

Badinger, Harald; Tondl, Gabriele

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Trade, human capital and innovation: The engines of European regional growth in the 1990s

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HARALD BADINGER/GABRIELE TONDL

Trade, Human Capital and Innovation: The Engines of European Regional Growth in the 1990s

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Althanstraße 39 - 45, A - 1090 Wien / Vienna
Österreich / Austria
Tel.: ++43 / 1 / 31336 / 4135, 4134, 4133
Fax.: ++43 / 1 / 31336 / 758, 756
e-mail: europafragen2@wu-wien.ac.at

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Trade, Human Capital and Innovation: The Engines of European Regional Growth in the 1990s

Harald Badinger Gabriele Tondl

Institute for European Affairs
Wirtschaftsuniversität Wien
Althanstrasse 39-45, A-1090 Vienna, Austria
Tel.: +43 1 31336-4133, Fax.: +43 1 31336-758
E-mail: harald.badinger@wu-wien.ac.at, gabriele.tondl@wu-wien.ac.at

Abstract:

This paper investigates the growth factors of EU regions in the 1990s. We test the hypothesis that regional growth is determined by endogenous growth factors, trade and technological catching-up in a growth accounting framework. Our estimations suggest that growth of EU regions is positively related to the accumulation of physical and human capital. Innovation activity as well as international technology transfer are important for growth. The latter is facilitated if a region is well endowed with human capital. Further, we observe that technological catching-up is promoted by intensive foreign trade, a result which underlines the importance of trade openness for EU regions.

JEL classification: O300, O400, O520, R110.

Keywords: regional growth, endogenous growth, catching-up, technology transfer, trade

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I. Introduction

Regional disparities have been a major policy concern in the European Union, in particular since its Southern enlargement. Widely known as the Union's cohesion problem, it gave rise to the implementation of EU regional policy effected with substantial financial assistance from the Union's budget. Although regional disparities have shown a tendency to decrease gradually, the regional convergence process was interrupted several times. After the post 1975 period of divergence, a period of convergence set in with the accession of Southern countries to the EU and the warm-up phase of the EU's Internal Market 1986-1992. Thereafter, growth developments of the 1990s again suggest a modest convergence.

In front of this background, this paper wishes to answer the question of what has determined growth of EU regions in the 1990s and to offer an empirical assessment of this process. Hereby we shall particularly focus on endogenous growth factors, potential channels of technology transfer, and trade. These specific growth aspects have been only partially analyzed in regional growth studies for the EU (Fagerberg and Verspagen, 1996; Fagerberg et al., 1997; Vanhoudt et al., 2000; Paci and Pigliaru, 2001; Tondl, 2001). A systematic assessment of regional growth based on an explicit endogenous growth model and trade theory is missing. Therefore, we shall combine theoretical aspects of human capital and innovation growth literature (Lucas 1988, Romer 1990), of catching-up theory (Abramowitz, 1986, 1989) and trade and integration theory (Grossman and Helpman, 1991; Balassa, 1961; Baldwin, 1993) to examine growth factors and mechanisms in EU regions. For our empirical analysis we have compiled a large dataset with many variables not used so far for some 130 regions for the 1990s, largely equivalent to the regions of the Eurozone, and will test the importance of educational attainment, patenting activity, regional trade, and technological catching-up for regional growth in estimating a cross-section growth accounting model, which as such also includes factor accumulation. Technology transfer will be considered to be conditioned on endowment factors and to be transmitted by trade.

Our results indicate that regional income growth is positively linked to the central growth factors physical capital and labour participation. Further, attainment levels of higher education and patenting are clearly associated with higher growth. Higher education is also an important prerequisite of lagging regions for technological catching-up. Finally, we find that a

high foreign trade share contributes to regional growth by promoting technological catching-up.

The rest of the paper is structured as follows: Section two discusses the issues of the paper and reviews the literature. Section three offers some stylized facts of growth relationships of EU regions in the 1990s. Section four describes the model for our estimation. Section five gives data definitions and presents the results of the estimation. Section six concludes.

II. How may trade and integration inter-twin with common growth factors?

Growth of European regions exhibits no distinct convergence mechanism, i.e. a growth surplus of poor regions vis-à-vis rich ones. Rather it is the case that one can find high growth both with rich as well as poor regions (see Figure1).

This suggests that multiple growth paradigms govern regional growth in Europe. Evidently, a neoclassical convergence mechanism has helped poor regions to converge (European Commission, 2000; Tondl, 1999). Endogenous growth based concepts permitted rich regions to maintain a leading income position (Tondl, 2001). In addition, European regions have become increasingly integrated with other European as well as global markets, particularly in the 1990s after the creation of the Single Market and the WTO Uruguay Round. Trade flows and other kinds of international interactions seem to have become substantial for EU regions and are likely to favour technology transfer on an international scale.

We will examine these possible sources of European regional growth more closely and review the findings of the existing literature in order to extract the working hypotheses for our investigation.

First, given European regional income disparities and considering the neoclassical convergence hypothesis, one may suppose that physical capital accumulation should play an important role for the growth of lagging regions, the more as investment in a new generation of capital is also linked with technological advance (Kaldor, 1961). Empirical evidence on the role of investment for EU regions is mixed. While Bacchetta (1994) finds no clear impact on growth, Vanhoudt et al. (2000) detect an important growth effect.

A second conjecture is that human capital plays an important role for EU regional growth. This idea has heavily influenced EU regional policy in the past decade, although there is only few empirical support for this hypothesis for EU regions so far. The traditional arguments on the role of human capital go back to Lucas (1988) who views human capital – in the sense of knowledge – as a central factor of production, which enables sustained growth due to its non-decreasing returns. Mankiw et al. (1992), in an influential paper, extend the neoclassical growth model by human capital as an additional accumulable factor and provide an empirical test for the OECD countries. They conclude that changes in human capital translate into significant changes of growth rates.

Yet there are other channels how human capital can influence the growth rate. First, human capital is a central prerequisite for innovation activity as set out in Romer (1990). Second, human capital influences the capacity to adapt technological advances from abroad (technological catching-up, see below).

Empirical country studies on the growth effect of human capital, however, provide rather mixed results which is largely due to the variety of different, often problematic indicators for human capital and measurement problems. Researchers used the average number of years in education (e.g., Barro, 1991), the share of primary/secondary/third level educational attainment, or sometimes school enrolment as a proxy. Prominent studies such as Benhabib and Spiegel (1994) and Pritchett (1996) suggest that it is the level of educational attainment that influences growth but not its change. More recent studies also find a positive impact of human capital growth. As Krueger and Lindahl (1999) and de la Fuente and Domenech (2000) demonstrate, human capital data sets may show considerable measurement errors, which can lead to particularly erratic observations when looking at human capital growth. The recent estimates of de la Fuente and Domenech (2000) are based on a carefully revised dataset and suggest that the elasticity of output with respect to human capital is about 0.27 for OECD countries. Studies of Bassannini et al. (2001) and Cohen and Soto (2001), both based as well on revised data sets, confirm these results. Furthermore, Temple (2001) replicates the Benhabib and Spiegel and the Pritchett study assuming a different functional relationship between income and human capital and concludes that changes in human capital do have an effect on growth rates.

Due to the even more pronounced problems of data availability for regions, there is only little evidence on the effects of human capital at the EU regional level. Tondl (1999, 2001) shows that incomes and productivity of Southern EU regions are positively linked to school enrolment. Further, Vanhoudt et al. (2000) find an output elasticity for human capital, measured as educational attainment, for EU regions of 0.18 when estimating a production function for 1996.

