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A knowledge economy approach in empirical growth models for the Nordic countries

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Abstract

We estimate, employing a “knowledge economy” approach, the steady state growth rate for the Nordic countries. An endogenous growth framework is developed, in which total factor productivity is a function of human capital (measured by average years of education), trade openness, research and development, and investment ratio. We identify the key variables having a significant level and growth effects within this framework. We find that education plays an important role on the long-run growth rates of Sweden, Norway, and Denmark; trade openness, instead, has growth effects in Sweden, Finland, and Iceland. The investment ratio is able to explain patterns of growth only in Finland. Surprisingly, research and development has no level or growth effects in any of the Nordic countries. This may be attributable to the fact that research and development are driven by openness and education. Policy measures are identified to improve the long-run growth rates for these countries.

Keywords: Endogenous growth models, Trade openness, human capital, investment ratio, Steady state growth rate, Nordic countries

JEL Classification: C22, O52, O40

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1. Introduction

During the second half of the 1990s the Nordic countries (Sweden, Finland, Norway, Denmark, and Iceland) were among the most successful economies in the OECD. These countries, with the exclusion of Denmark, exhibited above average GDP growth rates from 1995 to 2010 (Norway 2.5%, Sweden 2.6%, Finland 2.9%, Denmark 1.5%, and Iceland 2.9%), in comparison to an average growth rate of 1.8% for the 15 European Union countries. The Nordic countries additionally, are among the top performers according to the Knowledge Economic Index (KEI) constructed by the World Bank. The KEI is based on an average of four sub-indexes the four pillars of the knowledge economy: (1) economic incentive and institutional regime, (2) innovation and technological adoption, (3) education and training, and (4) information and communication technologies (ICTs). The Nordic countries are exemplified by their strong performance in these four pillars. Denmark, Sweden, Finland and Norway rank within the top 5 in the KEI (see Table 1). Although Iceland comes lower down the KEI, it has seen the fastest improvement in rankings among the top 20 countries rising 8 spots to 13th place in 2009 from 1995 (World Bank 2012).

Compared to other regions, the Nordic countries are relatively homogenous with respect to human resources. This is due to the emphasis placed on free public education by the Nordic welfare state. Education is a key component of a knowledge based economy as it influences both the demand for, and supply of innovation. A well educated labor force is a pre-requisite for the adoption of innovation and investment in Research and Development (R&D). Investment in R&D and diversification through trade have been equally important for restructuring the Nordic economies towards knowledge based economies. The performance of these economies in terms of the KEI suggests that education, investment and trade have played a significant role in the emergence of new knowledge based industries and knowledge spillovers promoting long-term growth in the Nordic countries.

Many studies have shown evidence of R&D knowledge spillovers through trade as a channel of total factor productivity (TFP) growth[1]. Increased openness raises the intensity of competition through the transfer of technology embodied in traded products, lowers barriers to trade, reduces the monopoly power of domestic firms, and could facilitate R&D, through the dynamic competition of firms in a Schumpeterian flavor. Studies by Coe and Helpman (1995) and Nadiri and Kim (1996)

[1] For instance, Coe and Helpman (1995), Engelbrecht (1997), Lumenga-Neso et al. (2001), Madsen (2007b), Lichtenberg et al. (1998).

have highlighted the role of technological spillovers through trade liberalization, for improving the efficiency of the domestic R&D sector. Similarly, Griffith et al. (2003) show that R&D promotes innovation, the transfer of technology and R&D supported absorptive capacity. However, it is also possible that there is an interaction of an economy's R&D activity with its stock of human capital, due to the fact that the major input into the R&D process is highly skilled labour. This is evidenced by the studies of Blackburn et al. (2000) and Bravo-Ortega and Lederman (2010) who show that economic growth is independent of research activity which is driven by human capital accumulation[2]. Similarly, Bils and Klenow (2000) argue that human capital could accelerate the adoption of technology and is necessary for technology use. The studies of Welch (1970), Bartel and Lichtenberg (1987) and Foster and Rosenzweig (1996) support the argument that human capital is important for the adoption of technology while the studies of Doms et al. (1997), Autor et al. (1998), Berman et al. (1998) support the argument that human capital is decisive for technology use choices.

Hence, given the importance of knowledge spillovers as a channel of Total Factor Productivity (TFP) growth, we use an endogenous growth framework, in which total factor productivity is assumed to be a function of human capital (measured by average years of education), trade openness, investment ratio, and R&D. Within this framework we try to distinguish between variables which have significant level effects and growth effects in the Nordic countries over the 1960 to 2010 period. This is the first study to our knowledge, which examines level and growth effects from a knowledge economy perspective for the Nordic countries. Country-specific time series data technique is used to conduct this study[3]. Our approach broadly follows the specification and methodology in Rao (2010), Balassone *et al.* (2011), Paradiso and Rao (2011), and Casadio *et al.* (2012).

[2] Reis and Sequeira (2007) examine the interaction between the technological change and human capital accumulation and its implications for investment in R&D from a theoretical perspective.

[3] Country-specific time series studies are important because it is hard to justify the basic assumptions of cross-section and panel data studies that the forces of economic growth and underlying structural parameters are the same for all countries and at all times, even if the countries belong to the same region or area. Furthermore, while cross-section and panel data studies may give some insights into growth enhancing policies, they are not useful to estimate country-specific steady state growth rates (SSGRs) and identify the effects of policies to improve SSGRs. See Greiner, et al. (2005) and Cooray et al. (2013) on this point.

Our empirical results are consistent with the views of Blackburn et al. (2000) and Bravo-Ortega and Lederman (2010) in that R&D is not statistically significant as a shift variable (both level and growth effects) for any of the Nordic countries. This is probably because openness and HKI interact with R&D, as mentioned above, so that R&D does not provide any additional information already embodied in trade openness and human capital.

The paper is organized as follows. In Section 2 we illustrate the characteristics of the Scandinavian model underlining the knowledge economy framework. Section 3 presents the model specification and implications for the estimates of the long run growth rate, which is the same as the steady state growth rate (SSGR) in the Solow growth model. Section 4 presents our empirical results. Finally, section 5 concludes.

2. Scandinavian Countries as Knowledge Economies

In the past few decades, developed countries have experienced the effects of globalization and technical innovation, knowledge has become the key driver of competitiveness and economic growth. Dahlman and Anderson (2000) define a knowledge economy as "one that encourages its organization and people to acquire, create, disseminate and use (codified and tacit) knowledge more effectively for greater economic and social development". Derek *et al.* (2004) postulated that the knowledge economy is based on four pillars: (1) educated and skilled workers; (2) effective innovation system of firms, research centers, universities, and other organizations; (3) modern and adequate information of infrastructure to facilitate information dissemination; (4) economic and institutional regimes to provide incentives for the efficient use of knowledge. In essence, these authors postulate that the amount of knowledge is used as a key determinant of total factor productivity (TFP). Strengthening the above four pillars will lead to an increase in the pool of knowledge available for economic production.

The five Nordic countries can be defined as knowledge economies according to the above mentioned characteristics. Based on the work of Derek *et al.* (2004), the World Bank has developed an index called the Knowledge Economy Index (KEI). The KEI is an economic indicator that measures a country's ability to generate, adopt and diffuse knowledge. The KEI summarizes each country's performance on 12 variables corresponding to the four knowledge economy pillars introduced above. Variables are normalized on a scale of 0 (worst) to 10 (best) and the KEI is constructed as the simple average of the normalized values of these indicators. For an overview of the methodology and the construction of the index see World Bank (2008). In Figure 1, we make an over-time comparison of the KEI of some countries in terms of their relative performance for two points in time viz., 1995 and 2009. Countries above the diagonal line have made an improvement in the KEI in 2009 compared to 1995, whereas countries below the line experienced a decline. As we can see, Denmark, Finland, Sweden, and Norway rank very high in terms of the KEI, although Denmark and Finland's KEI in 2009 is a slightly smaller compared to 1995. Iceland has a KEI index in line with other Western European countries but higher than some technological countries such as Japan. Table 1 presents the KEI and its four components for 2009 for the best 5 countries and Iceland, out of a total of 146 countries. Denmark ranks highest, followed by Finland, and Sweden; Norway is in fifth position, whereas Iceland is placed 13th. It is interesting to note that Iceland is penalized for not having a very high innovation system, whereas it is in line with the top countries for education and economic incentive regimes.

