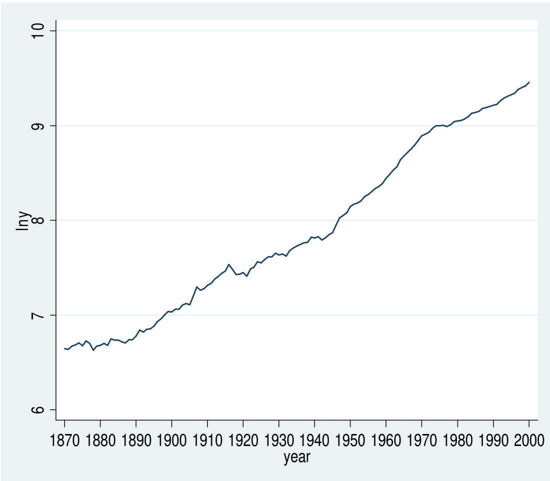


Fig. 2 Time series graph for 1st Diff. ln(y)

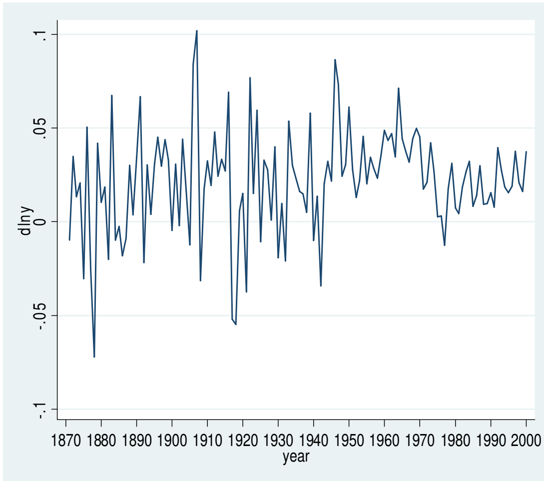


Fig. 3 Time series graph for ln(k)

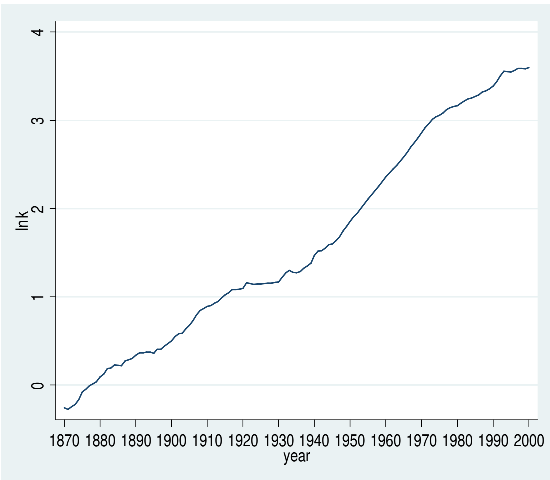


Fig. 4 Time series graph for 1st Diff. ln(k)

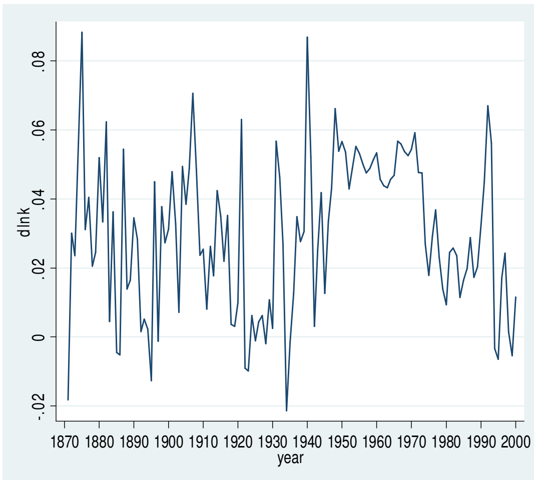


Fig. 5 Time series graph for ln(h)