Third, given that European regions belong to fairly rich, knowledge and R&D-driven economies we may expect that innovation activities are an important source for regional growth. On the theoretical scale, we can base our arguments on the familiar models of Romer (1990) and Aghion and Howitt (1992) of R&D based endogenous growth. These models look at R&D efforts as the starting point for innovations, and suggest that growth is a function of resources employed in the R&D sector.

Empirical studies in this area have shown that research activity can indeed explain a high growth performance of rich countries or regions. Fagerberg (1987) verifies a positive relation between the number of patent applications of a country and growth. De la Fuente (1998) finds that R&D expenditures are an important cause of high growth in rich EU countries. Bassanini et al. (2001) in contrast, in a recent OECD growth study, identify a positive growth impact only for business R&D spending but not for public one. For EU regions, Fagerberg et al. (1997) find that the superior growth performance of rich regions in the 1980s can be explained by the share of business sector workforce employed in R&D. Similarly, Paci and Pigliaru (2001) detect a significant correlation between patent applications of European regions and their productivity growth. These studies show that it is not simply the total quantity of resources devoted to R&D, either researchers or expenditures, but the share of labour force employed in innovation activity, or an indicator for innovation output as patents which preferably explain its growth impact, - a fact that has first been pointed out by Jones (1995) when watching ailing US growth rates despite its growing number of researchers.

Fourth, with fairly open and integrated economies like the EU countries, we may expect that trade and integration is an important factor for growth of their regions. First, openness manifests in a substantial weight of trade flows. Recent studies suggest that international trade relations of EU regions are quite large, particularly for regions in small EU countries (Tondl,

2001). In addition, openness includes more than physical trade flows, namely all kind of interactions that ease technology transfer on an international scale.

As argued in the modern trade literature and integration theory, trade triggers important supply side effects (Grossman and Helpman, 1991; Balassa, 1961; Baldwin, 1993; Breuss, 1996; Keuschnigg and Kohler, 1996), which induce efficiency improvements in the enterprise sector and finally lead to additional growth. On the one hand, entry into foreign markets and opening of the home markets means increased competition which forces firms to improve their efficiency in order to become more competitive. Firms will have to close their productivity gap vis-à-vis the leaders to stay in the market (pro-competitive effect). On the other hand, as already argued by Adam Smith, firms can face a larger sales market if operating internationally, which permits to benefit from economies of scale (market size effect). As a consequence, free trade and integration lead to improvements in productivity. Economies with a high trade share will therefore show a higher growth performance than non-traders.

A number of empirical studies for different sets of countries have shown that foreign trade is promoting growth (e.g. Balassa, 1978; Kormendi and Meguire, 1985; Dollar, 1992). For EU countries this has been verified e.g. by Baldwin and Seghezza (1996), Ben-David (1996), Breuss (1998), and Badinger (2001). Since there is very few data on external trade of regions available, there are no studies which address the important issue of trade-induced growth effects for EU regions.

In addition to the described supply side effects, openness of EU regions should facilitate productivity increases through international technology transfers. Openness should permit regions to close their technology gap with the leader more easily.

As to theory, on the one hand the early catching-up literature resting on the neo-classical growth model suggests that technological transfer is an important source of technological advance of poor economies (Gerschenkron, 1962; Nelson and Phelps, 1966; Abramowitz, 1986, 1989; Bernard and Jones, 1996).

On the other hand, endogenous growth models with trade integration, as Romer and Rivera-Batiz (1991) attribute a central role to international technology spillovers. In their theoretical set-up knowledge spillovers from abroad add to national knowledge and thus increase the knowledge stock to effect R&D. Furthermore, as innovations become more profitable for a

larger sales market a higher innovation rate is expected. Thus integration can yield a growth bonus. In addition, also in the Rivera-Batiz and Romer model, economies importing goods from other countries/regions with a higher technological level can import technological progress and may be able to renounce of own innovation activity (Rivera-Batiz and Xie, 1993).

The possibility of technological transfer is influenced by several factors, such as the social capacity of an economy and particular transmitters to which new technologies are attached. Social capacity is largely determined by the human capital available in an economy and its own engagement in R&D, since knowledge and expertise make it more likely to adopt technologies from abroad. Transmitters of technology may be imported goods or foreign direct investment (FDI).

Technological catching-up depends on the ability of an economy to make use of internationally available technologies. Human capital in the lagging economy is important, as pointed out initially by Gerschenkron (1962) and Nelson and Phelps (1966), and later by Abramowitz (1986), Parente and Prescott (1994) and Benhabib and Spiegel (1994). Griffith et al. (2000) find that own R&D improves the absorptive capacity for technology transfer of lagging OECD countries.

An important contribution which attempted to measure the scope of international trade related technology spillovers is Coe and Helpman (1995) who stress the importance of imported intermediaries as a means of technology spillovers. This is measured by the import volume of a country weighted by R&D of the export country. Keller (1998) offers a similar approach. Another group of studies attempts to measure international technology spillovers by patent citations, e.g. Jaffe and Trajtenberg (1996) for countries and Maurseth (2001) for EU regions. Yet a different and growing branch of literature investigated the potential for technology spillovers via FDI (Lichtenberg and van Pottelsberghe de la Potterie, 1996; Baldwin et al., 1999).¹ Unfortunately, there is practically no evidence on these effects for EU regions.

¹ Apart from international technology transfer, regional economists have particularly emphasized the possibility of regional technology spillovers. That technology spillovers are geographically rather limited because of the importance of face-to face contacts was suggested by Audretsch and Feldman (1996) and Krugman (1991). Empirically, Paci and Pigliaru (2001) found that productivity growth of an EU region is highly correlated with those of its neighbouring regions when estimating spatial lag models. Paci and Usai (2000) detect R&D spillovers between Italian adjacent regions. Funke and Niebuhr (2000) investigate R&D spillovers with spatial interaction models for West German regions and find a significant contribution of R&D spillovers to

Following the above discussion there are five hypotheses on regional growth determinants in the EU which will be examined in this paper:

- (i) capital accumulation should enhance growth of per capita income
- (ii) a high educational level in the population (change of it) should lead to higher growth
- (iii) a high innovation rate, as given by patent applications should permit higher growth
- (iv) international technology transfer should be important for growth and should be facilitated by a region's educational standards, own R&D volume and transmission through imports
- (v) international technological catching-up should be stimulated by strong export engagement.

Of course, we expect that an increase in labour participation implies a higher income growth.