The indicators used in the empirical analysis for estimation of the four components are the following - *Economic and institutional regime*: To proxy for the innovation system, we use trade openness as an indicator of the level of economic and institutional regime operating in the country[4]. An open country is a country with (a) low tariff and non-tariff barriers on trade, (b) low barriers to technology transfers and (c) low power of national monopolies in areas such as telecommunications, air transport, finance and insurance industries (Houghton and Sheehan 2000)). *Innovation system*: We use trade openness and R&D as proxies for innovation in a country. Trade openness is perceived by many authors to have a positive impact on efficiency and innovation in the economy. The idea is that international trade leads to faster diffusion of technology, and hence higher productivity growth. In addition, there are also spillover effects due to "learning by doing" gains and better management practices triggered by new technology leading firms to the best practice technology (Krugman 1987)[5]. R&D is associated with the development of new ideas, new products, product improvements and new technologies leading to innovation in a system. This is supported by Griffith et al. (2003) showing that R&D promotes innovation, the transfer of technology and R&D supported absorptive capacity. *Human capital and education*: One commonly

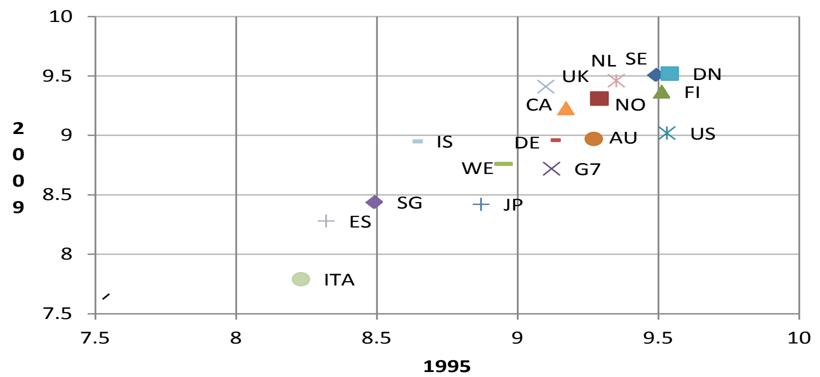
[4] See for example Jenkins (1995), Baldwin and Gu (2004), Greenway and Kneller (2004), Coe and Helpman (1995), Engelbrecht (1997), Madsen (2007b), Lumenga-Neso et al. (2001) and Lichtenberg et al. (1998).

[5] The studies of Jenkins (1995), Baldwin and Gu (2004), Madsen (2007b), Greenway and Kneller (2004), Coe and Helpman (1995), Engelbrecht (1997), Lumenga-Neso et al. (2001) and Lichtenberg et al. (1998) support the argument of R&D spillovers through trade as a channel of TFP.

used measure of human capital is the average years of schooling of the adult population[6]. Average years of schooling is clearly a stock measure and reflects the accumulated educational investment embodied in the current labor force[7]. *Information infrastructure*: Empirical assessments of the effects of ICTs on aggregate output and economic growth typically entail the use of ICT investment. However, due to the non availability of this series for a long time span and the importance of non-ICT investments as well in economic growth, we use the aggregate series of investment (as a ratio of GDP) in our estimations[8].

Figure 1

Knowledge Economic Index by Countries: 1995 versus 2009



Source: World Bank-Knowledge Assessment Methodology (KAM), www.worldbank.org/kam. Notes: Countries above the diagonal line have made an improvement in the KEI compared to 1995, whereas countries below the line experienced a regression. Legend: DN = Denmark; SE = Sweden; FI = Finland; NL = Netherland; US = U.S.A.; NO = Norway; IS = Iceland; UK = United Kingdom; CA = Canada; AU = Australia; DE = Germany; G7 = Group of seven viz., France, Germany, Italy, Japan, United Kingdom, U.S.A., Canada; WE = Western Europe; JP = Japan; SG = Singapore.

[6] The average years of schooling are used by Hanushek and Woessmann (2008) and Krueger and Lindhal (2001) for example. We use the data constructed by Barro and Lee (2010). This data are available only at five years intervals since 1950. We linearly interpolate the data between the five years. Another frequently used measure in empirical research is enrollment rates. According to Bergheim (2008) the enrollment rate is not a useful measure of human capital because it does not include information on years of education. Other measures available are cognitive skills indicators (IQ test and standardized tests on reading, science, and mathematics) but these measures are not available over a long time span; for example the OCED Program for International Student Assessment (PISA) has data starting only from 2000.

[7] Engelbrecht (1997) acknowledges the role of human capital in domestic innovation and knowledge spillovers.

[8] De Long and Summers (1991) for example, show that equipment investment has a significant effect on economic growth. Further, Levine and Renelt (1992) and Sala-i-Martin (1997) have shown that the investment share is a robust variable in explaining economic growth.

[Table 1, about here]

3. Specification of the Model

This section presents the simple and traditional growth model that will be estimated. The steady state solution for the level of output in the Solow (1956) growth model is:

$$y^* = \left(\frac{s}{\delta + g + n}\right)^{\frac{\alpha}{1-\alpha}} A \qquad (1)$$

where $y^*(=Y/L)$ is the steady state level of income per worker, s = the ratio of investment to income, δ= depreciation rate of capital, g = the rate of technical progress, n = the rate of growth of labor, A =the stock of knowledge and α =the exponent of capital in the Cobb-Douglas production function with constant returns (see below). This implies that the steady state rate of growth per worker output (SSGR), assuming that all other ratios and parameters are constant, is simply the TFP:

$$\Delta \ln y^* = SSGR = \Delta \ln A = TFP \qquad (2)$$

However, the determinants of TFP are not known and are exogenous in the Solow (1956) growth model. The new growth theories based on endogenous growth models (ENGM) use an optimization framework and suggest several potential determinants of TFP. However, to the best of our knowledge there is no ENGM which rationalizes that TFP depends on more than one or two selected variables. We make TFP a function of a few of the determinants identified by the ENGMs. For example, if the findings of Levine and Renelt (1992) may be considered correct, then TFP depends only on the investment ratio in spite of the findings by Durlauf *et al.* (2005) and Jones (1995).

Note that the SSGR can be estimated by estimating the production function. The production function can also be extended by assuming that the stock of knowledge (A) depends on some important variables identified by the ENGMs[9]. We start with the well-known Cobb-Douglas production function with constant returns:

[9] See Rao (2010), Paradiso and Rao (2011), Casadio et al. (2012).

$$Y_t = A_t K_t^{\alpha} L_t^{(1-\alpha)} \ , 0 < \alpha < 1 \tag{3}$$

where Y_t is aggregate output, A_t the stock of knowledge , K_t the stock of physical capital, and L_t the labour force in period t.

We assume the following general evolution for the stock of knowledge A, where A_0 is the initial stock of knowledge, Z is a vector which may consist of more than one variable[10], whereas S and W are assumed to consist of one variable each and T is time.

$$A_t = A_0 e^{\left(\gamma Z_t \cdot T + \phi_1 S_t + \phi_2 S_t^2 + \varphi_1 W_t\right)} \tag{4}$$

Substituting (4) into (3) gives:

$$Y_t = A_0 e^{\left(\gamma Z_t \cdot T + \phi_1 S_t + \phi_2 S_t^2 + \varphi_1 W_t\right)} K_t^{\alpha} L_t^{1-\alpha} \tag{5}$$

Dividing both sides of equation (5) by L yields:

$$y_t = A_0 e^{\left(\gamma Z_t \cdot T + \phi_1 S_t + \phi_2 S_t^2 + \varphi_1 W_t\right)} k_t^{\alpha} \tag{6}$$

where $y = (Y / L)$ and $k = (K / L)$.

