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The growth crisis of Germany: A blueprint of the developed economies

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Bayerische Julius-Maximilians-Universität Würzburg

Wirtschaftswissenschaftliche Fakultät

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of the Developed Economies**

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The Growth Crisis of Germany: A Blueprint of the Developed Economies

Norbert Berthold and Klaus Gründler

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Abstract

Germany has experienced tremendous growth rates in the aftermath of World War II. Since the early 1970s, growth rates declined and settled down at a more or less constant rate of 2 percent per year, only to experience a renewed negative trend around the early 2000s. We investigate the evolution of the German growth rate and particularly aim to explain the last decline.

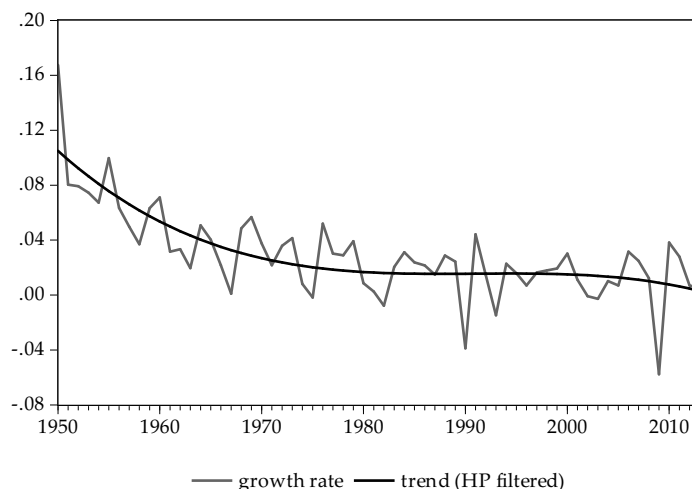
Endogenous growth theory suggest that long-run growth is mainly driven by human capital and technological progress. Our 3SLS estimations in a panel of 187 countries between 1965 and 2010 support this hypothesis. As it turns out, human capital accumulation in Germany severely lags behind the average level of the developed countries. As this may explain the moderate position of Germany in the group of the 25 richest countries, the developed countries in turn experience a period of below-average growth rates. Regardless the financial crisis from the late 2000s, growth reveals a downward trend since the turn of the millennium in nearly each of the developed economies. We argue that this decline must be traced back to a general lack of radically new ideas in the world economy. The explanation of the German growth crisis may thus be considered a blueprint of the situation in the developed economies.

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1 Introduction: The Problem

After World War II, the German economy generated growth rates that do not seem to be reproducible today. Figure 1 illustrates the development of the German growth rate and its trend from 1950 to 2010. While per capita income in the 1950s and the 1960s grew by an average of 8.3 and 4.5 percent per year, the increases significantly declined since the end of the 1960s. Between the early 1970s and the late 1990s, growth rates settled down to a more or less stable level. However, since the beginning of the new millennium, the downswing of the trend sharpened again. During the 2000s, income grew by only 1.2 percent per annum.

Figure 1: Per capita growth rates and trend in Germany, 1950 – 2013^f



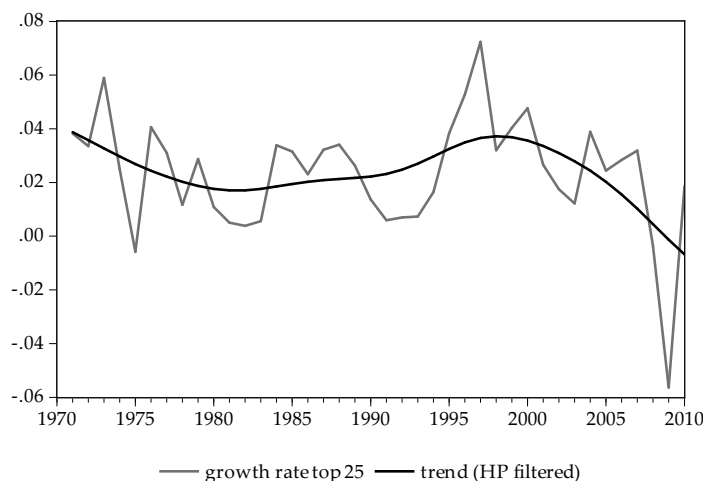
Source: EUROSTAT (2013), HESTON et al. (2012), MADDISON (2013), and own calculations. The growth rate for 2013 is forecasted by Eurostat.

This is not a specific German phenomenon but can be identified in almost all developed countries. Figure 2 shows the evolution of the average growth rate of the 25 richest countries in terms of per capita GDP and its trend from 1970 to 2010.¹ Astonishingly, the development of per capita growth mimics the growth path of Germany quite accurately. After high increases of per capita income during the 1970s, growth rates decrease until achieving a more or less stable level at the end of the 1970s. In the early 1990s, average growth in the top 25 increased tremendously. These above-average gains, however, are almost entirely driven by Equatorial Guinea. In 1990, income per capita was

¹The group includes countries that are among the 25 richest nations in 2012 as measured by the classification of WORLD BANK (2012). Due to data availability, Qatar, Brunei Darussalam and the United Arab Emirates are excluded.

652.60 USD and rose up to 5,935.89 USD in 2000. Incomes during the 1990s have almost increased tenfold due to the discovery of oil reserves. Around the year 2000, however, growth in the top 25 exhibits a renewed negative trend. Figure A.1 in the appendix illustrates the trend of growth rates of each of the 25 richest countries in the world in terms of per capita income. With exception of the oil-exporting countries Qatar, Kuwait and the United Arab Emirates, all developed countries experienced a more or less comparable decline in growth around the year 2000. Neglecting oil-exporting economies (Equatorial Guinea, Kuwait, Qatar and the United Arab Emirates), the mean value of growth in the top 25 countries was 3.1 percent in the 1970s, 2.3 percent in the 1980s, 2.1 percent in the 1990s and 1.3 percent in the 2000s.

Figure 2: Growth rates and trend of developed economies, 1950-2010



Source: HESTON et al. (2012) and own calculations.

The aim of this paper is to explain the development of the German growth rate since the beginning of the 1950s and the particular noteworthy decline since the new millennium. As we will demonstrate, our explanation also holds for the entire group of developed economies, transforming the German problem into a blueprint of the current situation in the world's richest countries. The paper proceeds as follows: first, we take a brief glance at some key ideas from neoclassical and endogenous growth theory. As human capital and innovations can be regarded the main drivers of economic growth in developed countries, we make several somewhat more elaborate notes on both of these concepts. These considerations will help to better understand the empirical data. Especially the interaction between human capital and innovation as well as the diffusion of technology is briefly discussed. In section 3, we evaluate our theoretical hypothesis empirically in order to ensure that the illustrated key mechanisms of growth theory hold when testing them with data. For this purpose, we estimate

3SLS systems in a sample of 187 countries between 1965 and 2010 building on BARRO (2003) and BERTHOLD and GRÜNDLER (2012).

As it turns out, conditional convergence emerges as a clear empirical pattern. This prompts us to draw two conclusions: First, the relevant time span to investigate German growth rates is 1970-2010, since Germany experienced significant convergence effects after World War II that faded not until the end of the 1960s. Second, German growth may only be compared with developed countries that in turn have approximated their individual steady state level of growth. We thus analyze the key drivers of growth in a sample of the 25 richest countries in terms of per capita income.

