LATVIJAS BANKA

THE ROLE OF PRODUCTION PROGRESS AND HUMAN CAPITAL IN THE ECONOMIC GROWTH OF LATVIA

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The views expressed in this publication are those of the authors, employees of the Monetary Policy Department of the Bank of Latvia. The authors assume responsibility for any errors and omissions.

Fragments of the painting *White Move* (2005) by Juta Policja and Mareks Gureckis have been used in the design.

CONTENTS

ABBREVIATIONS

AMECO – annual macro-economic database of the European Commission's Directorate General for Economic and Financial Affairs
BACH – Bank for the Accounts of Companies Harmonized database
CSB – Central Statistical Bureau of Latvia
ECM – error correction model
EU – European Union
EU15 – EU countries before 1 May 2004
EU25 – EU countries after 1 May 2004
Eurostat – Statistical Office of the European Communities
GDP – gross domestic product
ISCED 1997 – International Standard Classification of Education 1997
OLS – ordinary least squares
OECD – Organisation for Economic Co-operation and Development
TFP – total factor productivity

ABSTRACT

The paper sets a goal to assess the significance of production progress and human capital for the Latvian economy and to estimate long-term growth rates of the country's economic development. The authors made an attempt to construct a production function using non-linear modelling. In order to improve the production function model for Latvia, the authors augmented the model by human capital approximation.

Key words: *production function, non-linear modelling, human capital, total factor productivity*

JEL classification codes: *C32, E23, J24, O47*

INTRODUCTION

When in the middle of the 20th century a number of new states emerged, many predicted that their economic development would be fast. Though in many cases such predictions were underpinned by certain theoretically constructed models (like the Solow–Swan model), they did not materialise. The studies later in the 1980s proved that the real situation since the 1960s was not consistent with the production function under the standard Solow–Swan model. R. J. Barro writes:

"Therefore, in the absence of shocks, poor and rich countries would tend to converge in terms of levels per capita income. However, this convergence seems to be inconsistent with cross-country evidence, which indicates that per capita growth rates are uncorrelated with the starting level of per capita product." (1)

Observations made in the 1990s renewed the discussion of what the production function should be. The main problem solution, it was discovered, was the production function augmented by human capital.

The paper sets a goal to assess the impact of production progress and human capital and to estimate long-term growth rates of Latvia's economic development. The authors made an attempt to construct a production function using non-linear modelling. An approach, slightly differing from that used so far for the description of technological process in the models for Latvia's production function, has been applied because the authors of this paper believe it reveals the evolution of the technological process more realistically. In order to improve the production function model for Latvia, the authors augmented the model by human capital approximation.

Chapter 1 deals with theoretical aspects of human capital accumulation and the problems arising when correlations described in literature are tested empirically. Chapter 2 aims to apply the existing models to Latvia's economic growth and to test them empirically; likewise, an attempt has been made to find out whether the GDP dynamics observed so far can be estimated by means of a production function augmented by human capital. Chapter 3 outlines briefly other data and methods that may prove helpful for human capital estimation in Latvia.

1. THEORETICAL BACKGROUND AND PROBLEMS

When the analysis of cross-country historical economic development was conducted in the 1980s, an absolute fact came to the foreground: no convergence in terms of real GDP had occurred since the 1960s. Consequently, the correlation between the per capita GDP growth and initial per capita GDP in a given period, which could be implicitly derived from the Solow model, could not be estimated empirically. R. J. Barro and X. Sala-i-Martin (4), R. J. Barro (1), G. N. Mankiw, D. Romer and D. N. Weil (22) conclude that the majority of GDP variances can be estimated by a regression derived from the standard Cobb–Douglas (hereinafter, C–D) production function yet it produces an unfoundedly high capital share in GDP. Hence the Solow–Swan model reflects the reality incompletely.

In all the models, the C–D production function is employed:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha} \qquad [1]$$

where Y_t is real GDP, K_t is real accumulated capital, L_t is employment in the economy, α is capital share in GDP, and A_t is total factor productivity which is exogenous.

The fact that regressions of this type reflected the historical GDP dynamics incompletely had relatively subtle implications for the economic policy process. When this model is employed (assuming that the ratio of A_t and saving rate to GDP are constant), all countries converge to one and the same development level (28). Thus the model implies that there is no need to interfere in country's growth because the convergence of per capita GDP takes place automatically, provided that A_t is constant and saving sufficiently high (the aim of higher saving and labour productivity are both attainable by way of, e.g. attraction of foreign investment as well as liberalisation of foreign trade and capital movements).[1]

Other studies (22) show that despite regressing equation [1] displays a rather strong relationship, i.e. the dynamics of Y_t is fairly well explained, to a great extent, by the growth in variables on the right-hand side of the equation; however, the implied capital share α = 0.59 of this model cannot be correlated with the empirically estimated variable (approx. 0.30). Therefore, this regression is unlikely to be taken as a Solow model and, consequently, the C–D specification of equation [1] does not hold either. The following equation seems to be a better approximation:

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta} \qquad [2]$$

where an additional variable H_t denoting human capital is included.

G. N. Mankiw, D. Romer and D. N. Weil (22), introducing a proxy obtained from education indicators as a factor for human capital and using a simple one-period cross-country regression, produced a capital share of 0.31 and human capital of 0.28 (hence residual of 0.41 is the employment share).

Other studies employing these and similar regressions also arrive at a significant correlation between GDP and human capital factors (1; 3). The result obtained, however, is unlikely to be treated as holding or being final. The problems related to methodologies and data are discussed in the next chapters.

[1] It should be kept in mind, however, that in empirical modelling the total factor productivity A_t is the Solow residual, which is a constant, trend and residual and is not specified (i.e. the only conclusion in respect of developing countries is that "the states have to adjust everything else in line with the developed countries"). It is a relatively unpretentious conclusion without any weighty implications for the economic policy process, as one knows nothing about "everything else" – how it works, what its interrelation with capital and employment or their shares is, or what it is. Nevertheless, historically this has not been an obstacle to interpreting model results freely in line with one's views and political situation.

1.1 Methods

The papers on the impact of human capital on the GDP growth use cross-country regressions as a rule, though regressions of a single country are also common. The construction of such regressions has several drawbacks.

Generally, the production function can be expressed by

$$Y_t = K_t^{\alpha}(A_t L_t)^{\beta} H_t^{\phi} \quad [3].$$

Taking log of it, we obtain:

$$\log(Y_t) = \beta\log(A_t) + \alpha\log(K_t) + \beta\log(L_t) + \phi\log(H_t) \quad [4].$$

Though a precise functional form is not known, usually the model with the constant returns to scale[2] function is used (i.e. a version of equation [4] where $\alpha+\beta+\phi=1$ and $0<\alpha<1$, $0<\beta<1$, $0<\phi<1$).

Such assumptions are usually tested against the so-called reasonable alternatives:

a) a model of endogenous growth (in equation [4], $\alpha=1$ and $0<\beta<1$, $0<\phi<1$);

b) a Solow model with no human capital included (in equation [4], $\alpha+\beta=1$, $\phi=0$ and $0<\alpha<1$, $0<\beta<1$).

This, however, is not a quite appropriate practice, as the tested alternatives are as a rule the Solow model ((b) version), or an endogenous growth model with capital accumulation estimated by constant returns to scale ((a) version). That is why such endogenous growth models reflect the reality less completely and are usually rejected. If the model comprises capital with constant returns to scale, it indicates an explosive growth (32). It implies that on the basis of such a model infinite GDP in finite time is obtained (not a particularly realistic assumption), which is unlikely to happen in reality. Nevertheless, the existence of such production functions is possible in an individual economic sector or a period of time; the possibility cannot be practically tested, yet it becomes important when policy inferences are in view.

Even more important is the fact that there are lots of theoretical models with decreasing returns to scale relative to one of the factors but increasing returns to scale $\alpha+\beta+\phi>1$ and $0<\alpha<1$, $0<\beta<1$, $0<\phi<1$ on the whole. Though this type of a model is difficult to test against a neoclassical alternative, it is sometimes done (from statistical point of view, it is difficult to distinguish between the functions of constant returns to scale and slightly increasing returns to scale). Moreover, an economy as a whole can be characterised by sectors in which features of all mentioned production functions are inherent; as they change in time (depending on the business cycle), identification problems arise (it is not clear which of the indicators is robust and which is not).

[2] This study uses three types of returns to scale: increasing returns to scale, decreasing returns to scale and constant returns to scale.