Appling the natural logarithmic transformation of (6), we obtain,

$$\ln y_t = \ln A_0 + \gamma Z_t \cdot T + \phi_1 S_t + \phi_2 S_t^2 + \varphi_1 W_t + \alpha \ln k_t \tag{7}$$

Equation (7) captures the actual level of per capita output due to two types of variables viz., factor accumulation and variables due to factors other than factor accumulation such as Z, S **and** W. Specification of these other variables that may affect output is an empirical issue. Their effects may be trended (Z), nonlinear (S) or simply linear (W). The variables that should be included in the vector Z, and in S and W is also an empirical matter. We have experimented with various alternatives but to conserve space report only the best and plausible results.

Taking first differences of (7) gives:

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[10] For simplicity we ignore the *i* subscript.

$$\Delta \ln y_t = \gamma \Delta Z_t \cdot T + \gamma Z_{t-1} + \phi_1 \Delta S_t + \phi_2 \Delta S_t^2 + \varphi_1 \Delta W_t + \alpha \Delta \ln k_t \qquad (8)$$

Only trended variables (i.e., Z variables entering the vector multiplied by trend) have a permanent growth effect. For this reason, the variables in the *Z* vector are the sole determinants of the long-run steady state growth rate. The other two variables *S* and *W* have only a level effect on output (i.e., they can raise the economy's income level permanently but they have only transitory growth effects), but with an important difference. *S* influences the level of output in a non-linear manner, whereas *W* affects output in a linear manner.

For equation (8) to make sense $\phi_1 > 0$ and $\phi_2 < 0$, so that the *S* variable has its maximum effect when $S = -0.5(\phi_1 / \phi_2)$. This variable, prior to reaching its maximum effect, increases at a decreasing rate. Each additional unit of *S* contributes less and less to the level of output. Examples in the empirical growth literature of variables that may influence the output this way are trade openness and education. Dollar and Kraay (2004) suggest that countries that had greater increases in trade volumes saw greater increases in growth, but that countries with greater levels of trade volumes saw lower levels of growth. This would seem to suggest that the effect of trade openness on growth is such that it takes an inverted U-shaped pattern. In this case there might be an 'optimal' level of openness. A country possessing a trade regime more closed than its optimal level would increase growth by liberalizing; a country owing a more open trade regime than its optimal level it would see lower levels of growth (Nye *et al*., 2002).

Regarding the education variable, several analyses show that the production of human capital exhibits increasing returns to scale for low levels of education and decreasing returns to scale for high levels of education. Krueger and Lindahl (2001), Paradiso *et al.* (2011), Casadio *et al.* (2012) find that the best fit of the data is provided by a regression model that considers a quadratic form of education. In particular, Krueger and Lindahl (2001) find that on average 7.5 average years of schooling is the maximum level of the inverted U-shaped relation between schooling and output. Above this level, marginal education has a negative effect, so incremental education is expected to depress the growth rate. Several empirical studies have found a negative impact of schooling on economic growth - see Pritchett (2001), Benhabib and Spiegel (1994), Spiegel (1994), Lau *et al.* (1991), Jovanovic *et al.* (1992), Bils and Klenow (2000). Pritchett (2001) advanced three possible reasons for this: 1) The institutional/governance environment could have been sufficiently perverse so that the accumulation of educational capital lowered economic growth; 2) The marginal returns to education could have fallen rapidly as the supply of educated labor expanded while demand remained stagnant; 3) Educational quality could have been so low that years of schooling created no human capital. The author sustains that the extent and mix of these three phenomena explains the negative impact of education on growth. It is unlikely that these factors would cause schooling to have a negative effect in the Nordic countries. In the case of the Nordic countries, the negative effect of education above a certain level might be better explained by wage compression (Fredriksson and Topel 2010), high tax rates (Fredriksson and Topel 2010), labour market segregation (Nordic Co-operation on Gender Equality 2010). Wage compression occurs when wage structures are not in proportion to professional maturity. This phenomenon has been historically very high in the Nordic countries. There could be distortionary effects of higher education levels associated with wage compression when schooling is over a certain level, for example, high skilled workers have high expectations in terms of wages, and wage compression may discourage the moral and the effort of high skilled workers pushing down productivity and therefore output. Furthermore, Bils and Klenow (2000) show that countries with higher enrolment rates do not exhibit faster human capital growth. This is because countries with high levels of human capital are maintaining these high levels. Bils and Klenow find that as the years of enrolment increase, the returns to schooling falls.

In steady state, when $\Delta \ln k \to 0$ and all differences go to zero, the Steady State Growth Rate (SSGR) is equal to the growth rate of the stock of knowledge ($\Delta \ln A$)[11] :

$$SSGR = \gamma Z_{t-1} \tag{9}$$

In what follows we try to understand the potential factors influencing the level effects and the SSGR (i.e., the variables entering in the *Z* vector) and policy that can improve it.

4. Empirical Estimates

Data from 1960 to 2010 (with the exception of Iceland for which the data sample is from 1970-2010) are used to estimate the SSGR, which is the long run growth rate. The long run relationship, equation (2), is estimated using standard time series methods of cointegration. Our selected growth-

[11] The steady state is defined as a situation where all variables grow at a constant, possibly zero, rate (Sala-i-Martin, 1994).

enhancing variables are: the ratio of trade openness (TRADE) to GDP, ratio of investment to GDP (IRAT), ratio of R&D expenditure to GDP (R&D), and human capital (HKI) measured by years of schooling. Definitions of variables and sources of data are provided in the Appendix. All variables are included in the estimation. Some of these variables may not be statistically significant due to multicollinearity. In particular, we find no role for R&D as a shift variable (either as a level or growth effect) for all Nordic countries[12]. This is probably because there is an interaction between TRADE and HKI and R&D, as explained in Section 1. In the paper, we report only the estimations showing economic and statistical contents.

Three estimations techniques are implemented viz., Fully Modified OLS (FMOLS), Canonical Cointegrating Regression (CCR) and Dynamic OLS (DOLS). These estimators deal with the problem of second-order asymptotic bias arising from serial correlation and endogeneity, and they are asymptotically equivalent and efficient (see Saikkonen (1991) on this last point). The standard least squares dummy variable estimator is consistent, but suffers from second-order asymptotic bias that causes test statistics – such as the *t*-ratio – to diverge asymptotically (Phillips and Hansen, 1990). Therefore, in order to draw inferences, we use FMOLS, CCR, and DOLS estimation techniques whose *t*-ratios are asymptotically standard normal[13].

Our estimation strategy is as follows. We estimate the long-run relationship with the three methods stated above (FMOLS, CCR, DOLS) and if all the results are similar and plausible, we verify the existence of a cointegrating relationship under the Engle-Granger (EG) residual test. If the test confirms the existence of a long-run relationship, we construct an Error Correction Model (ECM). Then we study the factor loading and tests for correct specifications i.e., we test for normality, absence of autocorrelation, and no heteroskedasticity in the residuals.

Dummy variables are added in the long-run estimations and are discussed in the Appendix. For Finland and Denmark we consider two dummies for the 1960s taking into account important changes in these two economies (see Appendix for explanation of these events), whereas we include a dummy variable for the financial crisis for all countries. Two issues have to be discussed regarding the use of these dummies. There is a debate in the literature on what critical values should be used to judge the significance of the residual-based ADF test when dummy variables are

[12] *R&D* is not statistically significant for Sweden, Norway, and Iceland. For Denmark and Finland *R&D* is statistically significant but the residual EG test does not reject the null hypothesis of no cointegration.