III. Some stylized facts

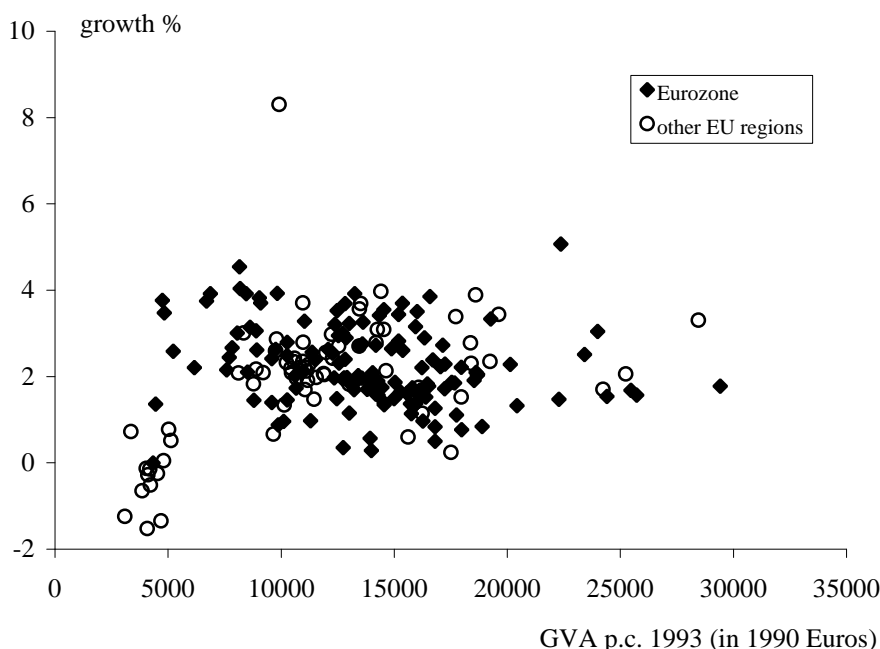
Our analysis covers 128 NUTS II regions of almost the entire Eurozone for the 1990s. The regarded set of regions encompasses regions of the core, relatively wealthy EU member states as well as the less prosperous regions of the Mediterranean area. Due to limited data availability it was not possible to consider the whole group of EU 15 regions. Our sample does not include regions from the UK, Sweden, Denmark, Austria and Greece.

In general, as illustrated in Figure 1, the whole group of EU regions exhibits a very modest tendency of income convergence over the considered period, if leaving aside the negative growth performance of Greek regions (lower left hand part of Figure 1). Many lagging regions, like the East German Laender, Centro and Alentejo in Portugal, or Extremadura and the two Castilles in Spain had a higher growth of their per capita income than rich regions. However, there is also a considerable number of (relatively) rich regions, such as the North-East of Spain, a number of regions in the Netherlands, Belgium and Finland (as well as from Sweden and the UK in the full EU sample) which show an outstanding growth performance in

productivity growth which decay fairly fast with distance. Bottazzi and Peri (1999) regard EU regions and similarly find that local clustering, i.e. spillovers, is important for R&D results, while R&D spillovers quickly fade with distance. Branstetter (2001) tests the likeliness of intranational versus international technology spillovers with U.S.firm level data. These studies concluded that technology spillovers are geographically rather limited and not effected on an international scale. What we are interested in this study is not the existence of regional spillovers but rather of international technology transfer, i.e. international spillovers.

their income group. This suggests that a multiplicity of factors rather than a simple convergence mechanism has shaped regional growth in that period.

Figure 1: Income convergence of EU regions: Average real growth of GVA per capita 1992-2000 and initial income in EU regions



In the following, we shall take a first look at our data set in view of the above stated hypotheses in order to give some first evidence on likely relationships. (For the description of the data set and its indicators see section IV and the appendix.)

Figure 2 suggests that there is a slight positive relationship between income growth and the growth of capital stocks. Among the lagging regions, particularly East German regions exhibit a high growth in the capital stock in that period of about 6 per cent per annum on average which may have been important for their high income growth. Further, capital stocks grew significantly in the Portuguese regions, which also ranked among the best growth performers. Among the rich regions, capital stock growth was also fairly high in Dutch regions, which – as we have seen – showed a very favourable growth performance. By contrast, capital growth was particularly weak in the low growth Southern Italian regions (and in the Greek regions).

Figure 2: Average growth of per capita income and capital stock 1993-2000
in EU regions (Eurozone, excl. A, Gr, Ire)

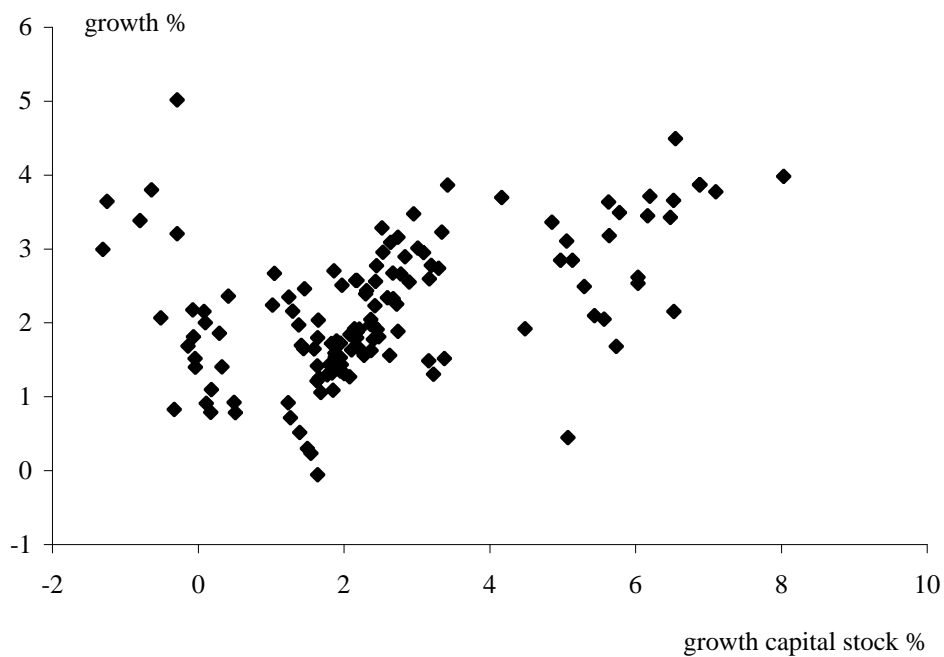
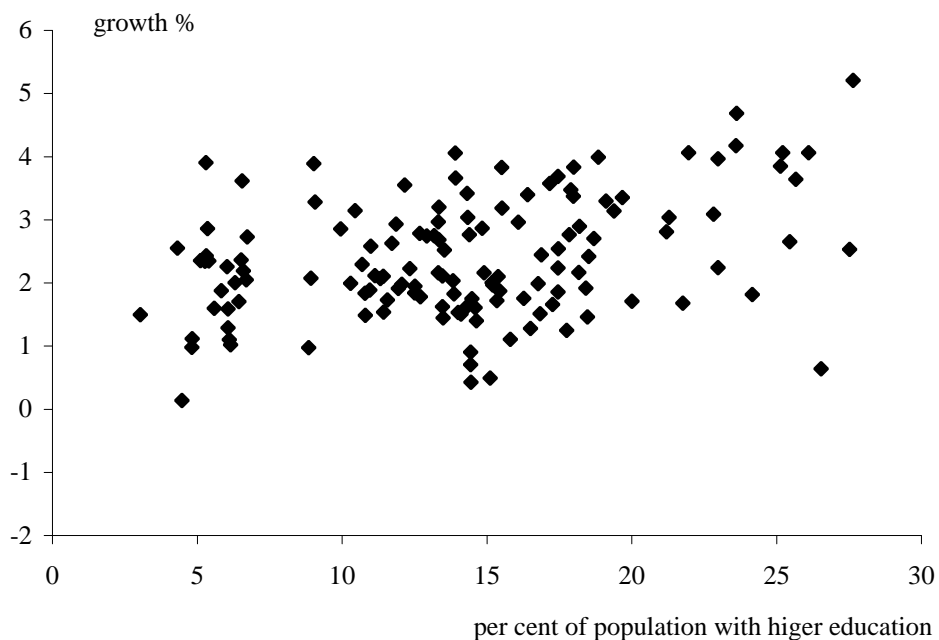


Figure 3: Average growth of per capita income 1993-2000 and higher level
educational attainment in the population (Eurozone, excl. A, Gr, Ire)



With respect to human capital, a first view on the data suggests that there may be a positive relationship for EU regions between higher educational attainment and growth (Figure 3), but not between medium level educational attainment and growth (not shown here). Higher level educational attainment shares are generally highest in metropolitan areas, which do not always show a high growth performance, e.g. Brussels and Brabant, London, Stockholm, Berlin, and Ile de France show a higher level educational attainment share of 24-36 per cent. While London registered average growth rates of 3 per cent and Brussels of 2.4 per cent, Ile de France showed only an average growth rate of 1.5 per cent and Berlin of 0.4 per cent. In general, the New German Laender show also fairly high attainment shares in higher education.