It should be also taken into account that the true world model includes some unobservable parameters that are automatically excluded from testing. However, the model should not be ignored solely on the grounds that statistical institutions incur problems of quantifying a phenomenon.

Due to the above reasons, precautious attitude shall always prevail when correctness of such models is to be proved; likewise, the results obtained continue to be mixed. R. J. Barro and J. W. Lee (3) conclude that a human-capital-augmented model reflects the reality very well; D. Canning, P. Dunne and M. Moor (9) oppose them and prove that neither the augmented Solow model ((b) version) nor the endogenous growth model ((a) version) explains the data. R. J. Barro and K. Sala-I-Martin (4) conclude that the data can indeed be estimated by a neoclassical production function with human capital and note that technological diffusion models are also useful (as a rule, they have decreasing returns to scale on a factor-level and increasing returns to scale on the whole). P. M. Romer (29) demonstrates that international data can be consistent with endogenous growth models with human capital, which is defined as the number of authors producing research ideas.

The examination of sector-level data shows that increasing returns to scale are observed at the sector- or industry-level (24): larger production volumes are associated with higher productivity of production factors. R. J. Caballerro and R. K. Lyons (8) find that increasing returns to scale are not observable at the industry-level but occur as a result of mutual interaction of the production sectors. For instance, if the development of several sectors or industries is interdependent, an additional 5% of GDP is produced. Such inferences generally give rise to doubt whether the total production function can be used as an adequate measure of the reality; it is not clear whether and how human capital and particularly its approximations (different schooling indicators) are included in the system comprised of various production functions.

Consequently, we may conclude that the results continue to be mixed. Ch. I. Jones (18) sums up the results in the following way: ".. the macro evidence.. cannot distinguish between a "neoclassical" growth model and an R&D-based growth model. Additional evidence must be brought to bear to make this distinction."

1.2 Data

The absence of an unbiased and independent human capital variable reduces the significance of production functions augmented by human capital. That is why various approximations are involved. However, the selection of any such approximation can be subject to doubt – on what grounds has this very approximation been selected? If a variable in a regression is endowed with a higher explanatory capacity, is it because of its strong link with the explained variable and not because the variable causes it? Even if there is a relationship, such equations cannot be easily interpreted.

Assuming in equation [3] (changing parameter designation to $Y_t = K_t^{\beta_1}(A_t L_t)^{\beta_2} H_t^{\beta_3}$) that the technical progress (productivity) growth γ is constant and, consequently, $A_t = A_0 e^{\gamma t}$, we obtain an equation that can be regression-tested:

$$\log(Y_t) = \beta_2 \log(A_0) + \beta_2 \gamma t + \beta_1 \log(K_t) + \beta_3 \log(H_t) + \beta_2 \log(L_t) + \varepsilon_t \qquad [5].$$

If a function ignoring human capital ($\beta_3 = 0$) is estimated, we obtain:

$$\log(Y_t) = \beta_2 \log(A_0) + \beta_2 \gamma t + \beta_1 \log(K_t) + \beta_2 \log(L_t) + \varepsilon_t \qquad [6]$$

where *t* is the trend (in this case A_0 is the technological level at the beginning of the given period).

Testing of the obtained equation is possible, yet even in the event of all coefficients being significant it does not imply a production function. First, the very construction of the income side of national accounts would make the absence of any relation surprising. Second, the traditional interpretation of production functions implies certain causality (i.e. if the production factor *x* increases by 1%, the production volume will grow by *z*%); however, it cannot be verified by the given function.

It is important to find out whether H_t causes a fast GDP growth, or, vice versa, human capital (to be more precise, any of its approximations, e.g. the number of persons with university education) is a result or side-product of growth, or an approximation of any other processes with a real impact on the production function. Even if we manage to prove that the GDP growth is always preceded by an increase in the number of persons with university education (an assumption similar to the Granger causality), it would only mean that the presence of persons with university education most likely is a necessary precondition for development (the opposite would be rather difficult to presume even without regression-based evidence), albeit not a sufficient one; in fact, the production function of this type in equation [2] confirms it. In addition, it has already been stressed that when estimating such a regression it is very difficult to distinguish between various coefficient size hypotheses.

Major studies, in which the need to include the human capital variable in the production function is emphasised (1; 3; 4), support the conditional convergence relation, meaning that states do converge to something but this convergence is determined by a human capital variable (i.e. the pace of growth for less developed states is faster, and the income levels gradually converge, provided the countries have the same conditional factor – human capital, in this case). R. J. Barro and J. W. Lee (3) assume male secondary education as a conditional indicator approximating human capital. If the average length of male secondary schooling is increased by 0.68 year, the average annual GDP growth would pick up 1.1 percentage points. But why should the male secondary education be the appropriate human capital indicator? In a World Bank paper *The Quality of Growth*, V. Thomas, M. Dalaimi, A. Dhareshwar et al. (34) point to female education as a qualitative indicator of human capital. Why do not regressions with aggregated indicators of schooling years point to a significant relation?[3]

Some researchers, however, used aggregated indicators of schooling and have made a significant inference (23). The connection between schooling and economic

[3] Employing such a specific indicator is quite likely to imply that statistical reporting is highly qualitative in certain country groups (e.g. OECD countries).

growth indicators has been verified by R. Levine and D. Renelt (20) who rank education level among the two single significant and robust indicators that explain the level of economic growth (investment level being the other indicator). Other scholars (36) maintain that expenditure on education or the number of researchers rank among the basic indicators (12).

At the same time, N. Oulton and G. Young (25) who used the same database as R. J. Barro and J. W. Lee (3) (freely available on Internet and used in all studies by R. J. Barro[4]), failed to come up with a significant relation between the level of schooling and economic growth. L. Pritchett (26) even discovered a negative relation between the two. In both papers, the Barro–Lee database has been used but male secondary education has not been distinguished as a separate factor (the authors maintain that there is no model via which the advantages of male secondary education as a better human capital approximation over any other education variable can be estimated).

Summing up the findings of available papers, it may be assumed that education indicators do relate to the GDP growth, albeit to some extent only. Any more daring opinions, e.g. on feasible causality, or how human capital enters, if at all, the production function, are unlikely to be reasonably grounded.

As to other areas, production functions with human capital variables are rarely used. Structural models used by central banks, as a rule, are standard C–D functions as in equation [1] (30). Including human capital would be rather difficult, as the reporting for national accounts still lacks unbiased indicators capturing human capital adjustments.

All in all, researchers have not yet formulated their opinion regarding the so-called true model. On the one hand, it is quite likely to include human capital, while on the other, human capital may be absent from the model (3; 25). Similarly, the standard model of constant returns to scale or the model of increasing returns to scale of R&D type may be admitted as most appropriate ones (29).

2. MODELLING LATVIA'S SITUATION

2.1 Latvia's model

When attempting to obtain reliable variables for the production function, researchers face one central problem – that of data. Equation [6] shows that data would be necessary on the following time series: real GDP Y_t, total factor productivity A_t, real capital K_t, human capital H_t and employment L_t. A_t is the Solow residual.

Real capital K_t is reported as accumulated capital, taking into account capital stock at the end of 1994, investment in gross capital formation and the level of depreciation, which is the average depreciation of the period (10% per annum). Labour force surveys constitute the data source for employment L_t. Until 2002, such surveys were conducted on a semi-annual basis; hence for the period prior to

[4] http://www.nber.org/pub/barro.lee

2002, no quarterly data are available. The employment time series for this period has been interpolated on the basis of short-term employment data.[5]

The reporting of human capital H_t presents problems and, as has been stated above, national accounts do not present such data sets. It means that any data series employed is merely an approximation. Besides, the previous chapter emphasised that the type of approximation is not specified.[6] The lack of quarterly data prior to 2002 makes the problem more complicated.

Census-X12 algorithm has been used to seasonally adjust all time series in econometric modelling.

Constructing of the C–D production function for Latvia has so far been attempted by several authors. D. Stikuts (33) derives a relation in which capital share β (or in compliance with equation [6] – β_1) is 0.225 (yet with an insignificant Durbin–Watson statistic). K. Beņkovskis and D. Stikuts (5) do not calculate β but obtain the value of 0.319 through calibration. (In the given study the annual growth in labour productivity γ is 4.6%.) Inability to account for specific economic features of the transition period is a drawback of such calculations.