[13] Montalvo (1995) shows that the DOLS estimator has a smaller bias compared to the CCR and FMOLS.

included in the cointegrating equations. Ireland and Wren-Lewis (1992) argue that since the dummy variable is not stochastic, it could be interpreted simply as a modification to the intercept term. This allows researchers not to regard the dummy variable as an extra variable and use the same critical values. This approach is followed for example by Bahmani-Oskooee (1995), and more recently in the long-run growth literature by Rao (2010), Paradiso and Rao (2011), Casadio *et al.* (2012). The second issue concerns the nature of the financial crisis dummy inserted in the long-run relation estimated. This dummy covers the last three observations for Sweden, Finland, and Denmark (2008-2010), the last four observations for Norway (2007-2010)[14], and the last two for Iceland (2009-2010). For this reason, the dummy could be interpreted such as a structural break occurring at the end of the sample period. We do not have enough instruments (from an empirical and econometric point of view) to detect the exact nature of this break, because the dataset stops in 2010 when the crisis is still in action[15]. The econometric techniques available, Geregory and Hansen (1996) cointegration test for example, are not able to detect the break occurring very close to the end of the sample period. For this reason, we consider this dummy as a temporary and not a shift dummy.

Since the period under investigation is very long (over 40 years) and comprises important economic changes, we investigate the stability of our estimated ECMs. In doing so, we subject the error correction equation to the Quandt (1960) and Andrews (1993) structural breakpoint tests. Using insights from Quandt (1960), Andrews (1993) modified the Chow test to allow for endogenous breakpoints in the sample for an estimated model. This test is performed at every observation over the interval $[\xi T,(1-\xi)T]$ and computes the supremum (Max) of the F_k statistics ($\sup F = \sup_{k\in[\xi T,(1-\xi)T]} F_k$) where ξ is a trimming parameter. Andrews and Ploberger (1994) developed two additional test statistics i.e. the average (ave F) and the exponential (exp F). The null hypothesis of no break is rejected if these test statistics are large. Hansen (1997) derives an algorithm to compute approximate asymptotic p-values of these tests.

[14] In Norway the financial crisis began in 2007, before the other Nordic countries, as reported by Grytten and Hunnes (2010) .

[15] Bagnai (2006) suggests the same reason for explaining that different studies have found a structural break in the US twin deficit relation in the 1990s only because they do not have a large data sample, whereas *ex-post* this was only a transitory phenomenon.

4.1 Sweden

In the model for Sweden, trade openness and average years of schooling enter as long-run growth determining variables. This is reasonable because Sweden ranks very high in terms of education according to The Global Competitiveness Report (2011-2012) of the World Economic Forum and the Barro and Lee (2010) education dataset. Sweden has also, historically supported trade liberalization in the interest of its industrial firms (the access to foreign markets is required for growth). According to equation (4) we have $Z_1 = HKI, Z_2 = TRADE, S = HKI$ and the equation that is estimated is:

$$\ln y_t = Interc. + \alpha \ln k_t + \phi_1 HKI_t + \phi_2 HKI_t^2 + \gamma_1 HKI_t \cdot T + \gamma_2 TRADE_t \cdot T \qquad (10)$$

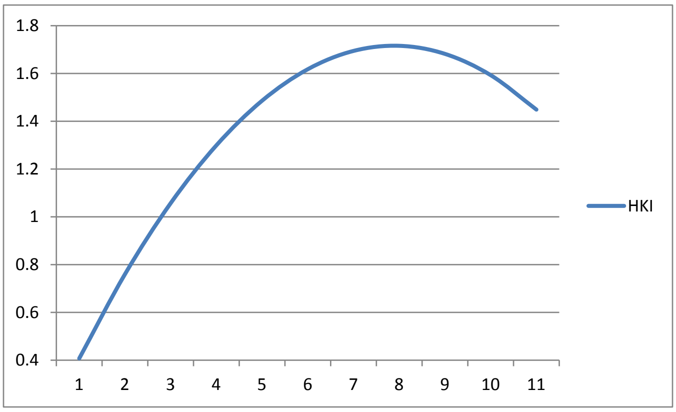
It is interesting to note that *HKI* enters as a variable having both a level (in a non-linear way) and growth effect; openness enters as a shift variable having a growth effect. The results for equation (10) are reported in Table 2. The estimates for equation (10) are satisfactory in that all of the coefficients are correctly signed and statistically significant. The EG residual test shows that a cointegration relationship exists at the 5% level of statistical significance. The ECM shows a statistically significant factor loading (λ) and has the expected negative sign. The diagnostic tests show that the model is correctly specified. Table 3 (Quandt-Andrews test) shows that the ECM is stable over the sample period under investigation.

[Tables 2-3, about here]

According to the results in Table 2, HKI as a level shift variable ($\phi_1 HKI + \phi_2 HKI^2 + \gamma_1 HKI_t \cdot T$) has its maximum level effect when it equals a value of 7.9 (average years schooling)[16]. This implies that further increase in education will have negative effects on growth. This is illustrated in Figure 2.

[16] The HKI pattern for $HKI \cdot T$ was simulated assuming that an added one year of education is obtained after 10 years. This assumption is in line with data on schooling for Sweden for the period 1960-2010.

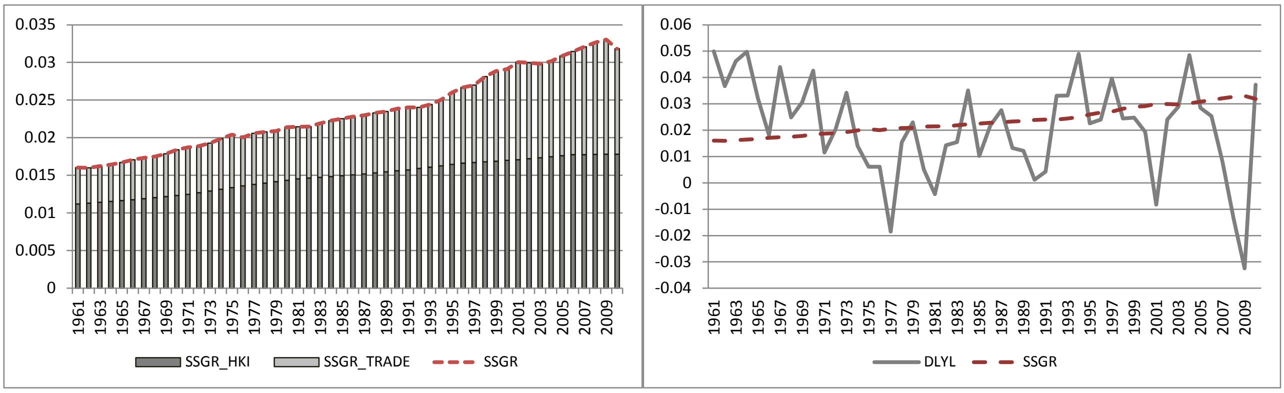
Figure 2: Level effect of HKI in Sweden



By the end of the sample period in 2010, HKI reaches a value of 11.57 well above the optimal value of 7.9. This effect is in line with the results of Krueger and Lindahl (2001). In long-run steady-state, this level effect is intended to be superseded by a trended component of HKI (and the other growth enhancing variables such as trade openness). But it is clear that there is a trade-off between the short-run and long-run effect of HKI on output. A possible reason could be that high wage compression and taxes in Sweden compared to international standards, may discourage the productivity of skilled workers in the short-run, while in the long-run, these detrimental effects are offset by positive effects of higher education linked to the introduction of new ideas and technological improvements.

The SSGR $(=\gamma_1 HKI_{t-1} + \gamma_2 TRADE_{t-1})$ for Sweden is illustrated in Figure 3. Trade openness and HKI play an important and positive role in TFP growth. HKI contributes to 1.7% of income per capita growth in the last 10 years, whereas TRADE yields a contribution of 1.3%. Finally, we plot the per worker GDP growth (DLYL) against SSGR. The SSGR shows a smooth pattern with a slight upward trend towards 3.3%.