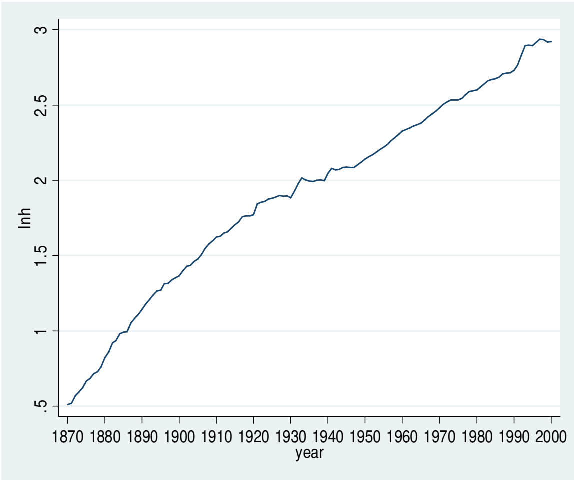
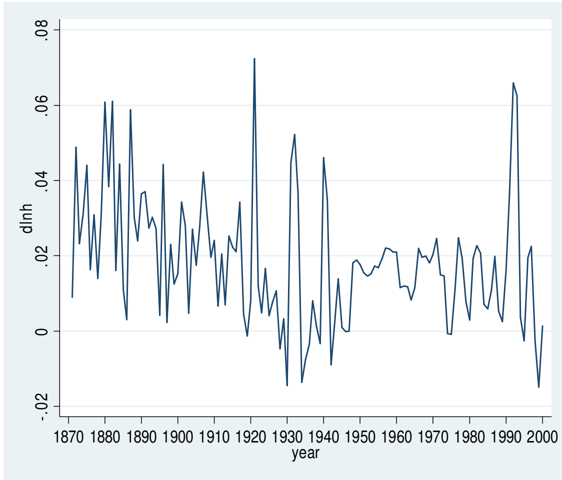


Fig. 6 Time series graph for 1st Diff. ln(h)



Source: Krantz and Schön (2007) & Ljungberg and Nilsson (2009)

4. Methods

4.1 Unit root test

Before proceeding to the estimation procedure, the first step in time series analysis should be a unit root test to determine the order of integration of the series. Various researchers use different test like Dickey Fuller (DF), Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests. The DF test is based on the assumption that the error term is white noise. Hence, it would be misleading in case the error term is not white noise. However, the ADF and PP tests can be used even if the error term is not white noise. To preclude spurious regression and to ascertain the order of integration of each of the series, I used both the ADF and PP unit root tests which are carried out under the null hypothesis of unit root. For the variables in levels, the estimated equation for the unit root tests takes the following form:

$$y_t = \alpha + \delta t + \gamma y_{t-1} + u_t \text{ ....(5)}$$

For variables in levels, the null hypothesis is γ=1, which implies the variable (y_t) contains unit root, while the alternative hypothesis is that the variable has trend stationary. For the first differences of the variables I estimate the following equation:

$$\Delta y_t = \alpha + \gamma \Delta y_{t-1} + \mathcal{E}_t \text{ ....(6)}$$

In case of the first differences, the null hypothesis is the same as for variables in levels, but the alternative hypothesis is that the variable is levels stationary.

4.2 Granger Causality test

I will perform Granger Causality test introduced by Granger (1969). The concept of the Granger causality test is based on the idea that events in the past cannot be influenced by events today or in the future. Therefore, if event X occurs before event Y, then only event X can 'cause' event Y. hence, what we are doing while we are using Granger causality is to test whether variations in one variable occurs before variations in another variable. Variable X is said to be ''Granger cause'' variable Y if the past values of variable X can improve the forecast Y. It is also possible that the two variables X and Y ''Granger cause'' each other. If it is the case we have bidirectional Granger causality. The null hypothesis of the Granger causality test is *"no Granger causality" or "X does not Granger-cause Y".* The null hypothesis of "no Granger causality" will not be rejected if and only if no lagged values of an explanatory variable have been retained in the regression.

4.3 The Multivariate Cointegration Model

Once the time series properties of the variables are known, then a possible long run relationship between them will be investigated. The vector autoregression (VAR) model is employed in this paper. This approach has recently become standard in time series modelling mainly because this approach, compared to the structural approaches, avoids the need to present a dynamic theory specifying the relationships between the jointly determined variables. According to Greene (2002), one of the virtues of the VAR is that it obviates a decision as to what contemporaneous variables are exogenous; it has only lagged (predetermined) variables on the right-hand side, and all variables are endogenous. Therefore, using VAR models avoid making strong assumptions about exogeneity. The VAR models have better forecasting performance than that of large structural models. In addition to forecasting, VARs have been used for two primary functions, testing Granger causality and studying the effects of policy through impulse response characteristics.

Prior to specifying the final VAR model, it is essential to decide how many lags to include. Too many lags could increase the error in the forecasts; too few could leave out relevant information. Experience, knowledge and theory are usually the best way to determine the number of lags needed. There are, however, information criterion procedures to help come up with a proper number. The most commonly used are: Schwarz's Bayesian information criterion (SBIC), the Akaike's information criterion (AIC), and the Hannan and Quinn information criterion (HQIC). All these are reported by the command 'varsoc' in Stata.