A similar function with the variable for technological progress obtained with the help of the Kalman filter has been estimated in this study (refer to (16) for a more detailed information on methodology used). The following production function is assumed:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \qquad [7].$$

The TFP is modelled as a stochastic process with an increase γ_t, which is random walk:

$$A_t = A_{t-1} e^{\gamma_t} \qquad [8]$$

and

$$\gamma_t = \gamma_{t-1} + \varepsilon_t^{\gamma} \qquad [9].$$

Taking a log of equations [7] and [8] and combining it with the TFP growth factor, we obtain the state-space system that can be technically estimated:

[5] The authors will provide any additional information on assumptions used in data interpolation.
[6] This study uses data on the ratio of education sector expenditure to GDP and some schooling indicators.

$$\log(Y_t) = \log(A_t) + \alpha \log(K_t) + (1-\alpha)\log(L_t) + \varepsilon_t^{\log(Y)}$$

$$\log(A_t) = \log(A_{t-1}) + \gamma_t$$

$$\gamma_t = \gamma_{t-1} + \varepsilon_t^{\gamma} \qquad [10].$$

In fact, this system is similar to the one in equation [6]; it is only assumed here that technological progress is not linear. This construction builds on the assumption that historically the most significant adjustments were not cyclical but have had a lasting impact on the supply side (production function). It could be an adequate approach for the economy with structural changes still in progress. It is assumed that model errors ε_t^{γ} and $\varepsilon_t^{\log(Y)}$ are normally distributed and independent.

On the whole, this approach is similar to the case where the simple C–D presentation is used in the calculation (equation [6]); however, this method allows for the stochastic and variable total factor productivity process. The authors of the study used a version of constrained coefficients (in fact, assuming a priori C–D production function with constant returns to scale).

The calculations by authors produced the following results.[7]

Table 1
State-space system estimations (for equation system [10])

Approach: maximum likelihood (Marquardt method).
Convergence achieved after 11 iterations.

	Coefficients	Standard error	*z*-statistic	Probability
α	0.303	0.064	4.754	0.000
	Final state	Root MSE*	*z*-statistic	Probability
$\log(A_t)$	−0.133	0.009	−14.954	0.000
γ_t	0.010	0.002	4.357	0.001
Log likelihood	95.049			

* Root mean standard error.

In this case, TFP is obtained as a state variable (see Chart 1 for projected TFP dynamics). Capital stock (0.303) slightly falls behind the one calibrated by K. Beņkovskis and D. Stikuts ((5); 0.319), and differs from the other estimated by D. Stikuts ((33); 0.225). The figure is consistent with values observed in production functions of other countries (which vary broadly; see 8; 11), or with calibrated values, which usually exceed 0.3. For instance, the capital share is estimated at 41% for the euro area (14), at 36% for France, with a TFP increase of 1.2% per annum (7), at 37% for Estonia (19), and at 36% for Lithuania (35). The dynamics of observable γ_t (in this case approximating TFP growth) is also interesting and on the whole consistent with expectations (see Chart 1).

[7] Here and hereinafter using the Kalman filter, the error is smoothed out restricting its variances by *var* = *exp*(−14). The period used in calculation is from the first quarter 1995 to the fourth quarter 2005. Additional tests are given in Appendix 1.

Chart 1
TFP dynamics consistently with equation system [10]

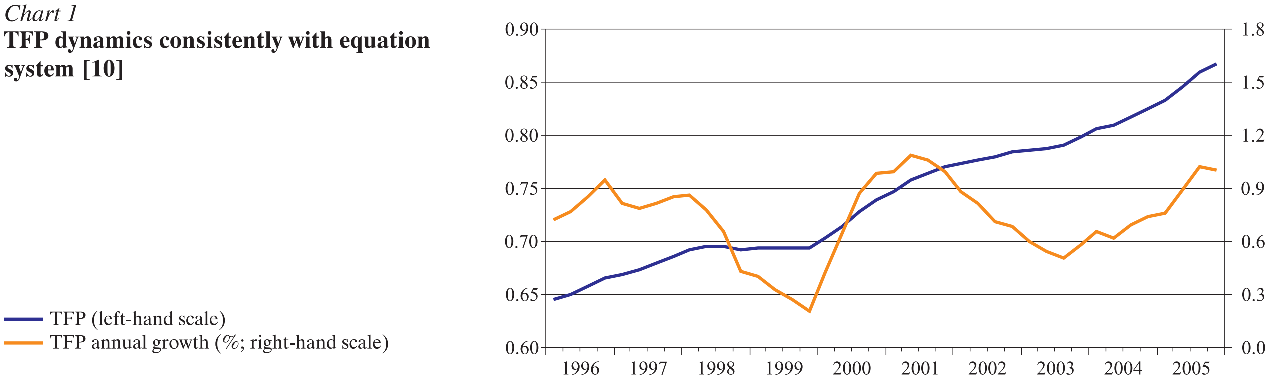


Chart 1 shows that the TFP growth varies in the reference period. During the Russian financial crisis, its growth subsided and was close to zero in the period between the fourth quarter of 1998 and the fourth quarter of 1999. Economic recovery, on the other hand, saw the TFP growth accelerating buoyantly but slowing down afterwards. Latvia's accession to the EU gave a fresh impetus to new acceleration in the TFP growth.

In order to separate short-term deviations from the long-term trend, an error correction model has also been estimated for the system:

$$\log(Y_t) = \log(A_t) + \alpha \log(K_t) + (1-\alpha)\log(L_t) + \varepsilon_t^{\log(Y)}$$

$$\Delta \log(Y_t) = \gamma_t + \phi \Delta \log(K_t) + (1-\phi)\Delta \log(L_t) + \lambda \varepsilon_{t-1}^{\log(Y)} + \varepsilon_t^{\Delta \log(Y)}$$

$$\log(A_t) = \log(A_{t-1}) + \gamma_t$$

$$\gamma_t = \gamma_{t-1} + \varepsilon_t^{\gamma} \qquad [11].$$

Table 2 shows the estimation of the given system.[8]

[8] Additional tests are given in Appendix 2.

Table 2
State-space system with error correction (for equation system [11])

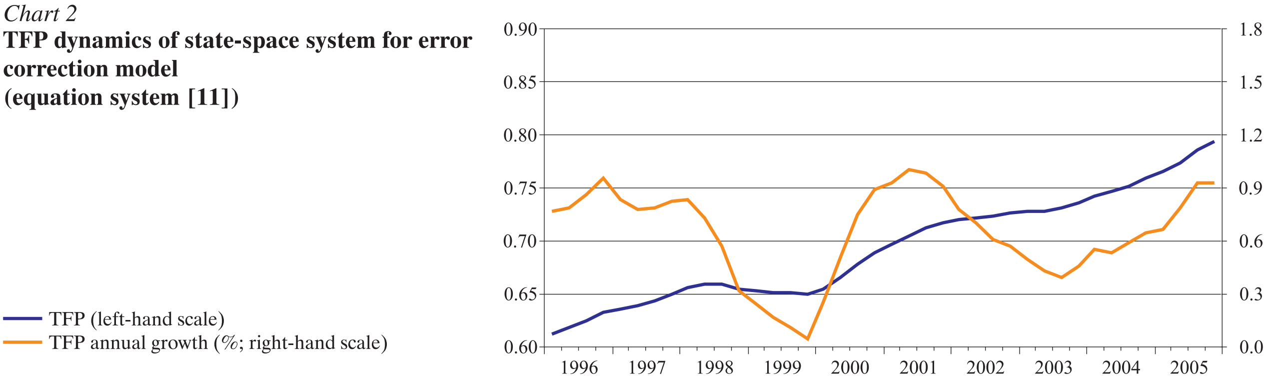
Approach: maximum likelihood (Marquardt method).
Convergence achieved after 26 iterations.

	Coefficients	Standard error	*z*-statistic	Probability
α	0.341	0.054	6.346	0.000
ϕ	0.365	0.063	5.817	0.000
λ	−0.443	0.165	−2.677	0.007
	Probability at end-period	Root MSE*	*z*-statistic	Probability
$\log(A_t)$	−0.221	0.008	−26.105	0.000
γ_t	0.009	0.002	4.125	0.000
Log likelihood	213.238			

* Root mean standard error.

Table 2 shows that in this case the capital share is larger in the short-term than in the long-term. The difference, however, is not significant. The TFP dynamics showed in Table 2 is quite similar to the model in equation [10] (see Chart 2).