In contrast to attainment rates, growth in education, either of higher or medium level, does not seem to be related to income growth. Figure 4 picks out the situation with respect to growth in higher educational attainment shares. With respect to growth in medium education, the picture is even more unclear (not shown here). Higher educational attainment was growing particularly fast in Spanish regions, in particular in the poorer ones with a good growth performance, as Murcia, Extremadura, Castilla-La Mancha and Andalucia. Finish regions as well showed an important growth in higher level educational attainment rates.

Figure 4: Average growth of per capita income 1993-2000 and growth of higher level educational attainment (Eurozone, excl. A, Gr, Ire)

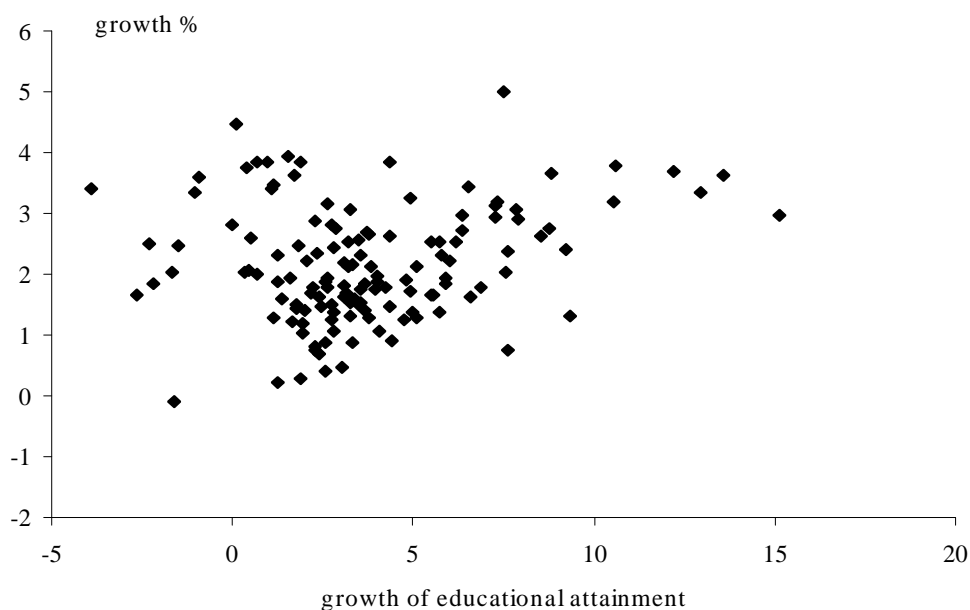
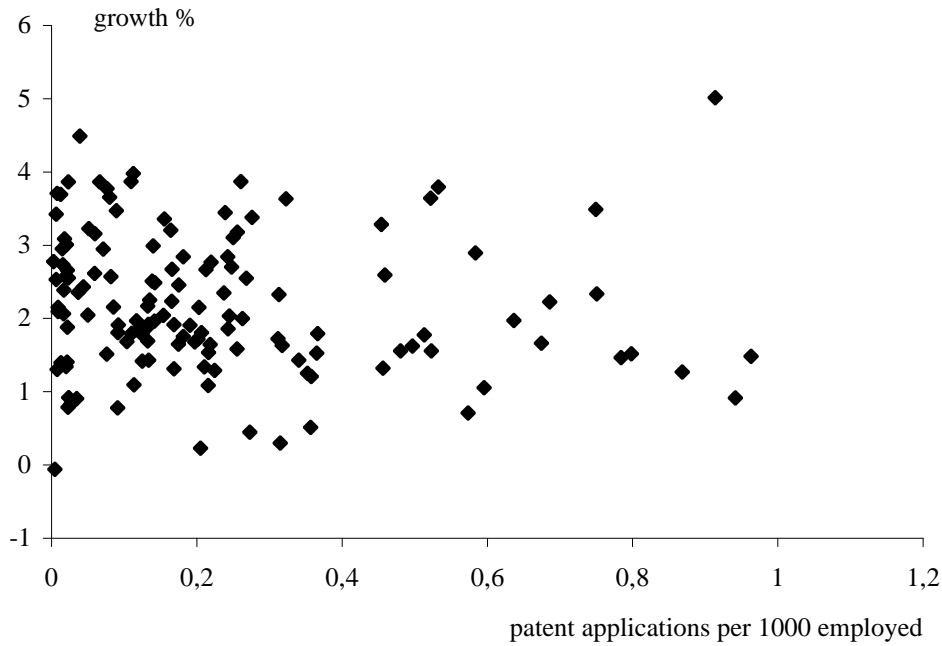
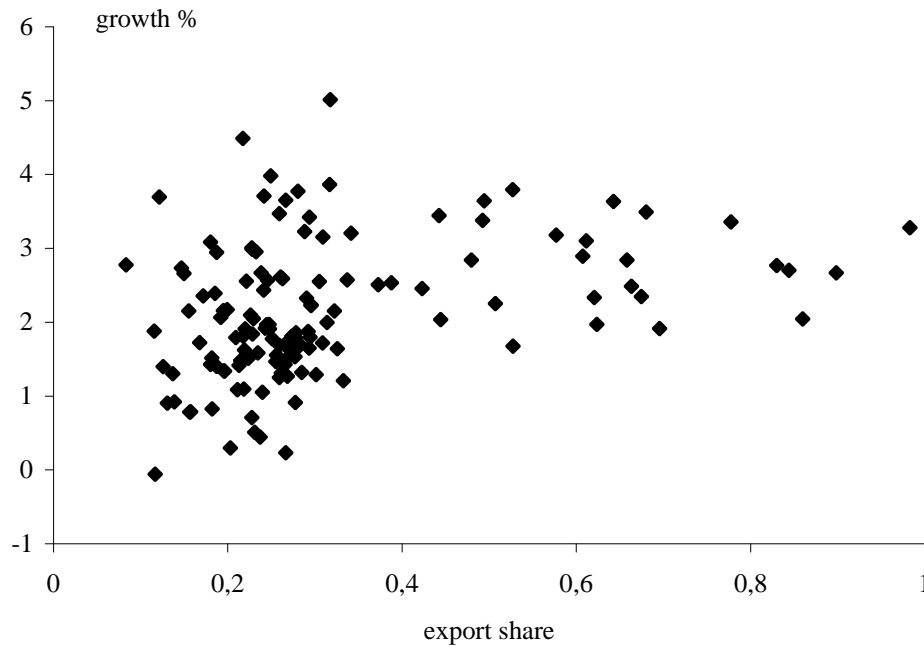


Figure 5: Average growth of per capita income 1993-2000 and patent applications per 1000 employees in EU regions (Eurozone, excl. A, Gr, Ire)



With respect to innovation activity, a first view on our indicator "patent applications" and regional income growth suggests no clear relationship. Europe's most innovating regions are located in a close distance in the South of Germany (Stuttgart, Darmstadt, Freiburg, Karlsruhe, etc.) which no longer show superior growth rates. Other innovating regions are more scattered: Brussels, Ile de France (and also Vorarlberg, not included in the sample). In Finland, we also find a few fairly innovative regions, such as Uusimaa, Etela-Suomi and Pohjois-Suomi. Lombardia is the only Italian region with a noticeable innovation activity, nevertheless ranking behind some of its rich neighbours as the other West German regions (and Oberoesterreich). All other Southern regions, in Italy, Spain, Portugal and Greece, as well as in East Germany have a significant innovation gap, indicating that R&D is probably no important source of growth for the best growth performers among those lagging regions.