Once the order of integration of the series is known, and once the lag length of the VAR model is determined, the next step is to test for cointegration using Johansen's method. I will follow the Pantula principle to determine the specification of the test. The null hypothesis of the Johansen's test is 'no cointegration relationship' in the first step. If we reject the null, we proceed to step two and the null will be 'at most 1 cointegration relationship' in this case. It will be 'at most 2 cointegration relationships' in step three, 'at most 3 cointegration relationships' in step 4, and so on. If the log likelihood of the unconstrained model that includes the cointegrating equations is significantly different from the log likelihood of the constrained model that does not include the cointegrating equations, we reject the null hypothesis.

After getting the number of cointegrating relationships, I proceed to the VEC estimation and my VEC model will take the following form. Let us first consider a *VAR (p)* with *p* optimum lags,

$$Z_t = v + A_1 Z_{t-1} + A_2 Z_{t-2} + \ldots + A_p Z_{t-p} + \mathcal{E}_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where:

- ✓ Z_t is kx1 vector of variables
- ✓ v is kx1 vector of parameters
- ✓ $A_1, A_2 \ldots A_p$ are *k x k* matrices of parameters
- ✓ $\mathcal{E}_t$ is kx1vector of disturbance term, (iid with zero mean and $\sum$ covariance matrix)

The above *VAR (p)* model in equation (7) can be, using some algebra, written in VEC form as

$$\Delta Z_t = v + \sum_{i=1}^{p-1} \boldsymbol{\Gamma}_i \Delta Z_{t-i} + \Pi Z_{t-1} + \mathcal{E}_t \ldots\ldots\ldots\ldots\ldots\ldots 8$$

Where: $\boldsymbol{\Gamma}_i = \sum_{j=1+1}^{j=p} A_j$ and $\Pi = \sum_{j=1}^{j=p} A_j - I_k$

Engle and Granger (1987) show that if the variables Z_t are I (1) the matrix Π in (8) has rank *0≤r<K*, where r is the number of linearly independent co-integrating vectors. If the variables co-integrate, *0<r<K* and (8) shows that a VAR in first differences is miss-specified because it omits the lagged level term ΠZ_{t-1}. If Π has reduced rank so that it can be expressed as $\Pi = \boldsymbol{\alpha\beta'}$, where α and β are both *k x r matrices of rank r.*

Allowing for a constant and a linear trend we can rewrite the VEC in (8) as

$$\Delta Z_t = v + \delta t + \sum_{i=1}^{p-1} \boldsymbol{\Gamma_i} \Delta Z_{t-i} + \boldsymbol{\alpha\beta} Z_{t-1} + \mathcal{E}_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

The parameters α (k x r matrices of rank r) in equation (9) are the speed of adjustments to equilibrium, while βs are the long run relationships.

Finally, after estimating the VEC model, I will perform postestimation tests to detect model misspecification, i.e. Lagrange-multiplier test for autocorrelation in residuals, test for normally distributed residuals, and tests to check stability condition of estimates.

5. Results

5.1 Unit root test

While using the ADF test, I started at 10 lags and continue to test down using fewer lags. For all the three variables in levels, both the trend and intercept are significant and hence included in the specification. In case of output per worker (lny) and capital per worker (lnk), the last significant lag is at the first lag. The parsimonious test equation is tested for autocorrelation by using the Breusch-Godfrey test and the result shows no autocorrelation. However, average human capital (lnh), though the last significant lag is at the first lag, has non-autocorrelated errors only at the second lag. Hence, I prefer to add the second lag. In case of variables at first differences, trend is excluded in the specification. For the PP test, I used similar specification as the ADF test. To deal with the problem of autocorrelation, I use three lags which is the Newey-West default lags in STATA for Phillips-Perron test. Finally, the results from ADF and PP tests reported in Tables 1-4 indicate that all the series are integrated of order one, I(1).