Figure 3: SSGR for Sweden



4.2 Finland

The model for Finland considers trade openness and investment ratio as long-run growth determining variables. HKI enters only with a non-linear level effect. Investment and trade openness enter multiplied by trend. That is, according to equation (4) we have $Z_1 = TRADE, Z_2 = IRAT, S = HKI$ so that:

$$\ln y_t = Interc. + \alpha \ln k_t + \phi_1 HKI_t + \phi_2 HKI_t^2 + \gamma_1 TRADE_t \cdot T + \gamma_2 IRAT_t \cdot T \qquad (11)$$

The results for equation (11) are reported in Table 4. All the coefficients are statistically significant and have the expected signs. The EG residual cointegration test confirms the existence of a long-run relationship. The ECM shows a highly statistically significant factor loading and has the expected negative sign. The residual diagnostic tests show that the model is correctly specified. Table 5 shows the Quandt-Andrews structural break tests for the ECM. The results are satisfactory because the ECM does not show a break and it is stable over the period investigated.

[Tables 4-5, about here]

Figure 4: Non-linear level effect of HKI in Finland

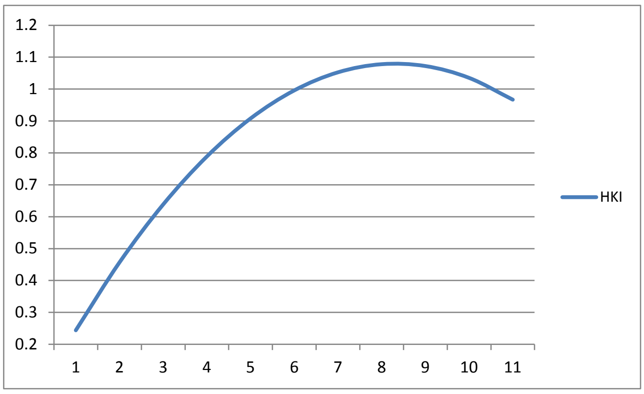
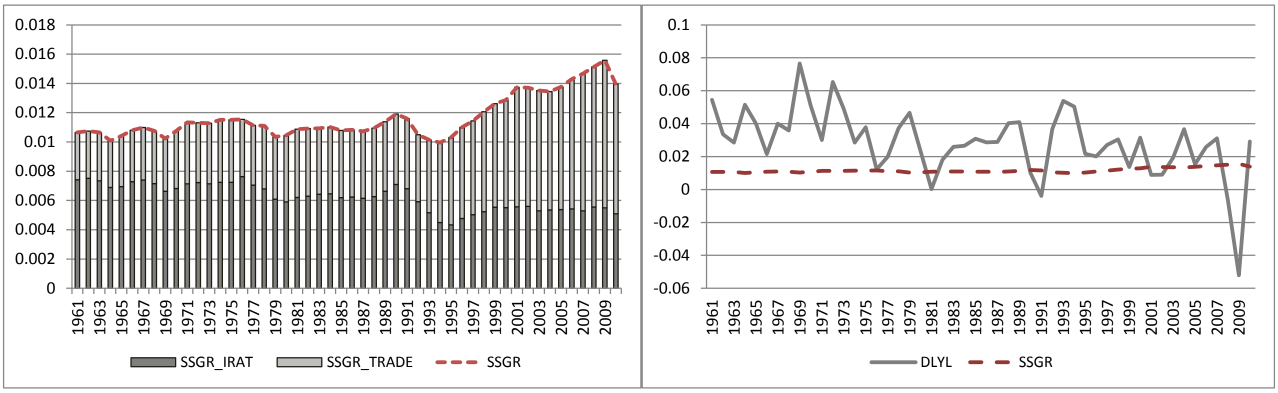


Figure 4 shows the non-linear level effect of average years of schooling. The maximum level effect is when average years of schooling is equal to 8.3 years. Thereafter the effect is negative. At the end of the sample period (2010), schooling is 9.97, and additional investment in education may be detrimental for income. This could also be due to the wage compression structure as in Sweden.

The SSGR $(= \gamma_1 TRADE_{t-1} + \gamma_2 IRAT_{t-1})$ is presented in Figure 5. TRADE and IRAT play a positive and significant role in determining the SSGR. The average contributions of TRADE and IRAT to SSGR are very similar: 0.5% and 0.6%, respectively.

Figure 5: SSGR for Finland



4.3 Norway

Norway has a historically higher number of years of education according to the Barro-Lee (2010) dataset. According to the Global competitiveness report (2011-2012) Norway has evolved into a very open economy, measured by the share of GDP and gross trade flows (exports and imports of goods and services are higher than in most other countries). Norway's long-run growth is determined only by the average years of schooling. Trade openness enters as a variable having a linear level effect only. Accordingly, we assume that, $Z = HKI$ and $W = TRADE$, so that:

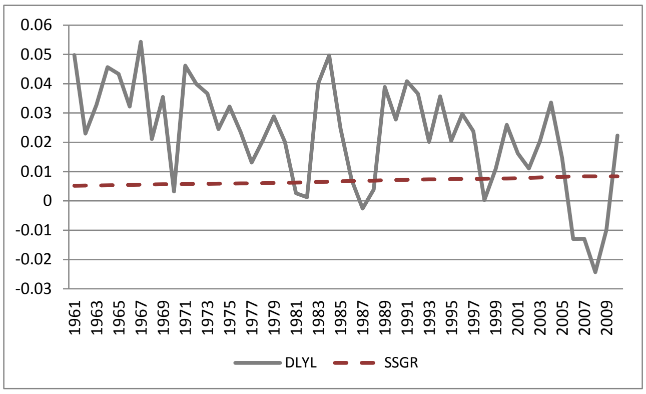
$$\ln y_t = Interc. + \alpha \ln k_t + \gamma_1 HKI_t \cdot T + \varphi TRADE_t \quad (12)$$

Estimates of this equation are reported in Table 6. All results appear satisfactory in terms of the statistical significance of coefficients, the EG residual test, ECM, and residual diagnostic tests. The Quandt Andrews test conducted in Table 7 shows that the estimated ECM is stable.

[Tables 6-7, about here]

In the case of Norway, $SSGR = \gamma_1 HKI_{t-1}$ and the contribution to SSGR is trivial (it only determined by HKI). Figure 6 shows the pattern of SSGR together with the per capita output growth dynamic (DLYL). SSGR shows a slight upward pattern toward 1% at the end of the sample.

Figure 6: SSGR and DLYL for Norway



4.4 Denmark

In the Denmark model, the average years of schooling is the sole variable explaining long-run growth. This result is not unexpected. According to the education index[17], published by the United

[17] The education index is one of three indices - the other two are the income index and life expectancy index on which the human development index is built. It is based on the adult literacy rate and the combined gross enrollment ratio for primary, secondary and tertiary education.

Nations' Human Development Index[18] in 2009, based on data up to 2007, Denmark has an index of 0.993, amongst the highest in the world, in line with Australia, Finland and Belgium. Literacy in Denmark is approximately 99% for both men and women. Accordingly, we assume that $Z = HKI$, so that:

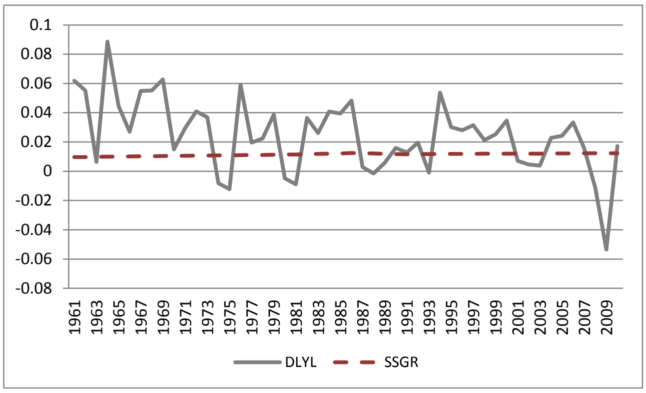
$$\ln y_t = Interc. + \alpha \ln k_t + \gamma_1 HKI_t \cdot T \tag{13}$$

The results appear satisfactory with regard to coefficient signs, the EG residual test, ECM, and diagnostic tests on the ECM. These results are reported in Table 8 below. The stability test conducted using the Quandt Andrews test (Table 9) shows that the ECM is stable over the period 1960-2010.