Chart 2
TFP dynamics of state-space system for error correction model (equation system [11])



The inclusion of the human capital variable in equation is an alternative approach. The following data sets likely to figure as human capital approximations are used for the purpose:

a) share of real education expenditure in real GDP (Section M of national accounts; quarterly data available; data available since 1995);
b) share of employed with secondary and university education in the employment group over 15 years of age (Eurostat data; in line with levels 3–6 of ISCED 1997);
c) share of employed with university education in the employment group over 15 years of age (in line with levels 5–6 of ISCED 1997);
d) share of employed with secondary and university education in employment group over 25 years of age (Eurostat data; in line with levels 3–6 of ISCED 1997);
e) share of employed with university education in the employment group over 25 years of age (in line with levels 5–6 of ISCED 1997);

f) share of male with secondary and university education in employment group over 15 years of age (in line with levels 3–6 of ISCED 1997);
g) share of male with university education in employment group over 15 years of age (in line with levels 5–6 of ISCED 1997);
h) share of male[9] with secondary and university education in employment group over 25 years of age (in line with levels 3–6 of ISCED 1997);
i) share of male with university education in employment group over 25 years of age (in line with levels 5–6 of ISCED 1997).

All schooling level data of the employed persons were available only as of 1998, with data for the first four years being semi-annual. The observations missing for the period between 1998 and 2002 were obtained via interpolation (on account of the data being semi-annual, implying that interpolation was not necessary for two consecutive periods, it did not seem of particular significance; fortunately, the data do not display excessive variances either, thus the results are not likely to depend on the selected method of interpolation[10]).

Approximation-related problems are inherent in these data series. For instance, the share of education in GDP is constantly shrinking (see Appendix 3); however, if other factors (e.g. the share of persons with university education in the employment group over 25 years of age; see Appendix 4) are considered, they do not point to a trend so unequivocally. Although all time series are expected to estimate the same human capital data collection process, they present different dynamics.

Testing the given variables in a similar state-space equation system

$$\log(Y_t) = \log(A_t) + \alpha \log(K_t) + \beta \log(H_t) + (1 - \alpha - \beta)\log(L_t) + \varepsilon_{1,\ t}$$

$$\log(A_t) = \log(A_{t-1}) + \gamma_{t-1} + \varepsilon_{2,\ t}$$

$$\gamma_t = \gamma_{t-1} \qquad [12],$$

we come to the conclusion that the relation where both α and β are significantly different from zero and meet the terms of the production function with constant returns to scale (i.e. $0 < \alpha < 1$, $0 < \beta < 1$ and $\alpha + \beta < 1$) is impossible to obtain. None of the above estimated variables displays a relation that could prompt its inclusion in the production function. When the share of real education expenditure in GDP was used as a human capital approximation, the coefficient was even negative.

9 The study also makes use of these data series (separating male data) because in the paper by R. J. Barro, G. N. Mankiw and X. Sala-i-Martin (2) it was the group of male with secondary and university education in the employment group over 25 years of age that contained a variable that seemed the best approximation for human capital.

10 In this case, two interpolation methods are tested: the linear (a simple mean of two closest values) and the cubic (interpolation method insignificantly smoothing time series). The results did not change depending on the method applied. Results given in Appendix 5 were obtained by the cubic interpolation method.

When the OLS method was additionally used in testing equation [6] and the state-space system as in equation system [10][11] (see Appendix 5 for the summary of state-space system results), none of the possible approximation variables displayed a significant relation to the GDP variable. It follows that, with all prior research history duly considered, at this point it is rather difficult to substantiate why human capital (or rather its approximation) should be included in the production function.

Some remarks

These conclusions are relevant only for a limited set of models. Only a small fraction of all possible types of models explaining the world architecture can be tested. The selection is not based on an unprejudiced criterion but simply relies on convenience.

1. The requirement for mathematical description. This problem is inherent in the entire economics – formalisation has its negative sides. When economic models are expressed in formulae, constraints are imposed on the types of models for testing, i.e. only the models that can be formalised can be tested. Moreover, they should be models that can be easily described (models that can be described within one research paper are used). In fact, it is a voluntary discharge of the nuisance models. In the case of production function, reference is to the much-exploited argument questioning the utility of production function (as an aggregation of a number of various sectors) in reflecting the reality and the adequacy of grouping all factors into simple labour and capital.

2. In addition to constraints under Clause 1, several assumptions are used only because one believes it would be appropriate. The assumption about the stability of the model (discarding non-robust models, i.e. assuming that natural robustness is inherent in the system; what is this assumption underpinned by?) when several "impractical" production functions are omitted, is an example. In this case, the research was limited to applying only the C–D function of constant returns to scale (without any restrictions, the function demonstrated a negative relation between GDP and capital, and finding an economically justifiable interpretation is quite a problem for it).

3. In addition to restrictions under Clauses 1 and 2, the need for empirical testing also gives rise to problems. In this case, data on capital stock (irrespective of its true meaning) and labour are available but accounting for human capital is not possible, therefore available data should be used. The C–D production function reflects a short-term tendency but the distinction between the short-term dynamics and a long-term trend is practically impossible to make (in this case, the entire short-term dynamics is included as an error, which implies several assumptions regarding the short-term tendency, i.e. normally distributed with constant variance).

It should be acknowledged that in this and any other case of empirical testing, many findings are implied beforehand during the model construction process or assumed afterwards through ambitious interpretation of obtained relations (e.g. the Solow residual may have a great number of distinctive interpretations in each of the tested equations depending on the adopted theoretical model).

[11] Overall, more than 30 regressions were made (OLS and state-space representations with different human capital approximations and using various interpolation methods for education data up to 2002).

2.2 Estimation of human capital intensity using theoretical model

There exists another approach. The role of human capital in the economy can be estimated also by using a generally accepted production function and carrying out simple computations.

The main difficulty in this case consists in the fact that A_t and H_t are unobservable and as such cannot be identified in the production function $Y_t = K_t^{\alpha} H_t^{\eta} (L_t A_t)^{1-\alpha-\eta}$. It implies that even if it is assumed that the parameters in all countries are identical, additional evidence on the variables is required.

The following assumptions have been used.

A. We assume that technology A_t is identical currently but was different initially. Following the EU accession, Latvia has generally aligned its legislation and modified its institutions (together with judiciary, the latter explains the standard parameter A_t, whereas such an unobservable factor as the quality of education is the explanation for parameter H_t). As $A_t = A_0 e^{gt}$, it implies that the EU and Latvia have different growth rates of A_t.

B. Human capital indicators in both the EU15 countries and Latvia are in steady state, and in the given period of time their growth is on average similar to the steady state growth, with rates being broadly the same, implying that the crisis of the last years of soviet rule is treated as capital collapse not affecting human resources.

C. Parameters of production technologies are identical in all countries.

D. Y_t / K_t is approximately the same in steady state $(Y_H / K_H)^* = (Y_F / K_F)^*$ (in the EU15 countries the ratio is around 0.3). Empirical evidence indicates that capital stock α is approximately the same in all countries. Hence it is implied that the marginal product of capital (equal to interest rate) is the same for all countries $r_W = MPK = \alpha (Y / K)^*$ (by assumption that free capital movement r_W is similar in all countries, empirical data show that α is also similar; it means that $(Y / K)^*$ should also be the same). The EU country data also support it, for Y_t / K_t mainly varies from 0.3 to 0.5.[12]

With these assumptions on hand, we do not need to assume any particular model because the C–D production function is sufficient. The production function $Y_t = K_t^{\alpha} H_t^{\eta} (L_t A_t)^{1-\alpha-\eta}$ can be written using variables in per capita terms.

$$y_{H,t} = k_{H,t}^{\alpha} h_{H,t}^{\eta} (A_{H,t})^{1-\alpha-\eta}$$

$$y_{F,t} = k_{F,t}^{\alpha} h_{F,t}^{\eta} (A_{F,t})^{1-\alpha-\eta}$$

[12] Data from CSP, AMECO and Eurostat databases and authors' calculations.

H and F are two countries and $y_{i,t} \equiv \frac{Y_{i,t}}{L_{i,t}}, k_{i,t} \equiv \frac{K_{i,t}}{L_{i,t}}, \quad h_{i,t} \equiv \frac{H_{i,t}}{L_{i,t}}$ where $i = H, F$.

$$\frac{y_{H,t}}{y_{F,t}} = \left(\frac{k_{H,t}}{k_{F,t}}\right)^{\alpha} \left(\frac{h_{H,t}}{h_{F,t}}\right)^{\eta} \left(\frac{A_{H,t}}{A_{F,t}}\right)^{1-\alpha-\eta} \qquad [13],$$

which by assumption A ($A_{F,t} = A_{H,t}$) is reduced to

$$\frac{y_{H,t}}{y_{F,t}} = \left(\frac{k_{H,t}}{k_{F,t}}\right)^{\alpha} \left(\frac{h_{H,t}}{h_{F,t}}\right)^{\eta}.$$

Thus the proportion $\left(\frac{h_{H,t}}{h_{F,t}}\right)$ is

$$\left(\frac{h_{H,t}}{h_{F,t}}\right) = \left(\frac{y_{H,t}}{y_{F,t}}\right)^{1/\eta} \left(\frac{k_{H,t}}{k_{F,t}}\right)^{-\alpha/\eta} \qquad [14],$$

i.e. the relative level of human capital can be estimated using relative GDP and per capita capital figures.