Table 1: Summary results of the ADF test at levels

Variable	No. of lags	Specification	Test statistic	5% Critical value	No. of obs.	Breusch-Godfrey test (p-value)	Conclusion
lny	1	Intercept&trend	-2.299	-3.446	129	0.5217	Can't reject Ho
lnk	1	Intercept&trend	-1.213	-3.446	129	0.5291	Can't reject Ho
lnh	2	Intercept&trend	-2.981	-3.446	128	0.8353	Can't reject Ho

Table 2: Summary results of the PP test at levels

Variable	No. of lags	Specification	Test statistic	5% Critical value	No. of obs.	Conclusion
lny	3	Intercept&trend	-2.458	-3.446	130	Can't reject Ho
lnk	3	Intercept&trend	-1.250	-3.446	130	Can't reject Ho
lnh	3	Intercept&trend	-2.958	-3.446	130	Can't reject Ho

Table 3: Summary results of the ADF test at first differences

Variable	No. of lags	Specification	Test statistic	5% Critical value	No. of obs.	Breusch-Godfrey test (p-value)	Conclusion
D.lny	1	Intercept	-7.365	-2.888	128	0.3754	Reject Ho
D.lnk	1	Intercept	-5.274	-2.888	128	0.6296	Reject Ho
D.lnh	1	Intercept	-6.967	-2.888	128	0.7215	Reject Ho

Table 4: Summary results of the PP test at first differences

Variable	No. of lags	Specification	Test statistic	5% Critical value	No. of obs.	Conclusion
D.lny	3	Intercept	-11.141	-2.888	129	Reject Ho
D.lnk	3	Intercept	-7.268	-2.888	129	Reject Ho
D.lnh	3	Intercept	-8.258	-2.888	129	Reject Ho

5.2 Granger Causality test

There is universal consensus that t he Granger causality test does not indicate real causality among variables. However, it suggests a preliminary approach to the possible relationships among the variables. Table 5 presents the Granger causality test results for each pair of variables of the model. According to the result, output per worker and physical capital per worker are both helpful in the prediction of all other variables, albeit the later granger causes the former only at 10 percent level of significance. Output per worker and average human capital show bidirectional causality at 5 percent level of significance. Nevertheless, average human capital does not help to predict physical capital per worker. Therefore, the evidence coming from the Granger-causality test demonstrates the idea that human capital had a positive impact on output per worker and vice versa in Sweden after industrialization.

Table 5: Granger causality test

Causality direction	chi2	p- value
Output per worker →Average human capital	5.4612	0.019
Average human capital →Output per worker	4.7176	0.030
Capital per worker →Average human capital	25.659	0.000
Average human capital →Capital per worker	1.5242	0.217
Output per worker →Capital per worker	19.569	0.000
Capital per worker →Output per worker	4.6725	0.097

5.3 The Multivariate Cointegration Model

Once the time series properties of the variables are known to be I(1), the next step is to decide how many lags to include. I used information criterion procedures that help come up with a proper lag length. As shown in Table 6 below, the AIC recommends three lag lengths while SBIC and HQIC suggest only two lags. I followed the later since the specification with three lags has some problems of normality in the error terms (the normality test result is presented in the Appendix).

Table 6: Selection of lag length using Information Criterion

Selection-order criteria
Sample: 1874 - 2000 Number of obs = 127

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	45.2408				.000103	-.665209	-.637913	-.598024
1	1016.03	1941.6	9	0.000	2.7e-11	-15.8116	-15.7024	-15.5428
2	1105.44	178.81	9	0.000	7.7e-12	-17.0778	-16.8867*	-16.6075*
3	1115.55	20.224*	9	0.017	7.6e-12*	-17.0953*	-16.8224	-16.4235
4	1121.43	11.752	9	0.228	8.0e-12	-17.0461	-16.6913	-16.1727

After determining the lag length of the VAR model, the next step is to test for the presence of cointegration using Johansen's method. I followed the Pantula principle to determine the specification of the test. The results from Table 7 indicate that I reject the null hypothesis of no cointegration, but I fail to reject the null hypothesis of at most one cointegrating equation. In line with the results from the trace test, the max-eigenvalue test also suggests that the null hypothesis of no cointegrating equation can be rejected at the 5 percent level of significance but I fail to reject the null hypothesis of at most one cointegrating equation. It implies that there is one cointegrating vector in the model. This means that a single vector uniquely defines the cointegration space. As Enders (2004) states, cointegrated variables share the same stochastic trends and so cannot drift too far apart. This suggests the existence of a long-run relationship between the series.