The investigation shows that Germany severely lags behind in the accumulation of human capital. Human capital, however, is a direct input factor in the production function and is furthermore necessary to close the technological gap, that is the transfer of scientific research into marketable goods and production processes. This innovation activity is the main driver in the endogenous models of ROMER (1986, 1987, 1990), AGHION and HOWITT (1992, 1998), GROSSMAN and HELPMAN (1991) and others. Yet, the potential for new products, that is the technological frontier, is subject to strong fluctuations over time. GORDON (2012) argues that faltering innovations led to a long-lasting decline in U.S. growth. Our analysis supports this appraisal suggesting that the worldwide innovation activity slackened since the early 2000s. This lag of radically new ideas led to below-average growth rates in most of the developed countries. Putting together the weak gains in human capital and the worldwide 'idea gap', the historical German growth rates since the early 1970s can be explained quite well. We conclude in section 4.

2 Theoretical framework

A brief glance at neoclassical and endogenous theory

One crucial hypothesis of the neoclassical growth model of SOLOW (1956), SWAN (1956), KOOPMANS (1965) and CASS (1965) is convergence. The model demonstrates that poor economies will eventually catch up to rich countries and that per capita incomes converge. Similarly, the model predicts that the growth rate of any economy declines as it approximates its steady state. Empirical results indicate that the starting position and the growth rate are negatively correlated when holding constant some variables that distinguish the countries. Reconciling the convergence hypothesis with data therefore means examining the concept of conditional convergence. The work of BARRO and SALA-I-MARTIN (1991), BARRO (2003) and MANKIW et al. (1992) indeed shows that poorer countries grow faster than economies that have approached their steady state.

Once the steady state level of income is reached, economies can no longer grow by the accumulation of physical capital. The endogenous models of ROMER (1986, 1987, 1990), LUCAS (1988), AGHION and HOWITT (1992, 1998) and GROSSMAN and HELPMAN (1991) illustrate that the accumulation of human

capital as well as vertical and horizontal innovations determine the level of the steady state growth rate.

The general idea of LUCAS (1988) is to describe the level of income as

$$y = F(k, \mu h, \Psi), \frac{\partial y}{\partial h} > 0,$$

where $h = H/L$ denotes the average level of human capital, k describes capital and Ψ is factor productivity. The fraction of human capital that works in the output sector $\mu \in (0, 1)$ is of particular interest as it positively influences present growth but leads to negative effects on future long-run growth. The accumulation of human capital presumably develops as

$$\Delta h \equiv \Psi(1 - \mu)h - \delta h,$$

where δ denotes the depreciation rate of human capital. Whenever the inequation $\Psi(1 - \mu)h > \delta h$ is true, new human capital is formed. Obviously, a high fraction of human capital working in the output sector hinders the accumulation of h .

By contrast, the models of ROMER (1986, 1987) are rather focused on horizontal innovations. Romer outlines the output y of firm i as

$$y_i = \Psi L_i^{1-\alpha} \sum_{j=1}^N (X_{ij})^\alpha, \quad (1)$$

where L denotes labor and $\alpha \in (0, 1)$ depicts production elasticity. The capital stock is divided into individual capital goods j where $j \in \mathbb{J}$, $|\mathbb{J}| = N$. Thus, X_{ij} denominates the amount of capital good j inserted in i . An increase in the number of available capital goods, that is $dN/dt > 0$, leads to an increase in per capita incomes. New capital goods can be achieved by innovations or international trade.²

AGHION and HOWITT (1992, 1998) and GROSSMAN and HELPMAN (1991), on the other side, emphasize the importance of vertical innovations. In general, vertical innovations increase per capita incomes as the replacement of less improved capital goods leads to an enhancement of productivity. This mechanism can be sketched using the production function

$$y_i = \Psi L_i^{1-\alpha} \sum_{j=1}^N (q^{\kappa_j} X_{ij})^\alpha, \quad (2)$$

where $\tilde{X} \equiv q^{\kappa_j} X_{ij}$ denominates the quality-adjusted amount of j utilized in the production of i . Due to $q > 1$, each quality step κ increases the marginal impact of j . Suppose that only the κ th version is utilized in the production process. In this case, q determines the distance between the rungs of the quality ladder, κ_j affects the amount of rungs, and the height of the ladder influences per capita incomes.

²The term 'capital good' is very broad and refers to all kinds of products and processes that can be utilized in the production of output.

Human capital

HANUSHEK and WOESSMANN (2012) consider human capital a function of family input F , individual abilities A , schooling quality q , schooling quantity Y and other relevant factors Z that include health and labor market experience. Human capital can thus be modeled using the function

$$h = \lambda F + \phi(qY) + \eta A + \alpha Z,$$

where $\lambda, \phi, \eta, \alpha \in \mathbb{R}^+$ denominate the marginal impacts of the particular determinant. As family input and individual abilities can hardly - if at all - be improved, schooling quality and quantity as well as health are the most important factors that distinguish the countries. The decision of individuals to invest in one unit of these factors of human capital at any time t can be described similar to JOHNES (1993) as

$$\int_0^F C(t) \exp\{-rt\} dt \leq \int_F^T R(t) \exp\{-rt\} dt. \quad (3)$$

In (3), $C(t)$ denotes the costs of achieving one marginal unit of human capital, $R(t)$ entitles the rent of the educational program, F refers to the time at which the training program is completed and T marks the time of retirement. Low costs of education, low interest rates, high returns to education and a young population thus lead to positive growth stimuli. When we analyze the level of human capital in Germany and the developed countries in the empirical section, we will study these factors more in detail.

Inventions, innovations and improvements

One general idea of SCHUMPETER (1911) is that inventions are created regularly over time. Horizontal innovations are concrete and marketable applications of these discoveries. Unlike inventions, innovations emerge discontinuously in the course of time. The reason for this divergence is that horizontal innovations are far more costly and risky than vertical innovations. Whenever a sufficiently large bundle of horizontal innovations j allows for a wide range of improvements κ_j , firms are likely to improve existing capital goods rather than invest in entirely new products. Yet, as the improvement gets more and more costly with each step on the quality ladder, the development costs of κ_j will approach the additional returns and eventually exceed it. In such a situation, the incentives to invest in new inventions rise. At some point in time, less risk-averse entrepreneurs will introduce new j^* that close the gap between the research front and the amount of marketable capital goods.

Quite similar, NELSON and PHELPS (1966) and later BENHABIB and SPIEGEL (2005) model the interaction between the technological front and factor productivity. In these models, technological progress in the sense of the Solow residual is positively correlated with the closing of the gap between the technological

front and the stock of factor productivity. In expansion to Schumpeter, NELSON and PHELPS (1966) suggest that the rate at which this gap is closed depends on the level of human capital. To be more precise and to harmonize this hypothesis with the model of LUCAS (1988), the crucial factor must be considered the amount of human capital multiplied by the fraction of h working in the research sector, that is $(1-\mu)h$. Let $T(t)$ be the exogenously given technological level that measures the stock of knowledge or body of techniques available to innovators. Suppose that ω denominates the time lag between the invention and its adoption. On an aggregate level, the technology used in practice on average equals the technological front ω years ago. It follows that

$$\Psi(t) = T[t - \omega((1-\mu)h)], \quad \frac{\partial \omega((1-\mu)h)}{\partial h} < 0.$$

The models of BARRO and SALA-I-MARTIN (2004) indicate that such an enhancement of factor productivity will boost the creation of j^* as it increases the net present value of the innovation. Thus, any investment in j^* (or κ_j) is more likely to produce profits exceeding the marginal costs of the innovation. In addition, factor productivity increases enable designs of new capital goods that could not have been made with the old technology. Even more important, an increase in $\Psi(t)$ facilitates the accumulation of human capital in the LUCAS (1988) model and therefore accelerates the closing of the technological gap.