[Tables 8-9, about here]

The SSGR is small because the average years of schooling is the only variable entering long-run growth. In this case $SSGR = \gamma_1 HKI_{t-1}$ is plotted in Figure 7 together with output growth (DLYL). The SSGR shows a similar pattern to Norway's SSGR, a slight upward trend but slightly higher (1.2% at the end of the sample).

Figure 7: SSGR and DLYL for Denmark



[18] The Human Development Index (HDI) is a comparative measure of life expectancy, literacy, education, and standards of living for countries worldwide published by United Nations. It is a standard means of measuring well-being. It is used to distinguish whether the country is a developed, a developing or an under-developed country.

4.5 Iceland

For Iceland, the long-run growth model is determined by trade openness. Average years of schooling enters as a level effect variable. The importance of openness for growth is not surprising since the benefit of the trade openness, as maintained by Alesina *et al.* (2005), is larger for small countries. In this case, we have $Z = TRADE, S = HKI$ and accordingly equation (7) becomes:

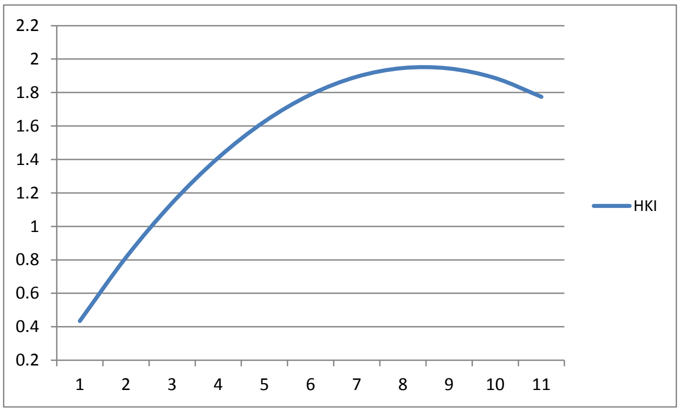
$$\ln y_t = Interc. + \alpha \ln k_t + \phi_1 HKI_t + \phi_2 HKI_t^2 + \gamma_1 TRADE_t \cdot T \tag{14}$$

The results of the cointegrating estimations are reported in Table 10. The results appear satisfactory in terms of coefficients signs, the residual cointegration test (EG test), ECM, and diagnostic tests on ECM residuals. Table 11 reports the Quandt-Andrews test for stability of the ECM. The result show that the ECM is stable over the period 1970-2010.

[Tables 10-11, about here]

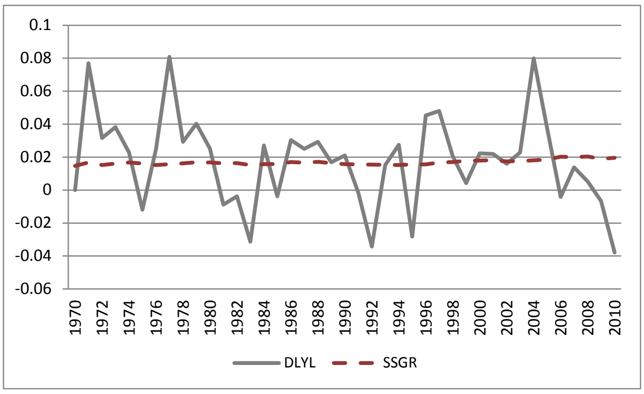
In Figure 8 we report the nonlinear level effect of HKI. The maximum level effect is reached at 8.45 years of education.

Figure 8: Non-linear level effect of HKI in Iceland



In the case of Iceland the SSGR is trivial ($= \gamma_1 TRADE_{t-1}$). Figure 9 illustrates the SSGR against per capita output growth (DLYL). The SSGR reaches a value of 2% toward the end of 2000.

Figure 9: SSGR and DLYL for Iceland



5. Conclusions

We use a knowledge economy approach to identify the variables having level and growth effects in the Nordic countries, where TFP is assumed to be a function of human capital, trade, investment and R&D. Trade openness, human capital (proxied by years of education) and the ratio of investment to GDP play key roles in determining their productivity and the long run growth rate (SSGR). We show that education plays an important role in determining the long-run growth rates of Sweden, Norway, and Denmark. Trade openness has growth effects in Sweden, Finland, and Iceland. The investment ratio plays a key function in influencing the growth rate in Finland. In addition to growth effects, education also has level effects in Sweden, Finland, and Iceland. Our results show no role for R&D however, either as a level or growth enhancing variable. This result is in line with studies maintaining that openness and education may influence R&D patterns (Coe and Helpman (1995), Nadiri and Kim (1996), Blackburn et al. (2000), and Bravo-Ortega and Lederman (2010)), so that incorporating R&D does not provide any additional information. Another argument put forward by Moen (2001), are the high implementation costs of new innovations which he attributes to the finding of a negative relationship between R&D expenditure and economic growth for the Nordic countries.

A noteworthy feature of our estimates is the non-linear level effects of years of education (HKI) in Sweden, Finland and Iceland. Evidence shows that wage compression and taxes have affected decisions to work and invest in human capital in Sweden (Fredriksson and Topel (2010)). For example, Fredriksson and Topel (2010) state that the combined effect of income, payroll and value added taxes led to a fall in the take home wage to 21% of pre-tax wages in Sweden which adversely affected capital formation and economic growth. Similarly, wage flexibility has been low in Finland also due to centralized wage bargaining systems (OECD 2010).Therefore the same could be said to apply to Finland which has similar labour market conditions to Sweden. Iceland however, has relatively flexible labour market conditions compared to Sweden and Finland. Therefore, the non-linear level effects of education here might be explained by labour market segregation (Barro 1998, Kalaitzidakis et al. 2001). Evidence shows that higher educational levels have not been translated into higher wage levels for females compared to males in Iceland (Nordic Co-operation on Gender Equality 2010). This is partially due to preference of females for certain occupations leading to a gender segregated labour market. In Denmark and Norway on the contrary, the results of the present study show that human capital has linear level effects and is thus not constrained from contributing to growth by assisting in the absorption of new technologies.

The challenge for Sweden and Finland are the strain of highly taxed labour in an environment of global mobility in factors of production. Therefore the policy implications stemming from this study are the need for greater labour market flexibility in the case of Sweden and Finland, and greater labour market integration in the case of Iceland to further maximize the effects of human capital on the absorption of new technologies to promote growth.

Appendix

Data Appendix

Y = Real GDP; *L* = Employment (Total economy); *CAP* = Real Capital Stock; *HKI* = Human Capital measured as average years of education; *IRAT* = Ratio of investment to GDP; *TRADE* = Ratio of imports plus exports to GDP; R&D = ratio of total research and development expenditure to GDP. All data, excluding *HKI*, are taken and constructed from the AMECO-EUROSTAT database with the exception of data for Iceland for which *Y* and *IRAT* are taken from the World Bank, *L* from the OECD Statistics Portal, and TRADE from the Penn World Tables (PWT) 7.0 (Heston *et al*., 2011). *HKI* is taken from the Barro-Lee (2010) database for all countries. R&D are from Madsen (2007a) who uses R&D data from the OECD, Main Science and Technology Indicators; OECD, Paris, OECD Archive (OECD-DSTI/EAS); National Science Foundation, Statistics Netherlands, and UN Statistical Yearbook.