Employing standard assumptions used in the literature, $\alpha+\eta=0.8$ and $\alpha=0.4$ (2; 15) as well as proportions $\left(\frac{y_{H,t}}{y_{F,t}}\right)=0.48$ and $\left(\frac{k_{H,t}}{k_{F,t}}\right)=0.3$ (an approximate value from national accounts), we obtain $\left(\frac{h_{H,t}}{h_{F,t}}\right)=0.53$.[13] These calculations build on a simple fact, that if the level of human capital in Latvia is similar to that in the EU15 countries, the only explanation for a smaller GDP would be a considerably lower level of per capita capital. Indeed, the level of per capita capital in Latvia is lower yet apparently not low enough to offset the differences in GDP levels completely.

The level of GDP convergence can be estimated using assumption D $(Y_H / K_H)^* = (Y_F / K_F)^*$ (for the EU15 countries the ratio is around 0.3).

When both sides of the production function are divided by K_t, we obtain:

$$Y_t / K_t = K_t^{\alpha-1} H_t^{\eta} (L_t A_t)^{1-\alpha-\eta} = k_t^{\alpha-1} h_t^{\eta} (A_t)^{1-\alpha-\eta}.$$

---

[13] Calculations are not too sensitive to reasonable changes in parameters α and η, but are quite sensitive to changes in $\left(\frac{k_{H,t}}{k_{F,t}}\right)=0.3$.

Again using countries *H* and *F*

$$\frac{Y_{H,t}/K_{H,t}}{Y_{H,t}/K_{H,t}} = \left(\frac{k_{H,t}}{k_{F,t}}\right)^{\alpha-1}\left(\frac{h_{H,t}}{h_{F,t}}\right)^{\eta},$$

in equilibrium $(Y_H / K_H)^* = (Y_F / K_F)^*$

we obtain that

$$1 = \left(\frac{k_H}{k_F}\right)^{*\alpha-1}\left(\frac{h_H}{h_F}\right)^{*\eta} \qquad [15].$$

As in compliance with the assumption B $\left(\frac{h_{H,t}}{h_{F,t}}\right) = \left(\frac{h_{H,t}}{h_{F,t}}\right)^*$, it is possible to estimate $\left(\frac{k_H}{k_F}\right)^*$, which is:

$$\left(\frac{k_H}{k_F}\right)^* = \left(\frac{h_H}{h_F}\right)^{*\eta/(1-\alpha)}.$$

With the parameters used, $\left(\frac{k_H}{k_F}\right)^* = 0.66$, which also implies that $\left(\frac{y_H}{y_F}\right)^* = 0.66$ convergence level.

Such evaluation of the situation builds on the pessimistic scenario of the world development, assuming that the relative human capital intensity cannot increase. It does not exclude, however, the growth of human capital, and $\left(\frac{h_{H,t}}{h_{F,t}}\right) = \left(\frac{h_{H,t}}{h_{F,t}}\right)^*$ indicates that human capital may record both per capita increases and also increases relative to any other parameter, with the restriction in this case applying to the relative value of Latvia and the EU15 countries.

It is quite likely that assumption A is too strict; yet it is reasonable, as the aligning of the Latvian and EU legislation has been accomplished.

If, by assumption, the level of human capital in Latvia and EU15 countries is similar, equation [14] can be written as follows: $\left(\frac{A_{H,t}}{A_{F,t}}\right) = \left(\frac{y_{H,t}}{y_{F,t}}\right)^{1/(1-\alpha-\eta)}\left(\frac{k_{H,t}}{k_{F,t}}\right)^{-\alpha/(1-\alpha-\eta)}$. Then the labour productivity parameter would be 28% of the average EU15 indicator; be it so, Latvia's convergence expectations should be linked with the converging of this very parameter (including areas of technology, legislation, institutions, etc). This type of convergence seems to be more difficult to attain than the convergence of human capital. Moreover, it should be borne in mind that such convergence encompasses restructuring of the economy. An example may help to find out the approximate GDP level per person employed if employment across sectors remains unchanged from the current level but production is based on EU15 technologies at the similar level of human intensity (human capital). Thus it is assumed that labour productivity of employed persons in Latvia and the EU15 countries is the same. The result is the same as in the previous example: 65% of the average EU15 level is achieved (see Appendix 6). The reason for it is an excessively high specialisation in sectors where productivity is not particularly high also in the EU15 countries. These results are particularly affected by bulky employment in agriculture, hunting and forestry. Other sectors with low productivity (manufacture of textiles, wearing apparel, wood and articles of wood and cork, excluding furniture) are also strongly represented in the Latvian economy. By contrast, employment is weak in real estate activities, manufacture of motor vehicles, trailers and semi-trailers, other transport equipment, electrical equipment and apparatus, fabricated metal products, etc.

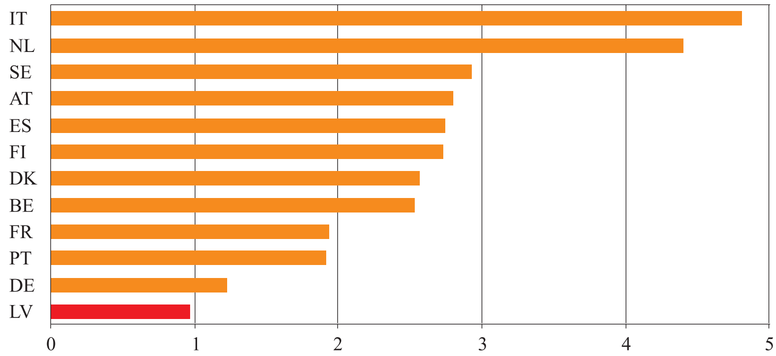
By implication, even the most optimistic expectations regarding the technology transfer capacity and opportunities will not come true (at least as shown by calculations in Chapter 2.2) within the current economic framework of Latvia, and the country is unlikely to ever attain the average income level of the EU15 countries. Even if the quality of labour and technologies in Latvia are absolutely identical to those in the developed European economies, the large share of sectors producing goods and offering services with a relatively low value added will be an obstacle on the way to attaining the income level consistently with the given economic framework, with maximum income accounting only for around two thirds of the EU15 average. Hence with the future convergence in view, the entire process should build on the economic restructuring.

Finally, the authors arrive at a general conclusion that the concept of Latvia's convergence towards the average level of the EU15 countries stems from the faith in positive changes in the future (changes either in $A_{F,t} / A_{H,t}$, or $h_{H,t} / h_{F,t}$). Moreover, instead of being comparable with the current status of the economy, the changes must be related to the EU15 countries (i.e. Latvia's performance must outpace these countries).

3. OTHER HUMAN CAPITAL INDICATORS

A rather broad spectrum of indicators, of which a part cannot be associated with human capital according to the authors of this paper, is as a rule used when estimating the research potential of a country. Countries are often valued from the positions of R&D expenditure from the general government budget and by the private sector. The comparison of Latvia's intangible assets with the respective indicators of other countries is given in Chart 3.