NELSON and PHELPS (1966) and BENHABIB and SPIEGEL (2005) expect $T(t)$ to evolve at a more or less constant exponential rate of $\varphi > 0$, that is $T(t) = T_0 \exp\{\varphi t\}$. Yet, this is a quite restrictive and rather unrealistic assumption. Some inventions can be considered path-breaking, while others increase the level of $T(t)$ only exiguously. The impact of some inventions is so strong that they allow for a multiplicity of adoptions and have a protracted influence on all industries. These inventions are called 'general purpose technologies' (GPTs).³ In the model of NELSON and PHELPS (1966), the invention of these technologies leads to an instantaneous leap of the technological front. This augments the technological gap and creates a large potential for factor productivity gains, given that the stock of human capital is sufficiently large enough to master the new technologies.

On the other side, the adoption of GPTs allows for a wide range of applications, improvements and variations. This leads to a quantity of innovations j^* in the ROMER (1986, 1987, 1990) model, while the thereby enabled improvements κ_{j^*} induces further growth stimuli in the approaches of AGHION and HOWITT (1992, 1998) and GROSSMAN and HELPMAN (1991).

Combining the basic ideas of NELSON and PHELPS (1966) and BENHABIB and SPIEGEL (2005) and the growth models of BARRO and SALA-I-MARTIN (2004), LUCAS (1988), ROMER (1990) and the Schumpeterian growth models, firm-level production can be described using the functional form

³HELPMAN and TRAJTENBERG (1994) emphasize three major attributes of a GPT: pervasiveness, an innovation spawning effect, and scope for improvement.

$$y_i = T [t - \omega((1 - \mu)h)] L_i^{1-\alpha} \sum_{j=1}^N (q^{\kappa_j} X_{ij})^\alpha \mu h^\beta, \quad (4)$$

where $\beta > 0$ describes the elasticity of production of human capital. In this simple model, growth of per capita incomes $\dot{y} = dy/dt$ is a function

$$\dot{y} = F \left[\dot{h}, \dot{T}, \dot{N}, \kappa_j, \dot{\mu} \right]. \quad (5)$$

Innovation activities create an increase in the stock of basic knowledge as a by-product and enhance the productivity of future research. This increase is freely available to all researchers, allows for no partial excludability and is nonrival in its utilization. Due to disembodied technological know-how flows, technological progress in one country augments the technological level of a second country, given that these countries are in interaction with each other. International trade and openness therefore enhance Ψ and thus boost growth.

The formulation of (4) illustrates how the growth rates of a steady state economy develop. Whenever the theoretical technological level rises, growth potentials emerge through two channels: first, technological inventions rise the potential for productivity gains. Enhancements of productivity have a direct effect on per capita growth in (4), as the output can be produced more efficiently. Second, technological inventions allow for marketable adoptions leading to $dN/dt > 0$ and thus triggering a growth stimulus in (1) and (4). These additional capital goods in turn enable improvements and variations κ_j that additionally rise y .

However, both of these mechanisms are determined by the level of human capital employed in the research sector and the ability of the human capital in the output sector to handle these new technologies. Even if low values of μ may close the technological gap more efficiently, this leads to a decline in human capital working in the output sector. If the human capital gap $h^g \equiv (1 - \mu)h - \mu h$ is large, then production will be negatively affected.⁴ Yet, the marginal effect of $\dot{\mu}$ is ambiguous and depends on the levels of the other variables. Even more important, if the *absolute* value of human capital h is not sufficiently large enough, neither the transformation of theoretical technological knowledge nor the adoption within the production process can be mastered. As ROMER (1990) points out, the creation of blueprints for new capital goods also crucially depends on the level of human capital. So for any value of μ , the innovation process outlined in (1) and (2) will be negatively affected by an insufficiently large stock of human capital, or, to be more precise, by a scant rate of human capital accumulation.

⁴ROMER (1990) illustrates the diffusion path of human capital between the research sector and the output sector, where relative wages determine the amount of human capital working in the particular sector.

The diffusion of technology

Radical innovations have strong impacts on growth, while their absence leads to periods with disproportionately gains of per capita income. The diffusion of a new technology j^* introduced in the sense of ROMER (1987) by a specific firm can be formulated similar to PETSAS (2003) using an epidemic model of the functional form

$$\frac{\dot{\pi}(t)}{\pi(t)} = \phi [1 - \pi(t)] , \quad (6)$$

where $\dot{\pi}(t) \equiv d\pi/dt$ gives the change of the fraction of industries using the new technology and ϕ denominates the rate of diffusion. The utilization of this class of ordinary differential equations is quite common modeling the diffusion of technology and is discussed intensely in THIRTLE and RUTTAN (1987). A more general case $\pi'(t) = \phi\pi(t) [\Pi - \pi(t)]$ describes the approximation to any upper limit Π . Since $\pi(t) \in (0, 1)$, the upper limit equals one in equation (6). For reasons of clarity, the time index henceforth will be disregarded. The diffusion of technology in (6) is very slow if π in relation to the upper limit is small. However, the speed of diffusion rises (approximately) exponentially up to a certain point. For high degrees of saturation, the marginal rate of diffusion converts to zero. The solution of (6) provides the fraction of industries using a new technology as a function of time. This function owns a sigmoid shape that can be described by

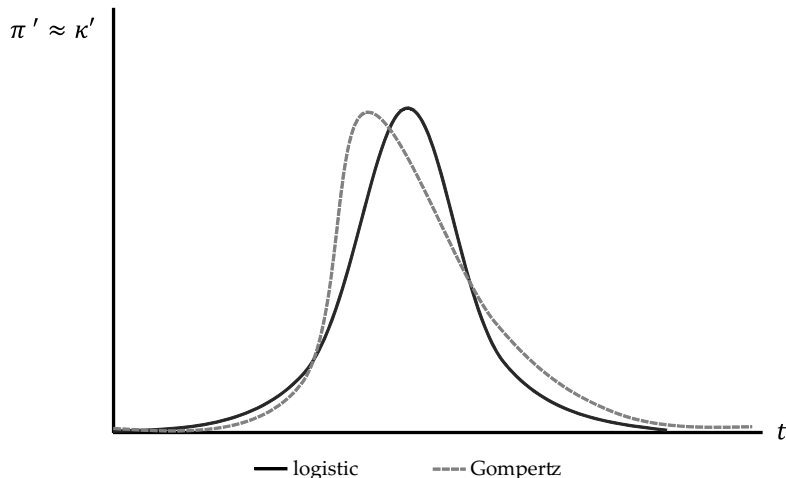
$$\pi = \frac{1}{(1 + \exp\{-(\gamma + \phi t)\})} , \quad (7)$$

where γ denotes the integration constant.⁵ In $t \rightarrow \infty$, each industry uses the new technology. The first derivative of (7) gives the growth rate of π . Consider that the new technology benefits each industry to the same extent. Suppose further that each industry owns a comparable fraction of entrepreneurs to potentially carry out improvements or variations κ_{j^*} . Then the development of the amount of improvements follows the growth rate of diffusion π' . Figure 3 illustrates this process. Depending on the assumption, the functional form can be based on various members of the class of sigmoid functions. While it is quite common to use a logistic function as suggested by (7), theoretical considerations may set an argument for a right-skewed Gompertz specification. This is because the potentials for improvements may never run out completely but become more and more irrelevant as new technologies replace the vintages.