The real capital stock for Iceland is constructed through the perpetual inventory method (PIM) using the gross fixed capital formation available from World Bank database. The PIM formula is:

$$K_{t+1} = K_t\left(1-\delta\right) + I_t$$

Where δ = depreciation rate and *I* = is real investment. The PIM requires data on I, a value of δ, and a value of the initial capital stock K_0.

The initial capital stock is chosen so the capital-output ratio in the initial period equals the average capital-output ratio over the period 1960-1970:

$$\frac{K_{1960}}{Y_{1960}} = \frac{1}{11}\sum_{t=1960}^{1970}\frac{K_t}{Y_t}$$

The depreciation rate is chosen such that the average ratio of depreciation to GDP using the constructed capital stock series matches the average ratio of depreciation to GDP in the data over the calibration period. The World Bank database reports depreciation as “consumption of fixed capital”.

The choice of depreciation rate δ matches the average ratio of depreciation to GDP in the data over the calibration period 1970-2010:

$$\frac{1}{36}\sum_{t=1970}^{2010}\frac{\delta K_t}{Y_t}=0.13$$

The above three equations (PIM, capital-output ratio, and the depreciation-GDP ratio) form a system used to solve for the initial capital stock K_0, the depreciation rate δ, and the capital stock series K_t.

Dummy variables in the long-run relation

The dummy variables are inserted after an inspection conducted on the residuals of the cointegrating regression. If we detect large departures in the mean-reverting behavior of the cointegrating residuals in some periods, we insert dummy variables in the long-run relationship. The departures correspond to important social and economic events described below for each country.

Sweden. One dummy is added for the 2008-2010 financial crisis.

Finland. A first dummy for years 1966-1968 is added in the estimation. This period was characterized by some important policy changes: income policies limiting wage increases to growth in productivity, abolition of all index clauses, a market devaluation by 24% in 1967 (Kouri 1975). A second dummy is inserted taking into account the 2008-2010 financial crisis.

Norway. Two dummy variables are added in the estimation. One dummy for the period 1989-1991. (Nordic crises; see Honkapohja (2009)), and the other for the 2007-2010 financial crisis (see Grytten and Hunnes (2010) for a chronology of financial crises in Norway).

Denmark. Two dummies are added in the estimated equations. One dummy for the years 1961-1963 (evolution in the Danish industrial structure, see Marcussen (1997)), and the other for the 2007-2010 financial crisis.

Iceland. A dummy is added for the financial crisis 2009-2010.

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Table 1: KEI and its Four Component Values for the Best Countries (2009)

Rank	Country	KEI	Economic Incentive Regime	Innovation	Education	ICT
1	**Denmark**	9.52	9.61	9.49	9.78	9.21
2	**Sweden**	9.51	9.33	9.76	9.29	9.66
3	**Finland**	9.37	9.31	9.67	9.77	8.73
4	**Netherlands**	9.35	9.22	9.45	9.21	9.52
5	**Norway**	9.31	9.47	9.06	9.6	9.10
.	.	.	.	.	.	.
.	.	.	.	.	.	.
13	**Iceland**	8.95	9.54	8.07	9.41	8.80

Source: World Bank-Knowledge Assessment Methodology (KAM), www.worldbank.org/kam.

Table 2: Results for Sweden: 1960-2010			
$\ln y_t = Interc. + \alpha \ln k_t + \phi_1 HKI_t + \phi_2 HKI_t^2 + \gamma_1 HKI_t \cdot T + \gamma_2 TRADE_t \cdot T$			
	FMOLS	**DOLS**	**CCR**
$Intercept$	-2.862 (0.435) [6.582]***	-3.283 (0.333) [9.869]***	-2.868 (0.442) [6.487]***
$\ln k$	0.682 (0.085) [8.027]***	0.532 (0.091) [5.860]***	0.696 (0.082) [8.472]***
$TRADE \cdot T$	0.015 (0.002) [8.192]***	0.015 (0.002) [7.827]***	0.015 (0.002) [7.699]***
$HKI \cdot T$	0.001 (0.000) [3.052]***	0.001 (0.001) [1.350]	0.002 (0.000) [3.237]***
HKI	0.543 (0.103) [5.284]***	0.521 (0.188) [2.771]***	0.553 (0.102) [5.434]***
HKI^2	-0.043 (0.007) [6.031]***	-0.046 (0.015) [3.081]***	-0.044 (0.007) [6.392]***
λ	-0.314 (0.098) [3.222]***		
EG residual test	-5.221**		
LM(1) test (p-value)	0.321		
LM(2) test (p-value)	0.434		
LM(4) test (p-value)	0.504		
JB test (p-value)	0.484		
BPG test (p-value)	0.776		

Notes: Standard errors are reported in ( ) brackets, whereas *t*-statistics in [ ] brackets. *, **, *** denotes significance at 10%, 5%, and 1%, respectively. FMOLS = Fully Modified Ordinary Least Squares; DOLS = Dynamic Ordinary Least Squares; CCR = Canonical Cointegrating Relationship. EG = Engle-Granger *t*-test for cointegration. λ = factor loading in the ECM; BPG = Breusch-Pagan-Godfrey heteroskedasticiy test; JB = Jarque-Bera normality test; LM = Bresuch-Godfrey serial correlation LM test. FMOLS and CCR use Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS leads and lags are selected according to SIC criteria. The standard errors for the DOLS estimation are calculated using the Newey-West correction. A dummy for 2008-2010 (financial crisis) and for 2004 (peak in the GDP growth (+4.2%)) are added in the ECM formulation.

Table 3: Quandt-Andrews structural break tests for Sweden ECM, 1960-2010

Statistics	**Value**	**Break**	**Probability**
Max LR F-stat	2.245	1996	1.000
Max Wald F-stat	13.228	1996	0.373
Exp LR F-stat	0.720	-	1.000
Exp Wald F-stat	4.988	-	0.211
Ave LR F-stat	1.388	-	1.000
Ave Wald F-stat	8.326	-	0.145

Note: Probabilities calculated using Hansen's (1997) method.

Table 4: Results for Finland: 1960-2010			
$\ln y_t = Interc. + \alpha \ln k_t + \phi_1 HKI_t + \phi_2 HKI_t^2 + \gamma_1 TRADE_t \cdot T + \gamma_2 IRAT_t \cdot T$			
	FMOLS	**DOLS**	**CCR**
Intercept	-3.382 (0.148) [22.843]***	-3.032 (0.202) [15.041]***	-3.372 (0.149) [22.692]***
$\ln k$	0.574 (0.015) [38.879]***	0.606 (0.015) [39.729]***	0.576 (0.016) [36.614]***
$IRAT \cdot T$	0.028 (0.002) [13.220]***	0.030 (0.004) [7.559]***	0.028 (0.002) [11.040]***
$TRADE \cdot T$	0.010 (0.000) [25.367]***	0.009 (0.000) [15.246]***	0.010 (0.000) [20.440]***
HKI	0.260 (0.030) [8.573]***	0.196 (0.040) [4.934]***	0.259 (0.031) [8.436]***
HKI^2	-0.016 (0.002) [8.477]***	-0.012 (0.002) [5.252]***	-0.016 (0.002) [8.282]***
λ	-0.529 (0.157) [3.374]***		
EG residual test	-6.069***		
LM(1) test (p-value)	0.669		
LM(2) test (p-value)	0.908		
LM(4) test (p-value)	0.989		
JB test (p-value)	0.789		
BPG test (p-value)	0.573		

Notes: Standard errors are reported in ( ) brackets, whereas *t*-statistics in [ ] brackets. *, **, *** denotes significance at 10%, 5%, and 1%, respectively. FMOLS = Fully Modified Ordinary Least Squares; DOLS = Dynamic Ordinary Least Squares; CCR = Canonical Cointegrating Relationship. EG = Engle-Granger *t*-test for cointegration. λ = factor loading in the ECM; BPG = Breusch-Pagan-Godfrey heteroskedasticiy test; JB = Jarque-Bera normality test; LM = Bresuch-Godfrey serial correlation LM test. FMOLS and CCR use Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS leads and lags are selected according to SIC criteria. The standard errors for the DOLS estimation are calculated using the Newey-West correction. A dummy for 2008-2009 financial crisis is added in the ECM formulation.