Figure 6: Average growth of per capita income 1993-2000 and export share of EU regions (Eurozone, excl. A, Gr, Ire)



Regarding the possible importance of exports as a source of growth our data in Figure 6 suggests that a high export activity of regions is associated with high growth. Europe's largest export regions are all located in the Netherlands and Belgium. Also, Finish regions, like Uusimaa, Pohjois-Suomi, etc. are high exporters. Thereafter, Southern German, North Italian and many French Northern and Central regions occupy a medium export position. The Southern regions of Spain and Italy are the areas with the lowest export shares. A very similar picture appears if restricting our view on exports directed towards other EU members. However, in this case many Southern regions (Norte, Centro, Lisbon and Alentejo in Portugal, and the whole North-East of Spain) have a much better position. They show a higher export share towards EU markets than towards other countries.

IV. The benchmark model

Taking our hypotheses formulated in section II, we now derive a formal model which will then be tested in section V. We have chosen a model in a growth accounting framework, an approach which we prefer to a convergence model since we are not interested in movements towards the steady state but in the issue of what determines growth. Empirical growth studies

now increasingly seem to employ the growth accounting approach (see e.g., Temple, 1999). The model we propose will also be compatible with different growth theories so as to comprise both a neoclassical model and an endogenous growth model as well as technological catching-up.

Our point of departure is the following augmented Cobb-Douglas production function

$$Y = AK^a H^b L^g \quad (1)$$

where Y = gross value added (GVA), K = stock of physical capital, H = stock of human capital and L = labour. We assume constant returns to scale, which implies that $g = 1 - a - b$. As we are ultimately interested in explaining gross value added per capita (and not per employee), we rewrite equation (1) as

$$Y = AK^a H^b POP^g PART^g \quad (2)$$

where POP = population and $PART$ = participation rate (L/POP). In intensive form and log-differences we have

$$\Delta \ln y_t = \Delta \ln A_t + a \Delta \ln k_t + b \Delta \ln h_t + g \Delta \ln PART_t \quad (3)$$

where $y = Y/POP$ = GVA per capita, A = total factor productivity (technological progress), $k = K/POP$ = physical capital per capita and $h = H/POP$ = human capital per capita.

As outlined above, technological progress (A) can be considered as a result of either innovation activity or technological catching-up. Additionally, there may also exist some exogenous technical progress, which we will neglect for the moment. First, let us take the case that technological progress is driven by a region's own R&D effort. A familiar formalisation of this argument appears in the model by Romer (1990), where knowledge (A) is generated in the R&D-sector according to the production function $\Delta \ln A_t = f H_A$. This implies that the growth rate of A , ($\Delta \ln A$), is a function of the level of human capital employed in the R&D-sector (H_A). We shall test this relationship, however the limited availability of regional research personnel data forces us to proxy H_A by the overall stock of human capital (H) in terms of the number of employees with a certain level of education. This gives us

$$\Delta \ln A_t = j_1 H_t \quad (4a)$$

Another possibility to capture the nexus of human capital and research would be to relate technological progress to the human capital share

$$\Delta \ln A_t = \beta_2 h_t \quad (4b)$$

This approach was chosen by Benhabib and Spiegel (1994) who tested this relationship using measures of human capital per capita (h) like mean years of schooling instead of the level of human capital (H) of the Romer model.² We shall test this relationship as well using educational attainment shares, i.e. the share of the population with a certain level of education.

Most empirical studies measure innovation by an input factor, which clearly gives a distorted picture. Innovations are not simply a function of inputs but subject to a number of further characteristics of the R&D process, such as the probabilistic nature of invention, the possibility that returns in the R&D sector are not constant (depletion of ideas), etc., as formalized for instance in the models of Grossman and Helpman (1991) or Aghion and Howitt (1992).

As an alternative to the purely input oriented measure of own R&D effort (H, h), one could focus more on the output side of the R&D sector. An eligible measure is the number of patent applications per employee (PAT), yielding the following specification for the growth rate of A

$$\Delta \ln A_t = \beta_3 Pat_t \quad (4c)$$

Recently, a growing number of regional studies viewed innovation activity as a matter of patent applications (Paci and Usai, 2000; Maurseth, 2001) although there are also some problems with this kind of innovation measure. For instance, patents are typically registered at the site of the mother company and not at the place where research is actually done.

Besides own R&D effort, a second source of technological progress is technology transfer which permits catching-up against the technology leader. The economic rationale here is that a large technology gap is *ceteris paribus* associated with a large potential for catching-up and thus a higher growth rate of A . Ideally, the technology gap would be measured in terms of total factor productivity (A). However, as A is not directly observable, we use the labour productivity (y^*) as a proxy variable. The catching-up process then implies that the growth of A is described by the following relationship

² Although it may be reasonable to relate an intensive measure of human capital to knowledge production, one should note that a strict test of the Romer model has to use (4a) and not (4b).

$$\Delta \ln A_t = \mathbf{h}_1 \left(\frac{y_{MAX,t}^* - y_t^*}{y_t^*} \right) = \mathbf{h}_1 GAP_t \quad (5a)$$

where $y_{MAX,t}^*$ is the productivity level of the technology leader and the parameter \mathbf{h}_1 indicates, how fast the technology gap (GAP) can be closed. A possible objection against equation (5a) is that catching-up does not come by itself. As Nelson and Phelps (1966) and others have shown, it requires human capital (H) for adapting and implementing new technologies. Originally, Nelson and Phelps argued that the catching-up parameter (here \mathbf{h}_1) is a non decreasing function of H . Benhabib and Spiegel (1994) took up this argument and modelled the catching-up process as

$$\Delta \ln A_t = \mathbf{h}_2 h_t \left(\frac{y_{MAX,t}^* - y_t^*}{y_t^*} \right) = \mathbf{h}_2 h_t GAP_t \quad (5b)$$

Equation (5b) states that holding human capital constant, economic units with a lower initial productivity level experience higher rates of productivity growth. Equivalently, for a given gap in technology, higher levels of human capital are associated with a faster catching-up process and thus a higher growth of A .

Trade has also played a prominent role in the discussion of the determinants of convergence (Ben-David and Kimhi, 2000; Griffith et al., 2000). Thus, a straightforward modification of equation (5b) is to replace (H) by a measure of trade

$$\Delta \ln A_t = \mathbf{h}_3 Tr_t \left(\frac{y_{MAX,t}^* - y_t^*}{y_t^*} \right) = \mathbf{h}_3 Tr_t GAP_t \quad (5c)$$

Trade (Tr) could either stand for imports (m) or exports (x) in percent of GVA. The economic rationale, underling equation (5c) is thus twofold. A higher import share would allow more spillovers from abroad (Coe and Helpman, 1995), thereby fostering the catching-up process. Alternatively, a high export share may be associated with a pro-competitive effect of trade, which implies that the requirement to compete in the export market stimulates the catching-up against the technology (respectively market) leader.