The technological front T enables the introduction of j^* , that is an increase in N . The improvements and variations following this introduction develop according to figure 3. As described above, the extent of human capital crucially determines this process. Thus, the growth rate of a steady state economy is influenced by the theoretical technological level and may easily vary over time,

⁵See SYDSAETER and HAMMOND (2001) as well as PETSAS (2003) for the derivation of this solution of (6).

Figure 3: The rate of diffusion of new technologies



depending on the evolution of the factors described in (5). If the technological gap is small, the growth potentials are low. These situations occur whenever there is a lack of fundamentally new ideas. ROMER (1993) describes such a situation as an 'idea gap'. The same result emerges for large technological gaps that are accompanied by poor rates of human capital accumulation.

3 Empirical evidence: the case of Germany

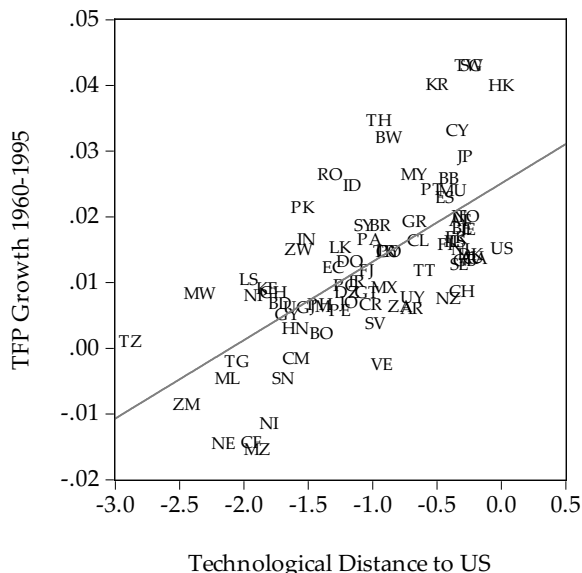
We learned from sketching some ideas of the neoclassical and endogenous growth theory that human capital and innovations are the main drivers of long-run growth. This section aims to answer two questions: can the importance of human capital and innovations be verified applying empirical data? And if so, how have these variables evolved in Germany and the developed economies? If human capital and innovations indeed are the key drivers of per capita increases in income, then a period with below-average growth rates must be attributed to exactly these concepts.

We will then address ourselves to the case of Germany and illustrate German post-war convergence as well as human capital accumulation and innovation activity and compare the results with the 25 richest economies in 2012.

Evaluating the theoretical predictions

One crucial hypothesis of the growth models presented in the previous section is that factor productivity growth is positively correlated with the technological gap, that is the difference between the theoretical and the practical level of

Figure 4: The technological gap vs. factor productivity growth



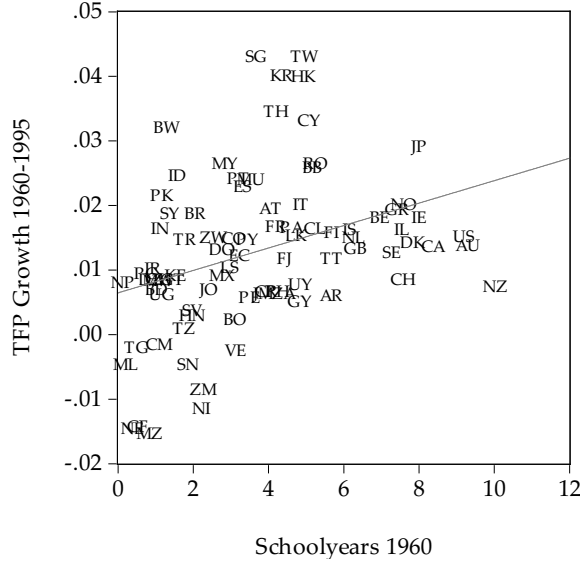
Data: BENHABIB and SPIEGEL (2005) and own calculations.

technology. The model also indicates that the transformation of technology provided by the research front into factor productivity depends on the amount of human capital. Figure 4 shows the average annual TFP growth between 1960 and 1995 and the technological gap in 1995 in a sample of 84 countries.⁶ As the United States can be considered the technological leader in the world, we set the theoretical technological front equal to the total factor productivity of the US. The technological gap is the logarithmic distance of the TFP of country i in relation to the TFP of the US, that is $T^g \equiv \log\left(\frac{TFP_i}{TFP_{USA}}\right)$. In many ways, this examination is similar to the catch-up hypothesis originally proposed by GERSCHENKRON (1962). Figure 4 illustrates that nations that have been able to close their technological gap did a much better job producing factor productivity growth. Nations that could not catch up with the technology of the US, such as Tanzania or Zambia, possess very poor TFP growth rates. The correlation between the variables in figure 4 is high (67 percent).

Figure 5 demonstrates the relationship between the average human capital endowment in 1960 and annual factor productivity growth between 1960 and 1995. Human capital is proxied using the average years of schooling. The correlation between the two variables is clearly positive, suggesting that economies with a higher stock of human capital tend to produce higher future rates of

⁶The selection of the countries and the time period is determined by the availability of data.

Figure 5: Human capital vs. factor productivity growth



Data: BARRO and LEE (2010), BENHABIB and SPIEGEL (2005) and own calculations.

factor productivity growth, holding all other determinants constant. Yet, the dispersion around the regression line is high. While Asian nations such as Taiwan, South Korea, Thailand, Hong Kong and Myanmar have been able to realize above-average TFP growth rates, some South and Central American Nations as well as a variety of African States, e.g. Venezuela, Nicaragua, Zambia, Mozambique and Niger, experienced poor TFP increases. The overall correlation of TFP growth and initial human capital is 36 percent.

A further hypothesis drawn in the theoretical section was the neoclassical prediction of conditional convergence. In addition, the models of ROMER (1986, 1987, 1990) and the Schumpeterian growth models emphasize the importance of horizontal and vertical innovations. We investigate these hypotheses building on BARRO (2003) who considers the empirical growth rate of per capita income a function

$$\frac{dy}{dt} = F(y_{t-\tau}, h, \Xi_{t-\tau}), \quad (8)$$

where $y_{t-\tau}$ denominates the logarithmic value of per capita GDP, lagged by $\tau \in (0, \infty)$ years. The matrix $\Xi_{t-\tau}$ containing an array of control variables, each lagged by $\tau \in (0, \infty)$ years, is of particular interest as it allows for the empirical examination of the theoretical hypotheses of the previous section. We estimate the marginal effects of (8) using 3SLS-Systems in a sample of 187 countries between 1965 and 2010. Each equation of the 3SLS-Systems contains five-year

averages, which is determined by the long-term perspective of growth regressions, the need to smooth short-term fluctuations and the availability of data. As data on physical capital endowment is unreliable due to inaccurate measures and the need to draw arbitrary assumptions on investment and depreciation, the interaction of the human capital stock with the initial level of per capita GDP proxies the stock of physical capital.⁷

Human capital is measured using educational attainment *YSCHOOL* and health *LIFEEX*, that is the life expectancy at age one. The matrix $\Xi_{t-\tau}$ further contains control and environment variables that reflect hypotheses from the neoclassical model and evidences from previous empirical estimations. *FERT* denominates the logarithmic value of the fertility rate, *GOVC* describes government consumption, *INS* names investment in dependence to GDP, *DEM* is a dummy variable that assumes the value of one if the country is democratically organized, and *HOF* is a rule of law index covering the extent of economic and political freedom. In order to attend to the specific environment of Sub-Saharan and Latin American countries, we include the dummy variables *SUB-SAHARA* and *LATIN AMERICA*. The most crucial variables for the investigation of this paper are patents in relation to GDP (*PAT*), citations in relation to GDP (*CIT*) and the openness *OPEN*. *CIT* comprises the amount of citations achieved by patents granted in a country within the respective five-year interval. The data sources of the variables are shown in table T.1 in the appendix.