Table 7: Johansen Test for Cointegration

Trace test							
Variables	**rank**	**unrestricted constant**			**linear trend in the CE**		
		Trace statistic	5% Critical value	Conclusion	Trace statistic	5% Critical value	Conclusion
lny, lnk, lnh	0	49.4092	29.68	Reject Ho	56.0485	42.44	Reject Ho
	1	15.138*	15.41	Can't reject Ho	19.705*	25.32	Can't reject Ho
Maximum eigenvalue test							
lny, lnk, lnh	0	34.2709	25.52	Reject Ho	36.3432	25.54	Reject Ho
	1	14.9864	18.63	Can't reject Ho	15.1371	18.96	Can't reject Ho

The existence of unique cointegrating vector implies that an error correction model can be estimated to investigate the long run and short run dynamic relationship. For the long run equation, I normalized on the logs of output per worker (lny), and finally the cointegrating (long run) relationships and the short run adjustment parameters estimated are presented in Table 8 below.

Table 8: Parameter Estimates

Variable	α			β		
	coefficient	**Std. Err.**	**p-value**	**coefficient**	**Std. Err.**	**p-value**
lny	-0.0673	0.0243242	0.006	1	-	-
lnk	0.0619	0.0143134	0.000	-0.5932	0.0562289	0.000
lnh	0.0433	0.0140242	0.002	-0.3949	0.1051694	0.000

Therefore, the long run equation finally takes the following form:

$$lny = 6.11 + 0.59lnk + 0.39lnh$$

For the long run relationships, both capital per worker and average human capital are highly significant (at 1 percent) and have the expected signs. The long run parameters suggest that capital per worker and human capital have significant positive impact on output per worker in Sweden which is consistent with theoretical expectation. A one percent increase in capital per worker leads to a 0.59 percent increase in output per worker. Similarly, a one percent increase in average human capital leads to a 0.39 percent increase in output per worker or economy wide labour productivity.

The highly significant and negative sign of the coefficients of the error correction term (adjustment parameter or α) for output per worker is in accordance with a priori expectations implying that output per worker is endogenous. It also indicates that the model is dynamically stable, that is, the model's deviation from the long run relationship is corrected by increase in output per worker. The magnitude, though, suggests that about 6.73 percent of the imbalance in output per worker is corrected every year.

The short run results (see Table 9 below) also indicate that most of the variables do not significantly explain variations in the output per worker. However, the first lag of the growth of capital per worker (Δlnk) has positive and significant effects on current growth of output per worker (Δlny).

Table 9: Short run results

	Dependent Variable		
Regressors	**Δlny**	**Δlnk**	**Δlnh**
Δlny_{t-1}	-0.0183	0.0794	0.0039
	(0.835)	(0.125)	(0.939)
Δlnk_{t-1}	0.2885	0.7515	-0.0493
	(0.043)	(0.000)	(0.549)
Δlnh_{t-1}	-0.2303	-0.7252	0.3158
	(0.223)	(0.000)	(0.004)
Constant	0.0219	0.0158	0.0115
	(0.000)	(0.000)	(0.000)
R-squared	0.4282	0.8180	0.6172

NB: p-values in brackets

On average in the short run, a one percent increase in the growth of capital per worker this year leads to 0.28 percentage increase on the growth of output per worker the following year. In contrast, in the short run, an increase in the growth rate of human capital leads to a decrease in the growth of output per worker the following year, albeit not significant.

5.4 Postestimation tests

Various postestimation tests are conducted to check for the problems of misspecification and stability. The single equation and overall Jarque–Bera statistics do not reject the null of normality at the 5% level. The skewness results for Δlny and Δlnh equations do not suggest non-normality, though the disturbance term in Δlnk equation has the sign of skewness. The kurtosis statistics, that tests the null hypothesis that the disturbance terms have kurtosis consistent with normality, do not reject the null hypothesis.

Table 10: Tests for normality, skewness, and kurtosis of the residuals in the VEC Model

Equations	**p-values**		
	Normality (Jarque-Bera) test	**Skewness**	**Kurtosis**
Δlny	0.97487	0.99381	0.82162
Δlny	0.07898	0.02793	0.62101
Δlny	0.55126	0.80081	0.28832
All	0.38842	0.17955	0.70021

Similarly, in the Lagrange-multiplier test, the null hypothesis that there is no autocorrelation in the residuals for any of the orders tested cannot be rejected (Table 11). Additionally, the correlogram of the error term does not show autocorrelation (Figure 7).