Chart 3
Intangible assets versus total assets
(%)

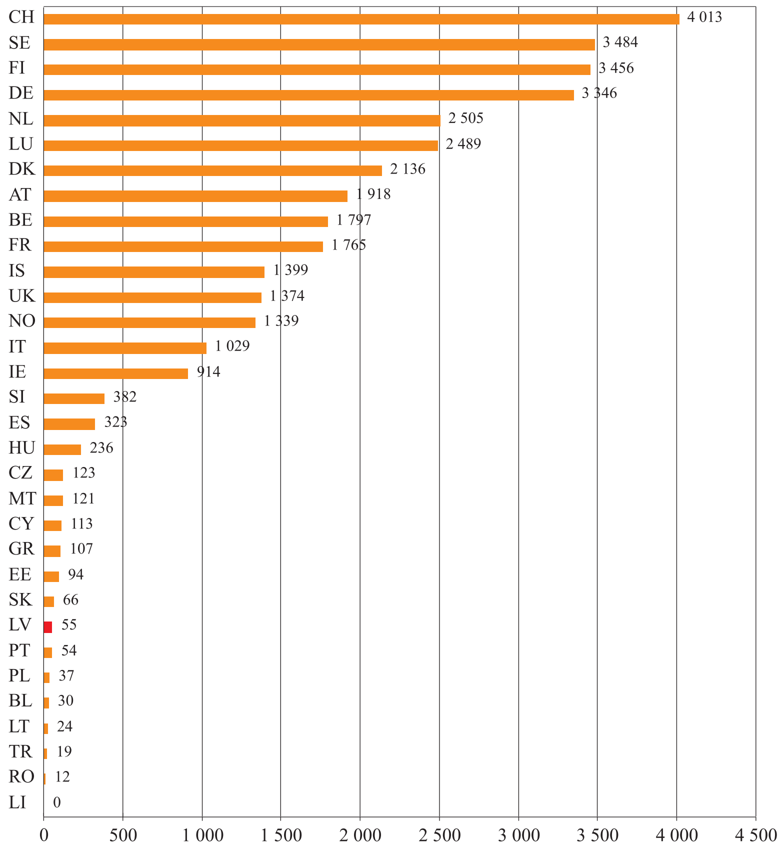


Sources: Data of 2001 are from the BACH database of the *European Committee of Central Balance Sheet Data Offices* on those EU countries for which they were available. Data on Latvia are those provided by the CSB and calculated by the authors.

This indicator is not completely unbiased because instead of system outputs it estimates inputs, which may as well capture the maintenance of political institutions and failure to find solution to educational reform issues, differences in accounting and a distinctive interpretation of innovations (in Latvia, intangible assets are mainly expenditure on licences and similar cost categories (13)). The same refers to the often-employed indicator "employment in high technology sectors". Nowadays, almost all high-tech companies outsource low-skilled labour operations (usually mounting and assembly) to the countries where labour costs are low; hence this factor is of little significance. In addition, it is dependent on distinctive historical development trends (e.g. privatisation process) across countries.

The patent data seem to be a more reliable and unbiased research factor, for, in contrast to the indicator above, it captures the outcomes of scientific research activities (i.e. indicates that an important investigation is accomplished but does not provide information on utility of the invention). Chart 4 sums up the data on patent activities between 1998 and 2003 in the EU15 countries, Switzerland, Norway, Iceland, Lichtenstein and the EU accession countries at that time.

Chart 4
Cumulative number of patent applications per 1 million people submitted to the European Patent Office (1998–2003)



Source: Eurostat.

Data are also available in the breakdown by sector, yet a direct comparison of such indicators across sectors is not useful. Additional factors are also to be accounted for.

– Differences across sectors: a sector boasting of the largest number of patent applications in a single country is not always the one with the most bustling research activity. Patent applications may turn out to be a sectoral peculiarity (e.g. to outpace other innovators, a sector needs to come forth with many small individual inventions). Consequently, patent estimates should be based on the cross-country comparison.

– Time factor: it is not worth accounting for sectors with a large number of patent applications in the 1990s but currently ceasing scientific activity; the latter may imply that regular research work is not going on. Hence the regularity of research activities should be taken into account.

On this background, the authors of this research resolved to use the following determinant for research activity: cumulative number of patent applications[14] to the average number of patent applications in a sector of market leaders (three major patent submitting countries.) This indicator allows for determining the sectors in Latvia's economy where research activity is similar to the respective activity of the market leaders. The results are summed up in Table 3.

[14] Sectors dispalying activity for at least three years between 1998 and 2003.

Table 3

Cumulative number of patent applications in Latvia versus average number of patent applications of respective market leaders for respective subdivision (1998–2003)*

Subdivisions consistently with the International Patent Classification	Relative to average indicator of three market leaders (%)
C 23 Coating metallic material; coating material with metallic material; chemical surface treatment; diffusion treatment of metallic material; coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapour deposition, in general; inhibiting corrosion of metallic material or incrustation in general	10.8
A 23 Foods or foodstuffs; their treatment, not covered by other classes	8.3
C 07 Organic chemistry	6.2
A 61 Medical or veterinary science; hygiene	3.1
C 12 Biochemistry; beer; alcoholic beverages; wine; vinegar; microbiology; enzymology; mutation or genetic engineering	1.4

* For the purpose of data comparison, the number of patent applications was divided by the number of employed in each respective country.

Sources: Eurostat and authors' calculations.

This is, of course, only an indicative parameter, primary evidence of research ambitions across sectors. However, validity of such ambitions should be put to test: have patent applications been approved and what do the categories capture?[15] These may possibly be inactive sectors, and probably no one outside Latvia would see an excess profit potential in them. The data do not encourage such inferences, and it is not the purpose of this study to make them.

Finally on the background of the relatively weak activity in the area of patents (implying that production is not very science-intensive), it can be stated that human capital is not a significant determinant of Latvia's GDP.

[15] Not all patents indicate that an important invention has been made. The significance of patent data should be estimated reasonably: though not all patents capture a significant invention, it is doubtful whether any big, excess profit bearing invention would be non-patented. Hence patents are an insufficient but necessary precondition for earning profit from an invention.

CONCLUSIONS

The employment of various human capital approximations in the production function for Latvia convinced the authors that extending the production function with any such independent variable is not reasonable at this point. The authors maintain that the dynamics of the Latvian current economic growth is best estimated by the standard C–D production function with non-linearly modelled productivity. Testing with the Kalman filter and assuming that the TFP process changes in time produced capital share of around 0.30.

The TFP growth rate estimated in the relevant period proved to be rather unstable. During the Russian financial crisis, TFP growth subsided and was close to zero in the period between the fourth quarter of 1998 and the fourth quarter of 1999. The period of economic recovery saw the TFP growth accelerating rapidly, albeit moderating later. Latvia's accession to the EU, in turn, gave a new impetus to the TFP growth.

In order to separate the short-term variance from the long-term trend, the error correction model was estimated. It resulted in around 0.34 long-term return on capital and a slightly higher 0.37 short-term return (however, the difference is statistically insignificant), with the TFP dynamics remaining broadly unchanged from the previous model estimation. The error correction coefficient is –0.44, indicating that the deviation from the long-term growth trend will result in a 44% adjustment for each period and will disappear in the course of approximately one year.

Using a theoretical model based on the standard C–D production function and certain assumptions (e.g. on technological process, human capital growth, parameters of production technologies and capital shares in the EU15 countries and Latvia), the authors of the study obtained a human capital indicator accounting for around 53% of the EU15 average, with the potential to converge to 66% of the EU15 level. The reason for it is an excessively high specialisation in sectors where productivity is not particularly high also in the EU15 countries. These results are particularly affected by bulky employment in agriculture, hunting and forestry. Other sectors with low productivity, e.g. manufacture of textiles, wearing apparel, and wood and articles of wood, are also too strongly represented in the Latvian economy. On the other hand, employment is insufficient in such sectors as real estate activities, manufacture of transport vehicles and electrical equipment and apparatus, metal and articles of metal, etc. Consequently, if the aim is to achieve certain convergence in the future, the economy should be restructured.

Qualitative data on patent activity in Latvia analysed in the paper also indicate low human capital intensity. The small number of patent applications implies that Latvia's economic framework cannot be taken as human capital intensive. That is why the respective indicators have not been significant for the total production function so far.

APPENDICES

Appendix 1

Model [10] normal error distribution test

Method	Test value	Adjusted test value	*p*-value
Lilliefors (D)	0.117499	Not available (NA)	>0.1
Cramer–von Mises (W2)	0.062936	0.063651	0.3388
Watson (U2)	0.061975	0.062680	0.3108
Anderson–Darling (A2)	0.358848	0.365382	0.4360

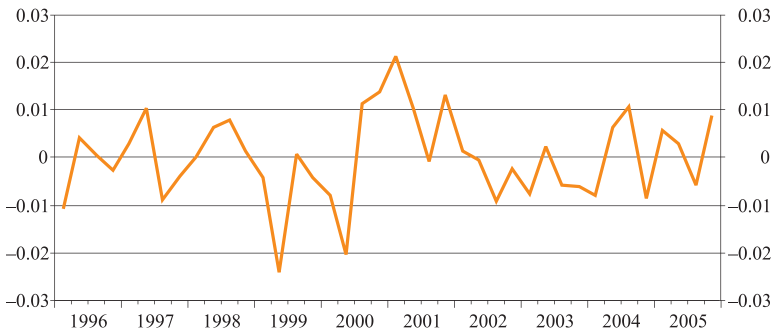
Method: maximum likelihood, degrees of freedom corrected

Parameter	Value	Standard error	*z*-statistic	*p*-value
Mean	0.000429	0.001431	0.299748	0.7644
Variance	0.009495	0.001024	9.273618	0.0000
Log likelihood	142.9720			

Appendix 2

Model [11] error tests

Error $\varepsilon_t^{\log(Y)}$



Error $\varepsilon_t^{\log(Y)}$ unit root test

Null hypothesis: $\varepsilon_t^{\log(Y)}$ is the unit root.