Table 5: Quandt-Andrews structural break tests for Finland ECM (Model 1), 1960-2010

Statistics	**Value**	**Break**	**Probability**
Max LR F-stat	2.915	1976	0.987
Max Wald F-stat	8.744	1976	0.319
Exp LR F-stat	0.596	-	0.974
Exp Wald F-stat	2.196	-	0.327
Ave LR F-stat	1.088	-	0.970
Ave Wald F-stat	3.264	-	0.343

Note: Probabilities calculated using Hansen's (1997) method.

Table 6: Results for Norway: 1960-2010			
$\ln y_t = Interc. + \alpha \ln k_t + \gamma_1 HKI_t \cdot T + \varphi TRADE_t$			
	FMOLS	**DOLS**	**CCR**
$Intercept$	-1.561 (0.031) [49.806]***	-1.617 (0.045) [2.623]***	-1.557 (0.031) [49.402]***
$\ln k$	0.586 (0.019) [31.062]***	0.559 (0.015) [36.806]***	0.591 (0.018) [32.737]***
$TRADE$	0.644 (0.060) [10.744]***	0.758 (0.075) [10.149]***	0.639 (0.060) [10.586]***
$HKI \cdot T$	0.001 (0.000) [15.689]***	0.001 (0.000) [7.456] ***	0.001 (0.000) [16.032]***
λ	-0.47 (0.156) [2.236]**		
EG residual test	-6.337***		
LM(1) test (p-value)	0.437		
LM(2) test (p-value)	0.259		
LM(4) test (p-value)	0.447		
JB test (p-value)	0.856		
BPG test (p-value)	0.220		

Notes: Standard errors are reported in ( ) brackets, whereas *t*-statistics in [ ] brackets. *, **, *** denotes significance at 10%, 5%, and 1%, respectively. FMOLS = Fully Modified Ordinary Least Squares; DOLS = Dynamic Ordinary Least Squares; CCR = Canonical Cointegrating Relationship. EG = Engle-Granger *t*-test for cointegration. λ = factor loading in the ECM; BPG = Breusch-Pagan-Godfrey heteroskedasticiy test; JB = Jarque-Bera normality test; LM = Bresuch-Godfrey serial correlation LM test. FMOLS and CCR uses Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS leads and lags are selected according to SIC criteria. The standard errors for the DOLS estimation are calculated using the Newey-West correction.

Table 7: Quandt-Andrews structural break tests for Norway ECM, 1960-2010

Statistics	**Value**	**Break**	**Probability**
Max LR F-stat	2.616	2002	1.000
Max Wald F-stat	13.078	2002	0.252
Exp LR F-stat	0.873	-	1.000
Exp Wald F-stat	4.948	-	0.123
Ave LR F-stat	1.687	-	0.997
Ave Wald F-stat	8.433	-	0.068

Note: Probabilities calculated using Hansen's (1997) method.

Table 8: Results for Denmark: 1960-2010			
$\ln y_t = Interc. + \alpha \ln k_t + \gamma_1 HKI_t \cdot T$			
	FMOLS	**DOLS**	**CCR**
Intercept	-0.301 (0.267) [1.129]	-0.332 (0.337) [0.987]	-0.356 (0.274) [1.313]
$\ln k$	0.449 (0.111) [4.045]***	0.428 (0.142) [3.022]**	0.424 (0.114) [3.733]***
$HKI \cdot T$	0.001 (0.000) [7.255]***	0.001 (0.000) [6.376] ***	0.001 (0.000) [7.209]***
λ	-0.196 (0.088) [2.216] **		
EG residual test	-6.172***		
LM(1) test (p-value)	0.470		
LM(2) test (p-value)	0.673		
LM(4) test (p-value)	0.938		
JB test (p-value)	0.748		
BPG test (p-value)	0.720		

Notes: Standard errors are reported in ( ) brackets, whereas *t*-statistics in [ ] brackets. *, **, *** denotes significance at 10%, 5%, and 1%, respectively. FMOLS = Fully Modified Ordinary Least Squares; DOLS = Dynamic Ordinary Least Squares; CCR = Canonical Cointegrating Relationship. EG = Engle-Granger *t*-test for cointegration. λ = factor loading in the ECM; BPG = Breusch-Pagan-Godfrey heteroskedasticiy test; JB = Jarque-Bera normality test; LM = Bresuch-Godfrey serial correlation LM test. FMOLS use Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS leads and lags are selected according to SIC criteria. The standard errors for the DOLS estimation are calculated using the Newey-West correction. A spike dummy for 1964 (innovation in Danish pension system with the introduction of earning-related pension supplement scheme) and one for the financial crisis (2008-2010) are added in the ECM formulation.

Table 9: Quandt-Andrews structural break tests for Denmark ECM, 1960-2010

Statistics	**Value**	**Break**	**Probability**
Max LR F-stat	1.749	2001	1.000
Max Wald F-stat	8.745	2001	0.688
Exp LR F-stat	0.544	-	1.000
Exp Wald F-stat	2.979	-	0.490
Ave LR F-stat	1.066	-	1.000
Ave Wald F-stat	5.332	-	0.367

Note: Probabilities calculated using Hansen's (1997) method.

Table 10: Results for Iceland: 1970-2010			
$\ln y_t = Interc. + \alpha \ln k_t + \phi_1 HKI_t + \phi_2 HKI_t^2 + \gamma_1 TRADE_t \cdot T$			
	FMOLS	**DOLS**	**CCR**
$Intercept$	9.523 (1.280) [7.439]***	9.066 (1.903) [4.763]***	9.351 (1.218) [7.679]***
$\ln k$	0.339 (0.067) [5.049]***	0.343 (0.086) [3.984]***	0.347 (0.069) [5.049]***
HKI	0.449 (0.101) [4.435]***	0.462 (0.162) [2.844] ***	0.457 (0.111) [4.112]***
HKI^2	-0.030 (0.007) [3.979]***	-0.027 (0.013) [2.047]**	-0.030 (0.008) [3.629]***
$TRADE \cdot T$	0.024 (0.005) [4.557]***	0.027 (0.008) [3.305]***	0.024 (0.006) [4.155]***
λ	-0.637 (0.175) [3.643] ***		
EG residual test	-5.059**		
LM(1) test (p-value)	0.756		
LM(2) test (p-value)	0.942		
LM(4) test (p-value)	0.954		
JB test (p-value)	0.706		
BPG test (p-value)	0.776		

Notes: Standard errors are reported in ( ) brackets, whereas *t*-statistics in [ ] brackets. *, **, *** denotes significance at 10%, 5%, and 1%, respectively. FMOLS = Fully Modified Ordinary Least Squares; DOLS = Dynamic Ordinary Least Squares; CCR = Canonical Cointegrating Relationship. EG = Engle-Granger *t*-test for cointegration. λ = factor loading in the ECM; BPG = Breusch-Pagan-Godfrey heteroskedasticiy test; JB = Jarque-Bera normality test; LM = Bresuch-Godfrey serial correlation LM test. FMOLS use Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS leads and lags are selected according to SIC criteria. The standard errors for the DOLS estimation are calculated using the Newey-West correction.

Table 11: Quandt-Andrews structural break tests for Iceland ECM, 1970-2010

Statistics	**Value**	**Break**	**Probability**
Max LR F-stat	2.714	2004	0.999
Max Wald F-stat	10.856	2004	0.298
Exp LR F-stat	0.611	-	1.000
Exp Wald F-stat	3.556	-	0.198
Ave LR F-stat	1.056	-	1.000
Ave Wald F-stat	4.223	-	0.369

Note: Probabilities calculated using Hansen's (1997) method.