Table 11: LM test for the VEC model

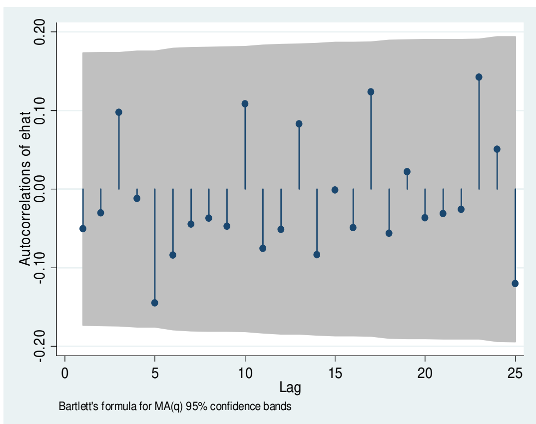
```
. veclmar, mlag(10)

   Lagrange-multiplier test
```

lag	chi2	df	Prob > chi2
1	12.9381	9	0.16543
2	14.3128	9	0.11163
3	4.9914	9	0.83506
4	9.1978	9	0.41922
5	6.8797	9	0.64965
6	13.5448	9	0.13946
7	9.4407	9	0.39763
8	11.7169	9	0.22974
9	7.5658	9	0.57843
10	7.7843	9	0.55602

```
   H0: no autocorrelation at lag order
```

Figure 7: Correlogram of the error term



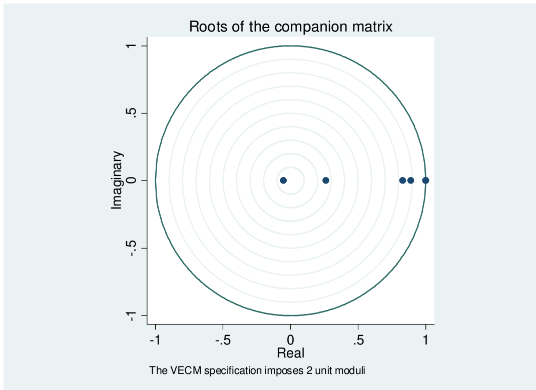
Moreover, I used the 'vecstable' command in STATA to check whether the cointegrating equation is misspecified or whether the cointegrating equation, which is assumed to be stationary, is not stationary. The general rule in this test is that there is a problem of stability if any of the remaining moduli computed (apart from those imposed to unity) are too close to one. Hence, the eigenvalue stability condition displayed in Table 12 below shows that the remaining moduli are not too close to one implying that the VEC is stable. Ultimately, almost all these tests find no evidence of model misspecification.

Table 12: Eigenvalue stability condition

Eigenvalue	Modulus
1	1
1	1
.8895298	.88953
.8300704	.83007
.261023	.261023
-.05273842	.052738

The VECM specification imposes 2 unit moduli

Figure 8: VEC stability condition



6. Discussion and conclusion

Using the recently developed series of human capital, this paper examined the causal relationship between human capital and economic growth for Sweden over the period 1870-2000 using a multivariate approach. The relationship between human capital and economic growth can take three forms. Human capital can cause output or GDP to grow, output or GDP can cause human capital or both can help each other to grow. It appears that Sweden is in the third stage where output or GDP and human capital are helping each other to grow. The result from the Granger causality test show that there is bidirectional causality running from human capital to output per worker and vice versa. This result is against the hypothesis stated earlier which presumed unidirectional causality from human capital to output per worker.

The result also contradicts several previous studies which argue in favour of unidirectional causality running either from economic growth to education/human capital (such as, Berthelemy and Varoudakis, 1996; Bils and Klenow, 2000; Diebolt and Monteils, 2003) or from education/human capital to economic growth (such as, Benhabib and Spiegel, 1994; Barro and Sala-i-Martin, 1995; Barro, 1991; Barro, 1997; Ljungberg and Nilsson, 2009), but it is consistent with the situation in Sweden where human capital and economic growth are working in tandem. It might be the case that, from 1870 onwards, rising income and industrialization in Sweden creates the demand for skilled labour force which in turn increases education and hence human capital. At the same time, an increase in education and human capital improves productivity and promotes economic growth.

Additionally, I used the Johansen's approach to test for cointegration and find one cointegrating vector. By estimating the VEC model, this paper shows that human capital has a significant positive impact on economic growth between 1870 and 2000 in Sweden, which is in line with my priori expectation that human capital and output per worker have positive long run relationships. This finding supports economic growth models which advocate the substantial role of education/human capital on economic growth. This finding has an implication that investing on human capital ignites growth in the long run. The channel of the impact may be either by enhancing private returns or stimulating external returns or through both channels. In the first channel, as human capital increases, workers become more productive and hence rewarded in the labour market, which in turn increases income and output. Additionally, there might be external returns from human capital, as one becomes more educated, others also become productive due to the fact that educated workers generate ideas that others can use. Therefore, identifying the channels for impact of human capital on economic growth is one possible area for future research.

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