Period lags: automatic, based on Schwartz information criterion (MAXLAG = 9).

		t-statistic	*p*-value*
Augmented Dickey–Fuller test statistic		–5.605074	0.0000
Test critical values	1%	–2.621185	
	5%	–1.948886	
	10%	–1.611932	

* MacKinnon (1996) one-sided *p*-values.

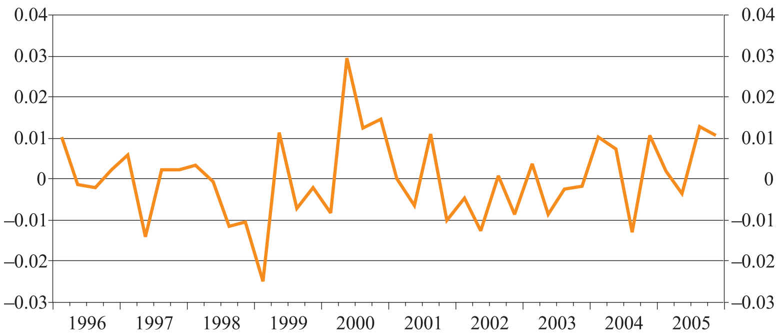
Error $\varepsilon_t^{\log(Y)}$ normal distribution test

Method	Test value	Adjusted test value	*p*-value
Lilliefors (D)	0.084033	NA	>0.1
Cramer–von Mises (W2)	0.031466	0.031832	0.8215
Watson (U2)	0.031140	0.031502	0.7941
Anderson–Darling (A2)	0.292612	0.298072	0.5881

Method: maximum likelihood, degrees of freedom corrected.

Parameter	Value	Standard error	*z*-statistic	*p*-value
Mean	0.000179	0.001385	0.128957	0.8974
Variance	0.009085	0.000991	9.165151	0.0000
Log likelihood	141.6340			

Error ε_t^{γ}



Error ε_t^{γ} unit root test

Null hypothesis: ε_t^{γ} is the unit root.

Period lags: automatic, based on Schwartz information criterion (MAXLAG = 9).

		t-statistic	*p*-value*
Augmented Dickey–Fuller test statistic		–6.766009	0.0000
Critical test value	1%	–2.621185	
	5%	–1.948886	
	10%	–1.611932	

* MacKinnon (1996) one-sided *p*-values.

Error ε_t^{γ} normal distribution test

Method	Test value	Adjusted test value	*p*-value
Lilliefors (D)	0.092113	NA	>0.1
Cramer–von Mises (W2)	0.039672	0.040134	0.6795
Watson (U2)	0.039430	0.039888	0.6290
Anderson–Darling (A2)	0.323388	0.329422	0.5154

Method: maximum likelihood, degrees of freedom corrected.

Parameter	Value	Standard error	*z*-statistic	*p*-value
Mean	0.000114	0.001568	0.072687	0.9421
Variance	0.010284	0.001122	9.165151	0.0000
Log likelihood	136.3027			

TPF, capital and employment time series cointegration relation in equation system [11]

Unrestricted Cointegration Rank Test (Trace)

Hypothesised number of cointegration vectors	Eigenvalue	Trace statistic	0.05 critical value	*p*-value**
None*	0.603667	45.95704	24.27596	0.0000
At most 1	0.151458	8.011560	12.32090	0.2358
At most 2	0.030688	1.277899	4.129906	0.3017

Trace test indicates 1 cointegrating equation at the 5% level.

* Denotes rejection of the hypothesis at the 5% level.

** MacKinnon–Haug–Michelis (1999) *p*-values.

Unrestricted Cointegration Rank Test (maximum eigenvalues)

Hypothesised number of cointegration vectors	Eigenvalue	Maximum eigenvalue statistic	0.05 critical value	*p*-value**
None*	0.603667	37.94548	17.79730	0.0000
At most 1	0.151458	6.733661	11.22480	0.2736
At most 2	0.030688	1.277899	4.129906	0.3017

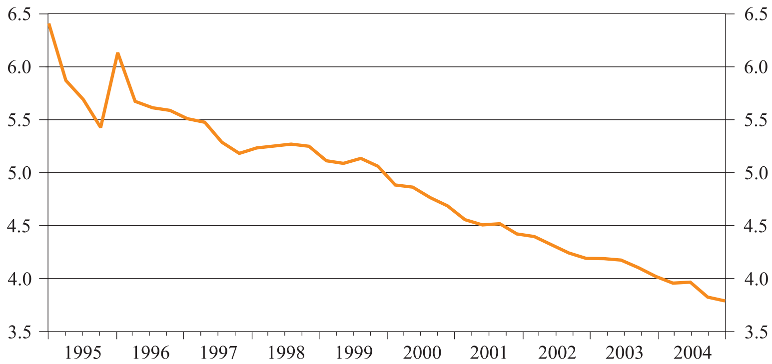
Maximum eigenvalue test indicates 1 cointegrating equation at the 5% level.

* Denotes rejection of the hypothesis at the 5% level.

** MacKinnon–Haug–Michelis (1999) *p*-values.

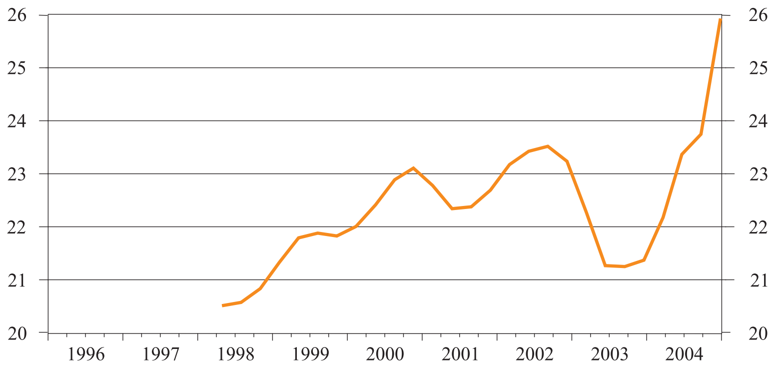
Appendix 3

Ratio of real education expenditure to real GDP in Latvia (%)



Appendix 4

Proportion of persons with university education in total employment of Latvia (%)*



* Persons over 25 years of age are recorded.

Appendix 5
Models with human capital

State-space system model with human capital
(equation [13]; 1996 Q1–2004 Q4)

Variables (consistently with the list on p. 11)	$\log(K_t)$	$\log(H_t)$
a)	0.91* (0.00)	–0.55* (0.00)
c)	0.44 (0.20)	0.07 (0.55)
d)	0.30 (0.43)	0.30 (0.26)
e)	0.47 (0.17)	0.04 (0.67)
f)	0.32 (0.36)	0.23 (0.23)
g)	0.50 (0.21)	0.01 (0.90)
h)	0.32 (0.36)	0.22 (0.27)
i)	0.60 (0.12)	–0.002 (0.98)

* Statistical significance of coefficient at the 0.01 level.

ECM state-space system model with human capital
(equation [12]; 1998 Q 3–2004 Q 4)

Variables (consistently with the list on p. 11)	$\log(K_t)$	$\log(H_t)$
a)	1.43* (0.00)	–0.67* (0.00)
b)	0.83* (0.00)	–0.04 (0.43)
c)	0.69* (0.00)	0.05 (0.37)
d)	0.81* (0.00)	–0.03 (0.78)
e)	0.73* (0.00)	0.03 (0.53)
f)	0.78* (0.00)	0.01 (0.87)
g)	0.78* (0.00)	0.01 (0.87)
h)	0.77* (0.00)	0.02 (0.78)
i)	0.78* (0.00)	0.01 (0.87)

* Statistical significance of coefficient at the 0.01 level.

Appendix 6
Latvia's economic potential consistently with the current economic framework

Detailed data on value added and employment are used in calculations. Value added data for 2003 are from the Eurostat database (labour productivity is defined as gross value added in thousands of euro divided by the number of employed). Data on employment in the EU are from the Eurostat database; data for Latvia are provided by the CSB.