Column (1) and (2) illustrate the results of the basic regression in the whole sample and in the restricted sample of rich economies in accordance to the classification of the World Bank respectively. Each of these regressions emphasize the effect of conditional convergence: when controlling for some variables that distinguish the countries, economies with lower initial GDP tend to grow faster than richer economies. As predicted by the standard growth model, population growth exerts negative effects on growth as *FERT* assumes a negative and significant coefficient. Human capital, on the other hand, is of great value in producing per capita increases: whereas *LIFEEX* has some effect in the sample of developed countries, school attainment is significant in each of the basic regressions. The political environment influences growth, even though the impact is less strong than the effect of other variables. As *DEM* is virtually irrelevant for growth, the rule of law index turns out to be significant in the basic regression systems.⁸ Latin American and sub-saharan countries presumably grow more slowly than other nations, the coefficient of *SUB-SAHARA* furthermore is significant in most cases. *GOVC* turns out to have some negative effects whereas the effect of the investment share can be neglected.

As we argued in the theoretical section, human capital is crucial for growth as it enables economies to close the technological gap and acts as a direct input factor in the production function. The results of table 1 emphasize the empirical

⁷See *BARRO* (2003) for a more intense discussion of the inadequacy of data covering physical capital stocks.

⁸See *BARRO* (1990), *BARNDT et al.* (2005), *ACEMOGLU* (2008) and *GUNDLACH and PALDAM* (2008a, 2008b) for an intense discussion on the effect of democracy.

Table 1: Results of the 3SLS growth regression

	(1)	(2)	(3)	(4)
	Basic system: all countries	Basic system: high income	Patents	Citations
constant	9,955*** [6,31]	11,372*** [5,26]	13,611*** [5,55]	18,125*** [6,08]
LOG(CGDP(t-1))	-0,979*** [-6,161]	-1,454*** [-9,18]	-1,684*** [-8,42]	-2,321*** [-8,21]
YSCHOOL	0,111* [1,85]	0,151** [2,45]	0,579 [0,79]	0,063 [0,74]
LIFEEX	0,013 [0,64]	0,055* [1,90]	0,043 [1,26]	0,085** [2,12]
FERT	-2,388*** [-6,45]	-1,77*** [-4,42]	-2,990*** [-5,86]	-3,590*** [6,87]
DEM	-0,031 [-0,12]	-0,036 [-0,13]	-0,186 [-0,46]	0,367 [0,81]
OPEN	0,008*** [3,61]	0,009*** [4,54]	0,012*** [3,61]	0,011*** [3,63]
HOF	0,195*** [2,99]	0,147** [2,07]	0,037 [0,39]	-0,021 [-0,20]
GOVC	-0,008 [-0,42]	-0,041* [-1,81]	0,015 [0,55]	-0,019 [-0,58]
INS	0,007 [0,73]	-0,004 [-0,26]	0,018 [1,11]	0,021 [1,00]
LATIN AMERICA	-0,102 [-0,43]	-0,260 [-0,98]	-0,176 [-0,53]	-0,439 [-1,13]
SUB-SAHARA	-0,746** [-2,55]	0,617 [1,22]	-0,949* [1,78]	-1,592** [-2,11]
PAT			2,10** [1,96]	
ZIT				0,13* [1,72]
N	900	530	602	332
R squared	0,24 0,31 0,08 0,34 0,58 0,27 0,33 0,36	0,25 0,58 0,26 0,45 0,73 0,50 0,64 0,46	0,37 0,56 0,13 0,34 0,56 0,36 0,41	0,61 0,16 0,41 0,70 0,40
S.E.	2,64 2,59 3,51 4,14 1,95 2,92 3,05 2,94	2,42 1,73 2,21 2,49 1,61 2,27 1,96 2,59	2,05 1,99 2,81 4,31 1,96 2,55 3,02	1,72 2,23 2,59 1,47 2,46

Notes: Method is 3SLS, t statistics are in parentheses. The independent variable in system (1) and (2) is per capita GDP growth in the periods 1970-1975, 1975-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005, 2005-2010. System (3) and (4) cover less equations due to data availability. System (3): 1975-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005, 2005-2010; system (4): 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005. Instruments are mainly lagged exogenous variables. Surplus instruments are primary school attainment PSCHOOL and the democratization index of VANHANEN (2012). R squared is the coefficient of determination of the particular 2SLS equation. *p<.10, **p<.05, ***p<.01.

effect on growth. The second and perhaps even more important determinant of long-run growth is innovation activity. Column (3) and (4) attend to the evaluation of the effect of patents and citations. Both results suggest that innovations indeed exert an important influence on growth as the coefficient of PAT in (3) and the coefficient of CIT in (4) are both positive and strongly significant. The level of the innovation activity apparently influences growth. Yet, table 1 proves that technical knowledge does not necessarily have to be created domestically. Spillovers from abroad in turn lead to an increase in factor productivity. The more open an economy is, the more it can benefit from internationally available technological knowledge. OPEN has a positive effect on income growth and is significant in each of the estimations in table 1.

The finding in this section can be summarized as follows: conditional convergence is an empirically well observable force. Nations that still benefit from convergence effects exhibit larger per capita growth rates of income. Once an economy has reached its steady state, human capital accumulation and innovation activities are the main drivers of welfare increases. The empirical analysis therefore strongly supports the theoretical hypotheses. Thus, the following discussion of the growth perspectives of Germany and the developed economies is based on exactly these three concepts.

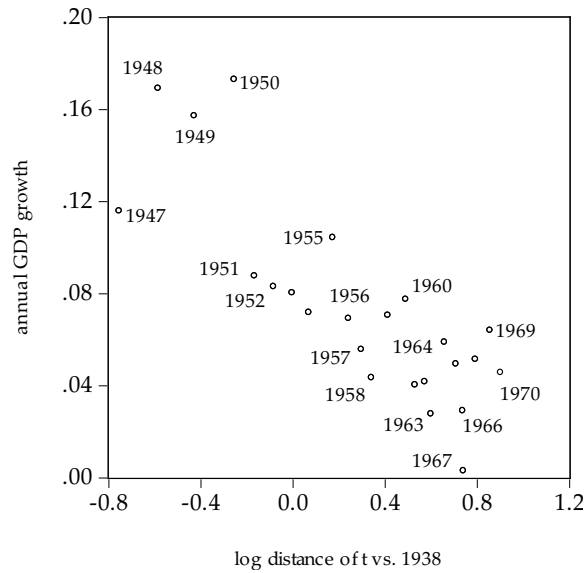
Post-war convergence in Germany

After World War II, the German capital stock has been severely destroyed. In the aftermath of the war, German production was only 38 percent of the prewar level.⁹ In accordance to the prediction of the standard growth model and the empirical evidences on conditional convergence, Germany subsequently experienced high growth rates of GDP. Figure 6 demonstrates how GDP growth has developed as the capital stock gradually recovered. The abscissa illustrates the logarithmic distance of output in period $t \in [1947, \dots, 1970]$ in relation to the prewar level in 1938, that is $\log\left(\frac{GDP_t}{GDP_{1938}}\right)$. The ordinate gives the associated growth rates in t . The correlation is strongly negative (-83 percent). This indicates that growth rates have been exceptionally high when the capital stock was heavily destroyed. Yet, as output approximates its prewar level, the growth rates declined. By the end of the 1960s, the effects from convergence expired. This result explains the first major decline of German growth rates around the year 1970. From the 1970s on, German output had fully recovered from the effects of World War II. The average German growth rate between 1918, the end of World War I, and 1939, the beginning of World War II, was 2.7 percent per year.¹⁰ Assuming that without war, the German economy would have continued to grow at this rate, it is easy to calculate a hypothetical growth path. Comparing the realized output with that hypothetical path shows that production resembled the hypothetical level for the first time in 1971.