Finally, own R&D activities can also be thought as prerequisite for closing the technology gap. Drawing on Quah (1999) and Griffith et al. (2000) we can argue that an economy effecting own R&D possesses the specific technological know how that would make it more easy to adopt new technologies of the same class. This rationale can be expressed more formally as

$$\Delta \ln A_t = \mathbf{h}_4 Pat_t \left(\frac{y_{MAX,t}^* - y_t^*}{y_t^*} \right) = \mathbf{h}_4 Pat_t GAP_t \quad (5d)$$

Inserting (4c) and the different specifications of (5) into equation (3) yields alternative testable specifications for the growth of GVA per capita (y), which are given by

$$\Delta \ln y_t = \mathbf{d} + \mathbf{a} \Delta \ln k_t + \mathbf{b} \Delta \ln h_t + \mathbf{g} \Delta \ln PART_t \quad (6)$$

$$\Delta \ln y_t = \mathbf{d} + \dots + \mathbf{j}_3 Pat_t \quad (6a)$$

$$\Delta \ln y_t = \mathbf{d} + \dots + \mathbf{j}_3 Pat_t + \mathbf{h}_1 GAP_t \quad (6b)$$

$$\Delta \ln y_t = \mathbf{d} + \dots + \mathbf{j}_3 Pat_t + \mathbf{h}_2 h_t GAP_t \quad (6c)$$

$$\Delta \ln y_t = \mathbf{d} + \dots + \mathbf{j}_3 Pat_t + \mathbf{h}_3 Tr_t GAP_t \quad (6d)$$

$$\Delta \ln y_t = \mathbf{d} + \dots + \mathbf{j}_3 Pat_t + \mathbf{h}_4 Pat_t GAP_t \quad (6e)$$

where growth is explained by factor accumulation ($\Delta \ln k$, $\Delta \ln h$) and growth of technology (A), which is in turn determined by an exogenous rate of technical progress \mathbf{d} , a region's own ability to innovate (here measured by Pat) and a catching-up component conditioned on either human capital, trade or patents. The variable $\Delta \ln PART$ controls for changes in the participation rate, as (6) is specified in per capita terms. Alternatively we estimate equations (6a) to (6e) with the variables h and H instead of Pat (see (4a), (4b)).

The models given by equations (6) permit to relate estimation results directly to economic theory and thus distinguishes from often found ad-hoc growth regressions, which have been criticized for good reason, notably by Durlauf who states that "it is no exaggeration to say that the theoretical and empirical growth literatures are evolving with little interaction." (Durlauf, 2001, p. 65).

V. Estimation and results

Data

We test equations (6) for a cross-section of 128 European regions over the period 1993-2000. As mentioned above, the sample largely covers the Eurozone regions, with the exception of Austria and Greece. The concrete sample has been mainly determined by data availability and

the exclusion of obvious outliers (Ireland³, French Overseas Departments, Ceuta y Melilla).

Table 1 summarises the variables and their respective indicators as used in the regression.

The data set contains several indicators which provide a better measure of the relevant variable than data sets used in other regional growth studies. First, our data set uses computed capital stock data and not investment rates which is the common proxy. Thus we have a more accurate measure for the development of capital per capita. Second, we use educational attainment rates computed from labour force surveys as an indicator for human capital, distinguishing also between medium and higher level attainment. Since data on educational attainment is not easily available for EU regions for several periods, other studies either used enrolment rates (Tondl, 2001) or could not investigate the impact of changes in educational attainment (Vanhoudt et al., 2000). For the reasons outlined in section IV and due to better data coverage, we chose to take patent applications as an indicator for innovation and not

Table 1 – *Definition and sources of the variables*

Variable	Definition	Units	Source
$Dlny_i$	average growth rate of GVA per capita	per cent p.a.	CamEcon
$Dlnk_i$	average growth rate of physical capital per capita	per cent p.a.	CamEcon, o.c.
h_i	average attainment rate – high education (tertiary)	per cent	Eurostat, o.c.
h_m_i	average attainment rate – medium education (secondary)	per cent	Eurostat, o.c.
H_i	average number of persons with higher education (tertiary)	1000 persons	Eurostat, CamEcon, o.c.
H_m_i	average number of persons with medium education (secondary)	1000 persons	Eurostat, CamEcon, o.c.
Pat_i	average number of patent applications per employee	number per 1000 persons	Eurostat
$x_i (m_i)$	export (import) quota in percent of GVA	per cent	Hallet (1999), Eurostat
GAP_i	$GAP = \left(\frac{y_{MAX,93}^* - y_{i,93}^*}{y_{i,93}^*} \right) = \text{gap to technology leader}^{1)}$ in 1993 (initial level)	-	CamEcon, o.c.

$i = 1, \dots, 128$ = index of regions. – CamEcon ... Cambridge Econometrics, o.c. ... own calculations. – Averages refer to the period 1993-2000 or to a subperiod, as part of the data were not available for the full period (in particular for the variables h , PAT). – ¹⁾ technology leader in 1993 was Ile de France. More details on the data used are given in the appendix.

³ While Ireland offers one of the most interesting growth stories to study separately, we have to exclude it from our sample as an exceptional outlier.

research expenditures or research personnel.⁴ Finally, we also could include data on international trade of regions in our data set which permits to analyse this novel aspect in regional growth research. A detailed description of our data set is given in the appendix.

Results of Estimation

Before presenting the results of our cross-section regressions for the period 1993-2000, some caveats shall be outlined. It is well known that cross-section regressions suffer from an omitted variable bias as they do not take duly into account differences in individual production functions (Islam, 1995; Durlauf and Quah, 1998; Temple 1999). However, limited data availability for our specific set of indicators and issues does not permit us to follow a panel approach. Second, inclusion of the variable $\Delta \ln k$ is likely to imply an endogeneity problem, as causality may not only run from investment to growth but also from growth to investment. Another candidate for reverse causality may be human capital. Both problems have been documented in the literature (Sinha and Sinha, 1998; Podrecca and Carmeci, 2001). Given the absence of suitable instruments one has to accept the likely bias of the parameter estimates. Finally, the issue of spatial correlation has been raised in the recent growth literature (Rey and Montouri, 1999; Niebuhr, 2001; Fingleton, 2001). Spatial autocorrelation may also cause biased or inconsistent estimates, depending on its concrete form. However, an estimation for the EU at the regional NUTS-II level may be a rather high level of aggregation, where spatial autocorrelation may not be too pronounced, as suggested by the spatial autocorrelation tests of Maurseth (2001).

Since the model underlying our estimation contains all elements of a production function and thus differs from ad-hoc estimations, our coefficient estimates should be rather reliable. We may expect this at least for the sign of coefficients. However, the econometric caveats outlined above have to be borne in mind and the concrete size of the coefficients must not be overstressed.

We start with a parsimonious model with factor accumulation (Table 2, column 1). The estimation indicates that per capita income growth is significantly positively related to the growth of both factors, physical capital and human capital. These results are in line with the recent findings of country level estimations (Bassannini et al., 2001; de la Fuente and

⁴ Nevertheless, as shown by Bottazzi and Peri (1999) patents and R&D expenditures are highly correlated for EU regions.