Labour productivity in the EU15 countries and employment in the EU15 countries and Latvia in 2003*

Sector	Labour productivity in EU15 (1 000 euro)	Employment (%)	
		EU15	Latvia
A Agriculture, hunting and forestry	25.6	3.8	12.9
B Fishing	38.1	0.1	0.4
C Mining and quarrying	180.7	0.2	0.2
D Manufacturing	–	16.9	15.2
DA Food products, beverages and tobacco	48.1	2.2	3.4
DB Textiles and textile products	29.8	1.5	2.4
DD Wood and wood products	37.4	0.5	3.2
DE Pulp, paper and paper products; publishing and printing	57.2	1.4	1.0
DF Coke, refined petroleum products and nuclear fuel	182.1	0.1	0.0
DG Chemicals, chemical products and man-made fibres	99.4	1.0	0.4
DH Rubber and plastic products	49.2	0.8	0.3
DI Other non-metallic mineral products	50.7	0.8	0.4
DJ Basic metals and fabricated metal products	46.2	2.4	1.0
DK Machinery and equipment n.e.c.	53.6	1.8	0.7
DL Electrical and optical equipment	53.8	1.8	0.5
DM Transport equipment	62.1	1.6	0.7
DN Manufacturing n.e.c.	34.6	1.0	1.2
E Electricity, gas and water supply	162.6	0.6	1.7
F Construction	42.2	6.8	7.0
G Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods	37.8	15.2	15.2
H Hotels and restaurants	30.7	4.9	2.2
I Transport, storage and communication	62.3	5.6	9.2
J Financial intermediation	88.8	3.1	1.6
K Real estate, renting and business activities, consulting	89.2	12.4	5.7
L Public administration and defence; compulsory social security	44.9	7.0	6.5
M Education	39.6	6.6	8.2
N Health and social work	35.0	10.0	6.0
O Other community, social and personal service activities	41.1	4.7	5.7
P Activities of households	11.4	2.2	0.4

* Data on employment do not add up to 100% due to rounding.

First, labour productivity was calculated for each sector of the EU15 countries and the same productivity was assumed for Latvia; then the relative proportion of Latvia's GDP to EU15 GDP was calculated.

BIBLIOGRAPHY

1. BARRO, Robert J. *Economic Growth in a Cross Section of Countries.* NBER Working Paper, No. 3120, September 1989.
2. BARRO, Robert J., MANKIW, Gregory N., SALA-I-MARTIN, Xavier. *Capital Mobility in Neoclassical Models of Growth*. NBER Working Paper, No. 4206, November 1992.
3. BARRO, Robert J., LEE, Jong-Wha. International Comparisons of Educational Attainment. *Journal of Monetary Economics*, Elsevier, vol. 32 (3), December 1993, pp. 363–394.
4. BARRO, Robert J., SALA-I-MARTIN, Xavier. *Economic Growth.* New York : McGraw-Hill, 1995.
5. BEŅKOVSKIS, Konstantīns, STIKUTS, Dainis. *Latvia's Macroeconomic Model.* Rīga : Bank of Latvia, 2006. Working Paper 2/2006.
6. BOISSAY, Frédéric, VILLETELLE, Jean-Pierre. *The French Block of the ESCB Multi-Country Model.* ECB Working Paper, No. 456, March 2005.
7. BOLT, Wilko, VAN ELS, Peter J. A. *Output Gap and Inflation in the EU.* De Nederlandche Bank Staff Report No. 44, 2000.
8. CABALLERO, R. J., LYONS, R. K. *Internal Versus External Economies in European Industry*. European Economic Review, vol. 34, 1990, pp. 805–830.
9. CANNING, David, DUNNE, Peter, MOORE, Michael. *Testing the Augmented Solow and Endogenous Growth Models.* Mimeo : Queen's University of Belfast, 1995.
10. DENIS, Cécile, McMORROW, Kieran, RÖGER, Werner. *Production Function Approach to Calculating Potential Growth and Output Gaps – Estimates for the EU Member States and the US.* European Commission Economic Papers, No. 176, September 2002.
11. DIMITZ, Maria A. *Output Gaps and Technological Progress in European Monetary Union.* Bank of Finland Discussion Paper, No. 20, 2001.
12. EATON, Jonathan, KORTUM, Samuel S. Trade in Ideas: Patenting and Productivity in the OECD. *Journal of International Economics*, No. 40, May 1996, pp. 251–278.
13. European Commission. *Annual Innovation Policy Report for Latvia. Covering Period: September 2003–August 2004.* European Trend Chart on Innovation, Enterprise Directorate-General [cited August 30, 2006]. Available: *http://trendchart.cordis.lu/country_reports.cfm.*
14. FAGAN, Gabriel, HENRY, Jerome, MESTRE, Ricardo. *An Area-Wide Model (AWM) for the Euro Area*. ECB Working Paper, No. 42, January 2001.
15. GUNDLACH, Erich. *Growth Effects of EU Membership: The Case of East Germany.* Interim Report 01-035, International Institute for Applied Systems Analysis, September 2001.
16. HAMILTON, James D. *Time Series Analysis*. Princeton : Princeton University Press, 1994.
17. JENKINS, Helen. *Education and Production in the United Kingdom.* Nuffield College, Oxford University, Economics Discussion Paper, No. 101, August 1995.

18. JONES, Charles I. *Human Capital, Ideas, and Economic Growth.* Paper presented to the VIII Villa Mondragone International Economic Seminar on Finance, Research, Education, and Growth. Rome, Italy, June 25–27, 1996.
19. KATTAI, Rasmus. *EMMA – a Qarterly Model of the Estonian Economy.* Eesti Pank Working Paper, No. 12, October 2005.
20. LEVINE, Ross, RENELT, David. A Sensitivity Analysis of Cross-Country Growth Regressions. *American Economic Review*, vol. 82 (4), September 1992, pp. 942–963.
21. MACKINNON, James G. Numerical Distribution Functions for Unit Root and Cointegration Tests. *Journal of Applied Econometrics*, vol. 11, No. 6, 1996, pp. 601–618.
22. MANKIW, Gregory N., ROMER, David, WEIL, David N. A Contribution to the Empirics of Economic Growth. *The Quarterly Journal of Economics,* vol. 107i2, May 1992, pp. 407–437.
23. NEHRU, Vikram, DHARESHWAR, Ashok. *New Estimates of Total Factor Productivity Growth for Developing and Industrial Countries.* Washington D. C. : The World Bank Policy Research Working Paper, No. 1313, June 1994.
24. OULTON, Nicholas, O'MAHONY, Mary. XLVI Productivity and Growth. A Study of British Industry 1954–86. Cambridge : Cambridge University Press, National Institute of Economic and Social Research, 1994.
25. OULTON, Nicholas, YOUNG, Garry. *The Social Rate of Return to Investment.* National Institute of Economic and Social Research Discussion Paper, No. 93, April 1996.
26. PRITCHETT, Lant. *Where has All the Education Gone?* Mimeo : Washington D. C. : The World Bank, 1995.
27. QUAH, Danny T. Twin Peaks: Growth and Convergence in Models of Distribution Dynamics. *The Economic Journal*, vol. 106, July 1996, pp. 1045–1055.
28. ROMER, David. Advanced Macroeconomics. New York : McGraw-Hill, Second Edition, 2001.
29. ROMER, Paul M. Human Capital and Growth: Theory and Evidence. *Carnegie–Rochester Conference Series on Public Policy*, No. 32, Spring 1990, pp. 251–286.
30. SMETS, Frank, WOUTERS, Raf. *An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area.* ECB Working Paper, No. 171, August 2002.
31. SOLOW, Robert M. A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics*, No. 70, 1956, pp. 65–94.
32. SOLOW, Robert M. Perspectives on Growth Theory. *Journal of Economic Perspectives*, vol. 8, 1994, pp. 45–54.
33. STIKUTS, Dainis. *Measuring Output Gap in Latvia.* Rīga : Bank of Latvia, 2003. Working Paper 2/2003.
34. THOMAS, Vinod, DAILAMI, Mansoor, DHARESHWAR, Ashok, KAUFMANN, Daniel, KISHOR, Nalin, LÓPEZ, Ramon E., WANG, Yan. *The Quality of Growth.* The World Bank, Oxford University Press, September 2000.
35. VETLOV, Igor. *The Lithuanian Block of the ESBS Multi-Country Model.* Bank of Finland – Institute for Economies in Transition, BOFIT. BOFIT Discussion Papers, No. 13, 2004.

36. WOLFF, Edward N. *Human Capital Investment and Economic Growth: Macro-Economic Perspectives and Evidence from Industrialized Countries.* International Conference on Human Capital Investments and Economic Performance. Santa Barbara, California, 1994.