⁹Data source: MADDISON (2013).

¹⁰Data source: MADDISON (2013).

Figure 6: Postwar convergence in Germany



Source: SMOLNY (2000), MADDISON (2013) and own calculations.

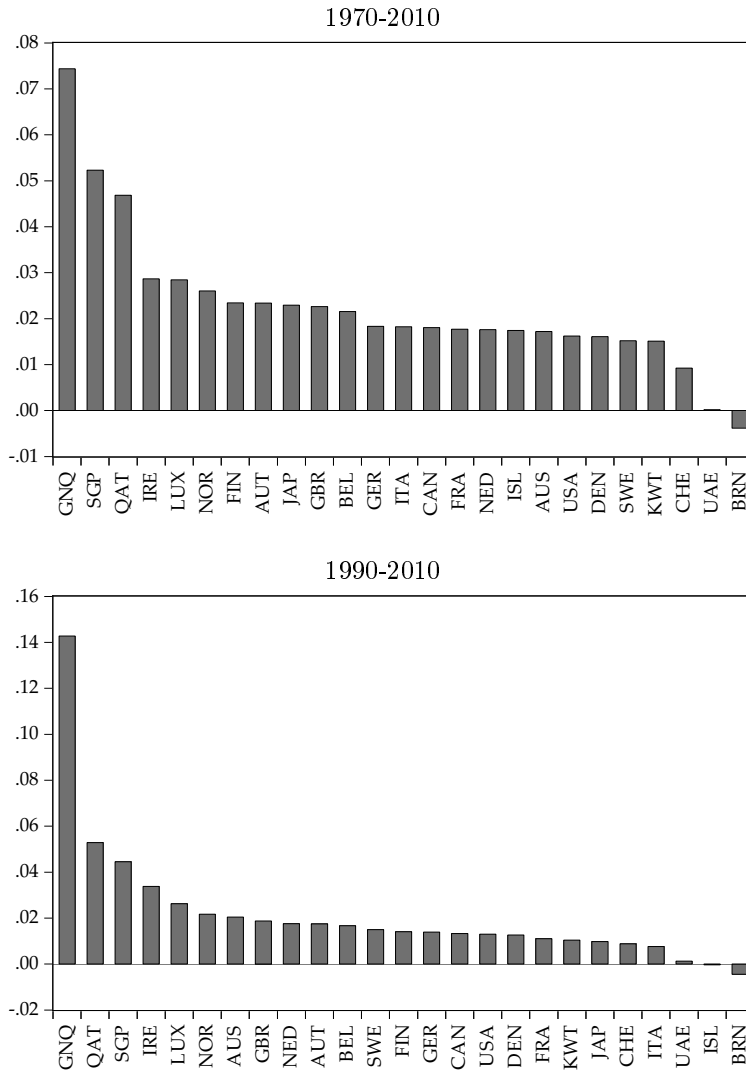
The findings in this section suggest that any comparison of historical growth rates in Germany may only take the period from 1970 into consideration. In addition, it follows that German growth rates may only be compared with per capita increases of developed countries that in turn have already approximated their individual steady state level. For this reason, we analyze the German situation and the development of the crucial determinants of long-run growth within the group of the 25 richest countries of the world.

Germany and the top 25 economies

The 25 richest countries in terms of GDP per capita in 2012 were (in descending order) Luxembourg, Qatar, Singapore, Norway, Kuwait, Brunei, Switzerland, the United States, the United Arab Emirates, the Netherlands, Austria, Ireland, Sweden, Denmark, Canada, Australia, Germany, Belgium, Finland, Iceland, Equatorial Guinea, the United Kingdom, France, Japan and Italy.¹¹ Germany ranks at the 17th position in this list. This sample includes some countries whose wealth is entirely based on oil, such as Brunei, Equatorial Guinea, Qatar and Kuwait. In order to investigate general growth mechanisms, there is much reason to leave these countries out of consideration.

¹¹This classification is based on data of WORLD BANK (2012a) and considers the average of per capita GDP between 2005 and 2011.

Figure 7: Per capita GDP growth of the top 25 economies



Data: HESTON et al. (2012).

Figure 7 illustrates the average annual growth rate of the top 25 economies within the periods 1970-2010 and 1990-2010. Neglecting the oil-exporting countries, the average growth rate of the top 25 was 1.92 percent (1970-2010) and 1.49 percent (1990-2010) respectively. Growth in the developed countries declines in nearly each economy. Only 6 of the top 25 nations succeed to grow at an average rate of 2 percent or higher between 1990 and 2010, two of them only by the export of oil. Obviously, the phenomenon of declining growth rates is not a specific German problem but can be identified in almost all developed countries. Within the group of the top 25, German growth rates almost exactly correspond to the mean (1.83 percent in 1970-2010 and 1.39 percent in 1990-2010). The t-test indicates that there is no statistically significant difference between the German growth rate and the mean value of the top 25.¹²

Human capital accumulation in Germany

The results of our 3SLS regression support our theoretical hypothesis that human capital is crucial for economic growth. As expected, the influence of human capital intensifies in developed countries. The coefficient of school attainment increases and becomes more significant considering the restricted sample of rich economies. In addition, the coefficient of life expectancy turns out to be significant only when analyzing developed countries.¹³ One important dimension of human capital is schooling. Yet, not only school attainment but also schooling quality can be expected to influence growth. Especially in the sample of developed countries where school attainment is highly comparable, schooling quality distinguishes the countries. Figure A.2 in the appendix illustrates the link between schooling quality as measured by PISA scores, TIMSS scores and the index of cognitive skills of HANUSHEK and WOESSMANN (2012). There is strong evidence that the quality of education determines the level of per capita incomes. Figure 8 shows the differences in schooling quality between the top 25 economies. The dotted line marks the median value of the sample. Apart from the good mathematical skills measured by the TIMSS and the high science scores obtained in the PISA study, Germany ranks below the median in every other category. Overall, Singapore, Finland, Canada and Japan achieve the highest test scores. Does Germany invest too little in education? Figure A.3 illustrates that educational expenditures in percent of GDP in Germany are considerably below the median. It is noticeable, however, that countries such as Singapore and Japan, whose test results turn out to be very positive, invest a relatively small share of GDP in the education sector. The United States, on the other hand, make higher investments in the education system than the median. The education outputs nevertheless are below average. These results suggest that a mere increase in educational expenditures does not necessarily lead to an improvement in schooling quality. In general, the correlation between

¹²The test gives $p = .6156$.

¹³See BERTHOLD and GRÜNDLER (2012) for an explanation on the insignificance of life expectancy in the basic sample.

education expenditures is moderate (PISA math: 36 percent, PISA science: 27 percent).