Domenech, 2000). Note however, that growth of EU regions is only sensitive to attainment of higher level education. Differences in medium level educational attainment or changes of it do not explain growth (column 2 where the coefficient for changes in medium level attainment rates is insignificant). The size of the coefficients in column 1 is quite reasonable, indicating an output elasticity of about 0.20 for physical capital and 0.10 for human capital. In addition the estimates indicate that an increase in the labour participation rate implies higher growth.

Table 2 - Results for models with factor accumulation and own R&D effort

dependent variable: $\Delta \ln y$						
	(1)	(2)	(3)	(4)	(5)	(6)
<i>intercept</i>	0.9674 (5.94 ^{***})	1.5684 (11.58 ^{***})	1.0199 (5.98 ^{***})	0.4860 (1.98 ^{**})	1.1182 (6.39 ^{***})	0.5137 (1.47)
$\Delta \ln k$	0.2301 (4.74 ^{***})	0.1213 (2.41 ^{**})	0.2366 (4.83 ^{***})	0.1948 (4.08 ^{***})	0.2477 (5.39 ^{***})	0.1973 (3.95 ^{***})
$\Delta \ln h$	0.1063 (4.48 ^{***})		0.1069 (4.53 ^{***})	0.1077 (4.66 ^{***})	0.1144 (5.07 ^{***})	0.1083 (4.70 ^{***})
$\Delta \ln h_m$		-0.0280 (-0.70)				
H			-0.0006 (-1.62)			
h				0.0397 (2.63 ^{***})		0.0383 (1.91 [*])
$\ln Pat$					0.1149 (2.29 ^{**})	0.0081 (0.13)
$\Delta \ln PART$	0.3468 (4.26 ^{***})	0.5109 (6.19 ^{***})	0.3377 (4.18 ^{***})	0.3521 (4.22 ^{***})	0.3826 (4.60 ^{***})	0.3545 (4.10 ^{***})
R^2 adj.	0.498	0.422	0.501	0.545	0.521	0.542
F -Test	43.010 ^{***}	31.870 ^{***}	32.831 ^{***}	39.091 ^{***}	35.495 ^{***}	31.023 ^{***}
AIC	2.036	2.177	2.038	1.944	1.997	1.960
No of obs.	128	128	128	128	128	128

t-values (in parentheses) based on White-Heteroscedasticity consistent standard errors (White, 1980). – *, **, *** indicate significance at the 10, 5 and 1 percent level. – AIC ... Akaike info criterion.

Next we extend the estimated model to include innovation activity (columns 3-6). If R&D efforts are proxied by the number of persons with higher or medium education, a specification close to the Romer (1990) model, we get no indication for a positive impact on growth (column 3). Nevertheless, when we use the level of educational attainment in the population,

we obtain a significant positive relationship (column 4). Thus regions that start from a higher knowledge stock are candidates for higher growth. The efforts of EU regions to raise educational levels seem to have contributed to growth. In column 6 we start from the estimated equation in column 4 with both higher level human capital in levels as in growth rates and add innovation as measured by patent applications. In this combination the coefficient for patent applications is insignificant. However, if higher level educational attainment rates are not entered but only patent application, the estimated coefficient of the latter becomes positive and significant. We found that both indicators are highly correlated, evidently since innovation per employee is based on the share of people with higher education

Table 3 - Results for models with factor accumulation, R&D effort (*h*) and catching-up (*GAP*)

dependent variable: $\Delta \ln y$							
	(4)	(4a)	(4b)	(4c)	(4d)	(4e)	(4f)
<i>intercept</i>	0.4860 (1.98**)	0.4967 (1.82*)	0.5107 (2.05**)	0.2897 (1.13)	0.3886 (1.55)	0.4933 (2.04**)	0.3161 (1.16)
$\Delta \ln k$	0.1948 (4.08***)	0.1984 (2.75**)	0.1398 (2.01**)	0.1214 (2.00**)	0.1353 (1.98**)	0.1955 (4.07***)	0.1075 (1.54)
$\Delta \ln h$	0.1077 (4.66***)	0.1082 (4.47**)	0.1019 (4.03***)	0.1108 (4.98***)	0.1014 (4.22***)	0.1069 (4.65***)	0.1083 (4.47***)
<i>h</i>	0.0397 (2.63***)	0.0389 (1.98**)	0.0382 (2.54**)	0.0520 (3.28***)	0.0503 (3.03***)	0.0414 (2.44**)	0.0503 (2.99**)
<i>GAP</i>		-0.0001 (-0.08)					
<i>hGAP</i>			0.0164 1.34				0.0061 (0.42)
<i>xGAP</i>				0.0099 (2.76***)			0.0090 (2.21**)
<i>m GAP</i>					0.0052 (1.93**)		
<i>PatGAP</i>						-0.0027 (-0.41)	
$\Delta \ln PART$	0.3521 (4.22***)	0.3514 (4.06***)	0.3675 (4.19***)	0.3326 (4.27***)	0.3599 (4.39***)	0.3461 (3.94***)	0.3401 (4.05***)
<i>R² adj.</i>	0.545	0.542	0.550	0.565	0.554	0.542	0.562
<i>F-Test</i>	39.091***	31.024***	31.989***	33.931***	32.607	31.080***	28.143***
<i>AIC</i>	1.944	1.960	1.943	1.909	1.932	1.959	1.922
<i>No of obs.</i>	128	128	128	128	128	128	128

t-values (in parentheses) based on White-Heteroscedasticity consistent standard errors (White, 1980). — *, **, *** indicate significance at the 10, 5 and 1 percent level. — AIC ... Akaike info criterion.

in an economy. Therefore, they can not enter together in the estimation. We can conclude that the level of innovation in EU regions does have a significantly positive impact on growth.

In Tables 3 and 4 we start from our basic model including innovation, either as measured by the share of persons with higher level education (Table 3, column 4) or directly by patent applications (Table 4, column 5) and include the possibility of technological catching-up. In Table 3, column 4a we see that the technology gap indicating the possibility for technological catching-up does not enter significantly in the estimation. However, if we condition the

Table 4 - Results for models with factor accumulation, R&D effort (Pat) and catching-up (GAP)

dependent variable: $\Delta \ln y$							
	(5)	(5a)	(5b)	(5c)	(5d)	(5e)	(5f)
<i>intercept</i>	1.1182 (6.39 ^{***})	1.0980 (4.92 ^{***})	1.2024 (6.38 ^{***})	1.1358 (6.46 ^{***})	1.1927 (5.71 ^{***})	1.2763 (5.49 ^{***})	1.2076 (6.70 ^{***})
$\Delta \ln k$	0.2477 (5.39 ^{***})	0.2552 (3.84 ^{***})	0.1276 (1.86 [*])	0.2007 (3.42 ^{***})	0.2128 (3.33 ^{***})	0.2623 (5.29 ^{***})	0.1037 (1.49)
$\Delta \ln h$	0.1144 (5.07 ^{***})	0.1149 (5.01 ^{***})	0.1050 (4.28 ^{***})	0.1198 (5.41 ^{***})	0.1116 (4.79 ^{***})	0.1143 (5.08 ^{***})	0.1099 (4.66 ^{***})
$\ln Pat$	0.1149 (2.29 ^{**})	0.0987 (-1.04)	0.1689 (2.90 ^{***})	0.1598 (2.67 ^{***})	0.1524 (2.35 ^{**})	0.1586 (2.20 ^{**})	0.1976 (3.02 ^{***})
<i>GAP</i>		-0.0004 (-0.22)					
<i>hGAP</i>			0.0372 (2.78 ^{***})				0.0336 (2.42 [*])
<i>xGAP</i>				0.0085 (2.13 ^{**})			0.0064 (1.71 [*])
<i>mGAP</i>					0.0042 (1.43)		
<i>PatGAP</i>						-0.0098 (-1.20)	
$\Delta \ln PART$	0.3826 (4.60 ^{***})	0.3753 (3.74 ^{***})	0.4350 (4.83 ^{***})	0.3784 (4.76 ^{***})	0.3994 (4.60 ^{***})	0.3735 (4.44 ^{***})	0.4269 (4.99 ^{***})
R^2 adj.	0.521	0.517	0.552	0.533	0.525	0.521	0.557
F-Test	35.495 ^{***}	28.208 ^{***}	32.301 ^{***}	30.025 ^{***}	29.044 ^{***}	28.621 ^{***}	27.665 ^{***}
AIC	1.997	2.012	1.937	1.978	1.996	2.004	1.932
No of obs.	128	128	128	128	128	128	128