The German deficits in human capital accumulation are very likely to sharpen in the future. First, the German population on average is relatively old. Figure A.3 shows that Germany owns the second highest fraction of people over 65 years (20.6 percent), only surpassed by Japan (23.4 percent). Second, the fertility rate in Germany (1.39) is significantly below the median value (1.87) of the top 25. As denoted in the theoretical section, the decision of an individual to invest in human capital depends on the duration of the payments of the returns to education. As the population gets older, these incentives decline. The high average age of the German population reduces the incentives of an individual to invest in his own human capital, while the decline of the fertility rate reduces the potential future human capital stock of the whole economy. Human capital thus will accumulate at an even lower rate in the future. Yet, as the theoretical models considering the technological gap as well as the empirical results suggest, declining rates of human capital accumulation decelerate long-run growth.

The regression in table 1 furthermore suggests that health is an important dimension of human capital, at least in the sample of developed countries. The most common indicator denoting health is life expectancy at age one.¹⁴ Despite of the old population, the average life expectancy in Germany is low and below the median of the top 25 (see figure A.3 in the appendix). Citizens of countries such as Australia, Canada, Iceland, Japan and Switzerland on average are much healthier. Hardly surprising, the oil-exporting countries prove to be major outliers in this statistic, as the wealth of these nations is unequally distributed among the population. For example, the GINI coefficient in Equatorial Guinea is about 50 percent.¹⁵

The considerations above illustrate that human capital consists of an array of different facets of which schooling quality is only one. Combining schooling quality with health, fertility and demography provides a more detailed index of human capital summarizing the arguments previously expressed. Let μ_x and σ_x be the empirical mean respectively standard deviation of variable x . We create an index of human capital \tilde{h} that covers the sum of the normalized distances to the mean value of the key dimensions of human capital as

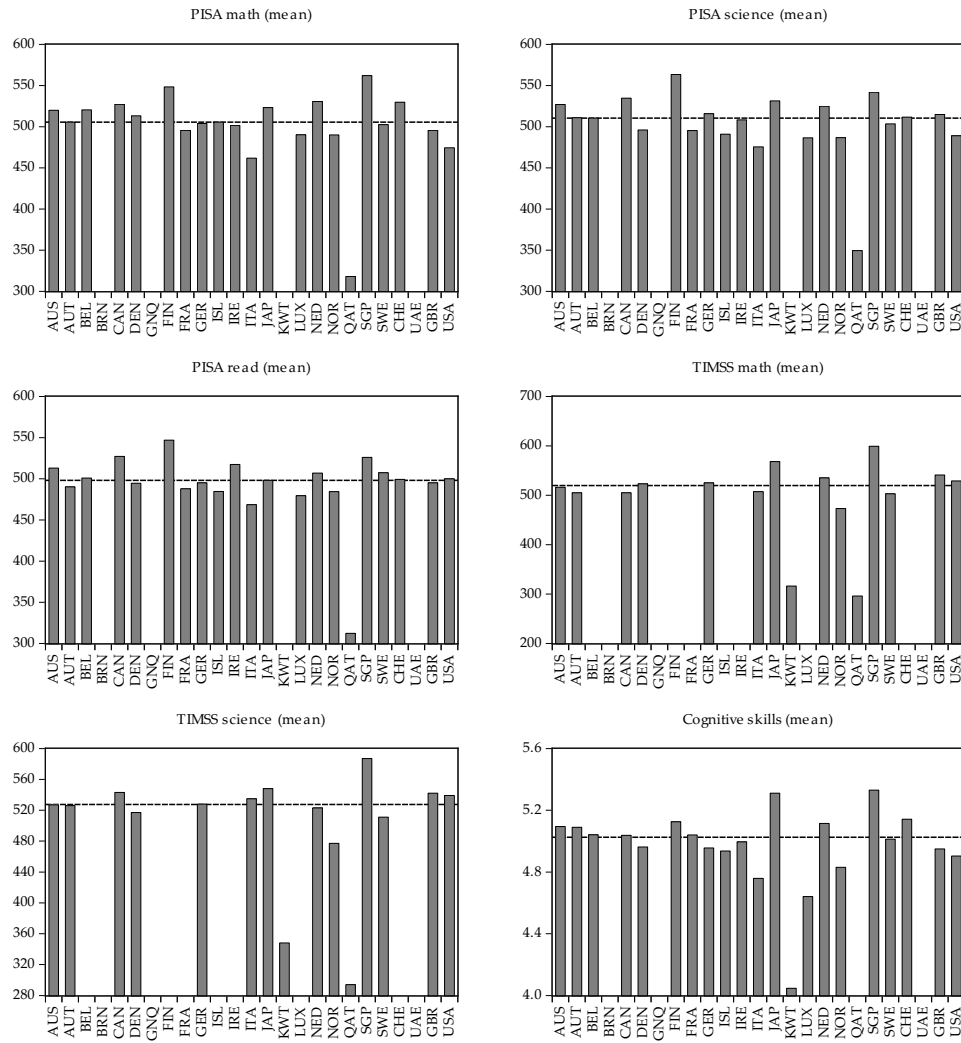
$$\tilde{h}_i = \left[\frac{\text{FERT} - \mu_{\text{FERT}}}{\sigma_{\text{FERT}}} + \frac{\text{LIFEEX} - \mu_{\text{LIFEEX}}}{\sigma_{\text{LIFEEX}}} + \frac{\text{MAT} - \mu_{\text{MAT}}}{\sigma_{\text{MAT}}} - \frac{\text{OLD} - \mu_{\text{OLD}}}{\sigma_{\text{OLD}}} \right] - \min(\tilde{h}_i),$$

where MAT denominates the mean value of mathematical skills as measured by PISA and OLD gives the fraction of the population that is of age 65 or older. The normalization of the particular distance ensures that each determinant contributes to \tilde{h} with the same weight, regardless of the underlying scaling. The index is furthermore adjusted by the minimum value of the countries in the sample to fit the domain $(0, \infty)$. Figure 9 plots this measures against the average rate of real per capita GDP growth in the period 2000-2005. The time span

¹⁴See BERTHOLD and GRÜNDLER (2012) and ARORA (2001) for a discussion of the most appropriate age at which life expectancy should be measured.

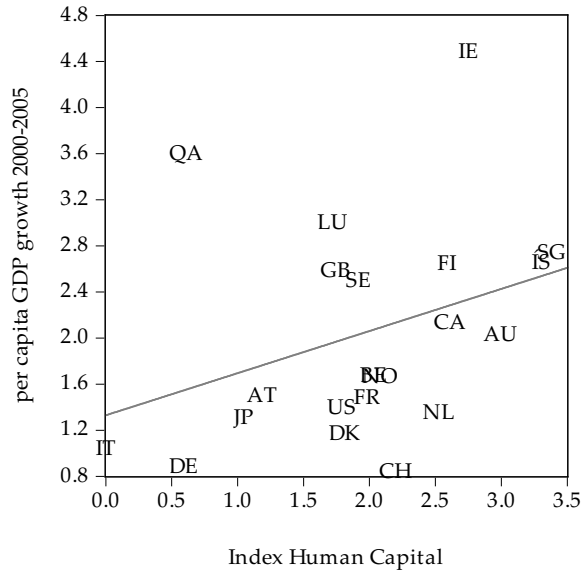
¹⁵See UTIP (2012).

Figure 8: Schooling quality in the top 25 economies



Source: HANUSHEK and WOESSMANN (2012), WORLD BANK (2013b) and own calculations.

Figure 9: Human capital index vs. per capita GDP growth 2000-2005, top 25 economies



Source: WORLD BANK (2013a, 2013b), HESTON et al. (2012) and own calculations.

ends in 2005 to keep the distortive effects of the financial crisis away from the examination.