t-values (in parentheses) based on White-Heteroscedasticity consistent standard errors (White, 1980). – *, **, *** indicate significance at the 10, 5 and 1 percent level. – AIC ... Akaike info criterion.

catching-up potential on human capital endowment, the coefficient becomes positive and its statistical significance improves (Table 3, column 4b). In the analogous specification in Table 4 (column 5b) the coefficient becomes statistically significant at the one per cent level. This indicates that there is some technological catching-up taking place in EU regions which is based on the human capital endowment of a region. Regions can achieve productivity improvement through this channel, which becomes quite important for their income growth. The next estimates consider the possibility of closing the technology gap if engaged in foreign trade (Table 3 and 4, columns c and d). The results show a positive and significant coefficient for the export weighted gap and thus indicate that exports can be considered as a stimulus to become more competitive and to close the technology gap. The coefficients of the import weighted technology GAP are also positive, but only half the size and statistically less significant. This may indicate that the possibility of technology transfer through imports is less important for regional growth. However, the lower significance of imports may also be due to measurement errors since our indicator for imports may be less reliable (see the appendix for a description of the methods used to proxy regional trade).

Finally, we also tested the possibility that technology transfer is facilitated by a region's own research efforts and can contribute to growth in this way. This hypothesis must be rejected (Tables 3 and 4, column e). A high own, general R&D activity is no precondition to enhance technology transfer. If comparing that result with those of Griffith et al. (2000), R&D would have to take place in specific sectors to mediate a transfer of technologies of the same domain.

Combining possible sources of technological catching-up, we find that human capital and trade (exports) are preconditions that simultaneously contribute to technological catching-up and growth (Tables 3 and 4, column f). In the innovation specification with patents the statistical significance improves. The fact that we find evidence of international technology transfer via different channels complements the existing literature of regional technology spillovers, which considered it to be either geographically limited (Paci and Pigliaru, 2001) or to take only place between equal regions (Maurseth, 2001).

In general, we should emphasize that our basic model parameters, physical capital growth and human capital growth and changes of the participation rate are rather stable. The coefficient of capital is higher in the innovation specification with patents and shows an output elasticity of about 0.20. That only decreases if including two ways of technological catching-up. Finally,

the overall fit of the model becomes quite satisfactory in the long specification with technological catching-up and reaches an adjusted R^2 of more than 0.50.

VI. Conclusions

This paper analyzed the growth pattern of EU regions in the 1990s and tested the hypothesis that endogenous growth factors together with trade played a major role for a high growth performance. We tested this hypothesis performing cross-section growth regressions in a growth accounting framework. The estimated model includes the central production factors physical and human capital, and captures technological progress through own innovation activity as well as international technology transfer that is conditioned on endowment factors and trade. The richness and sound theoretical basis of our estimated model goes at the expense of less econometric sophistication. In particular does the lack of time series data not permit us to estimate a panel data model. An analysis with refined econometric methods must be left to future research.

Our results indicate that capital accumulation as well as higher level educational attainment and changes of it are important and robust factors for growth of EU regions. These results clarify the findings of previous regional growth literature that used more simple indicators and achieved mixed results.

Our analysis offers another important result: High growth EU regions generate technological progress through own innovation activity and through international technology transfer. The latter can become a source of technological catching-up if a region possesses sufficient human capital in order to adopt available technologies. Finally, our results show that foreign trade plays an important role for technological catching-up of EU regions. Regions with high imports register a significant growth effect from technological catching-up which can be explained by import-related technology transfer. On the other hand, regions with high exports also show a significant growth effect of technological catching-up which can be interpreted as a pro-competitive effect of trade.

These findings suggest that trade openness as fostered by European Integration and international free trade agreements have become an important growth factor. Openness offers a growth potential both to rich and poor regions. Further, we can conclude that higher education standards and research activity are correct targets of EU policies as presently pursued with EU regional, technology and social policy since they are important for the growth of regions in advanced economies.

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Appendix

Data Description

Y_i = real gross value added in million Euro (1990 prices, 1990 exchange rate (ECU)), taken from the Cambridge Econometrics 2001 data set.

K_i = real capital stock in million Euro (1990 prices, 1990 exchange rate (ECU)), calculated using a perpetual inventory method: $K_t = K_{t-1} (1-d) + I_t$, with I_t = investment (investment expenditure, taken from the Cambridge Econometrics 2001 data set), d ... depreciation rate (assumption: 5%). Initial level K_0 calculated as $K_{1975} = I_{75}/(g_{I,75-01})$ where I_{75} = investment in 1975, $g_{I,75-01}$ = average growth rate p.a. of investment from 1975 to 2001 (see Griliches, 1980).

POP = population in 1000 persons, taken from the Cambridge Econometrics 2001 data set.

L_i = employment in 1000 persons, taken from the Cambridge Econometrics 2001 data set.

h_i = educational attainment in percent: share of population with attainment "high", calculated from Eurostat Labor Force Surveys.

h_m_i = educational attainment in percent: share of population with attainment "medium", calculated from Eurostat Labor Force Surveys.

$patents$ = number of patent applications, taken from the New Cronos/Regio from Eurostat.

$x_i(m_i)$ = exports (imports) in percent of gross value added (actual prices); data refer to 1994 and were taken from Hallet (1999), who approximated regional trade flows by assuming that the trade intensity in branch j ($j=1, \dots, 17$; NACE-Clio, RR17) is the same for all regions of a country and allocating the national trade flows to the regions according to the sectoral shares in GVA. Total trade of a region i , which belongs to country I , is thus given as sum of $\sum_j T_{Ij} w_{ij}$, where T_{Ij} is country I 's trade in sector j and w_{ij} is the share of region i in country I 's gross value added in sector j .

$i = 1, \dots, 1$ (region index): Our analysis covers 128 NUTS II regions of practically the entire Eurozone for the 1990s. Due to limited data availability it was not possible to consider the whole group of EU 15 regions. Our sample does not include regions from the UK, Sweden, Denmark, Austria and Greece. In addition we excluded Ireland because of its outstanding performance which would constitute a significant outlier for the regression analysis. As a result of missing data the French Overseas Departements and the region Ceuta y Melilla were excluded as well.

Derived variables: $y = 1000Y/POP$, $k = 1000K/POP$, $Pat = patents/L$, $H = 1000Lh$.

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