Due to data availability, figure 9 does not include all the top 25 economies. Nevertheless, Germany performs very poorly in this comparison. The human capital index assumes the second lowest values of all countries in the sample. Only Italy turns out to be less equipped with human capital. The correlation of the human capital index and GDP growth is clearly positive. Yet, there are some interesting outliers: Ireland and Qatar have been able to boost production by a rate that considerably exceeds the theoretically possible increase, given their stock of human capital. As for Qatar, it is very likely that the outstanding growth rates can be attributed to the export of oil. On the other side, countries such as Germany, Japan, Denmark, the United States, Italy and Switzerland grew at a rate that is behind its potential. Even so, if Germany could have managed to realize the full growth potential emerging from the human capital stock, per capita GDP growth would still lag behind. The reason is the potential itself: the low fertility rate, the substandard health, the below-average test scores and the old population lead to a comparatively low value of \tilde{h} . Neither of these factors can be expected to enhance in the medium term. Human capital induced growth potentials in Germany are thus quite small.

Innovation activity in Germany and the world

The results of table 1 provide strong evidence that the innovation activity exerts a considerable influence on growth. The results also suggest that international spillovers matter and that factor productivity and capital goods may also be imported from abroad, given that domestic human capital is capable of mastering the internationally available knowledge. We already mentioned in the theoretical section that inventions may occur randomly over time. Especially when it comes to GPT, the technological frontier may evolve in leaps. On the other hand, in times when research only provides little progress, T may develop in small, continuous steps. It is important, however, that the technological front is not country-specific. In fact, if economies and societies are closely linked, T is composed of technological and scientific contributions of a large number of countries. While this potential is equal for each country, the adoption of the technology differs between the economies. We already mentioned that the ability to close the technological gap depends on the human capital stock. The crucial question here, however, is: how does the potential itself develop and how does factor productivity evolve?

When new GPT arise, the potential for new capital goods, their improvements and variations increases. The diffusion of technology as discussed in section 2 indicates that, with some time lag, the number of new capital goods will strongly increase. In the models of horizontal innovations, this leads to $\frac{d^2 N(t)}{dt^2} > 0$. This, in turn, enables a plurality of improvements and variations κ_j . As the costs of investing in κ_j are much lower than in investing in j^* , the tendencies to adopt entirely new technologies will regress. As the κ th step is easier to achieve than the $(\kappa + 1)$ th step, improving and varying existing capital goods will gradually become more difficult. At some point in time, the prospect of a monopolistic position will encourage entrepreneurs to invest in the pent-up inventions. This consideration incited a variety of authors, such as SCHUMPETER (1911, 1939) and - in more recent times - HELPMAN and TRAJTENBERG (1994) and BRESHNAHAN and TRAJTENBERG (1995), to argue for a relapsing development of the innovation activity.

We examine the development of the historical innovation activity using patent data from the United States, Germany and the World between 1790 and 2011. The elimination of the trend will be achieved using a polynomial of the functional form

$$\log(\rho)_t = \alpha + \sum_{n=1}^{\mathfrak{N}} \beta_n \tau_t^n + \varepsilon_t, \quad \mathfrak{N} = 1, \dots, 4, \quad (9)$$

where τ^n denominates the n th degree trend variable.¹⁶ The residuals of this estimation illustrate the up- and downturns in the innovation activity. In order to smooth short-term fluctuations, we use moving averages of ξ th degree. The innovation index thus is

¹⁶The selection of n refers to the minimization of the exceeding probability.

$$\Lambda(t) \equiv \bar{\varepsilon}(\xi) = \frac{\varepsilon_t + \varepsilon_{t-1} + \dots + \varepsilon_{t-(\xi-1)}}{\xi}. \quad (10)$$

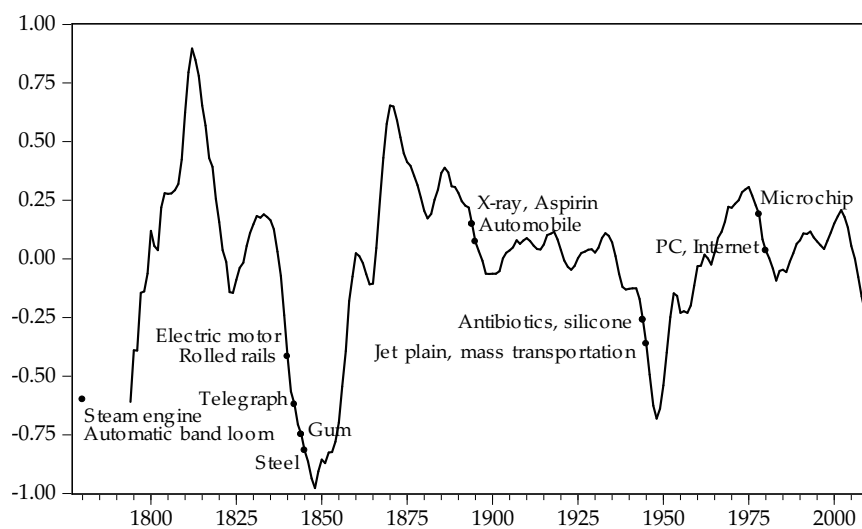
We mentioned in the theoretical section that the diffusion of GPT can be modeled using a logistic or Gompertz function and that the amount of improvements and variations of that technology follow the first derivative of these functions. We denoted such a cycle with κ' . Hence, we assume that $\Lambda(t)$ corresponds to concatenations and overlaps of these κ' cycles.

Figure 10 illustrates the innovation index $\Lambda(t)$ with $\xi = 5$ and pictures the time points at which major inventions appeared. The growth of patent applications in the past evidently was subject to strong fluctuations. These fluctuations have many similarities with the diffusion cycles considered in the theoretical section. Comparing the variations with the occurrence of GPT, it appears that patent applications rose above-average whenever radically new inventions appear. Yet, it emerges as a clear empirical regularity that the increase in patent application occurs only after a time delay of 5-10 years. This lag may occur due to time requirement for the development of new infrastructure and the necessary skills. The delay corresponds to our theoretical hypothesis and militates in favor of a sigmoid shape of the diffusion function of GPT. Some time after the adoption of the new technology, the potential of transfer applications and improvements is exhausted. The models sketched in the theoretical section indicate that this will ipso facto lead to a slowdown in growth.

Since different methods of detrending can easily yield divergent results, figure A.4 in the appendix compares the innovation index $\Lambda(t)$ with a comparable index using the HP filter. It occurs that the shape of the curve is very similar, although some fluctuations tend to be less pronounced. Figure A.4. furthermore compares $\Lambda(t)$ with the German innovation index, gathered by applying the same method described above using patent data from Germany. The German index follows $\Lambda(t)$ with some delay. Yet, at the end of the examination period, the delay shrinks. The time delay between $\Lambda(t)$ and the German cycle further argues for the sigmoid diffusion of technology. As many inventions pictured in figure 10 have their origin in the United States, international spillovers cause the innovation index in Germany to rise with some delay.

What is the growth potential currently provided by the innovation index? Figure 10 clearly demonstrates that the innovation activity declined since the early 2000s. The HP filtered innovation cycle and the German innovation index (both illustrated in A.4) support this assessment. In addition, figure 11 pictures the innovation index of the world, derived by the method described in (9) and (10) using aggregated worldwide patent data. This index reveals a similar turning point in patent application growth around the year 2000. As there may be some arguments that patent data must be considered biased and inappropriate to gauge the 'real' innovation activity, it is still the only variable available for a huge sample of countries and a sufficiently long time span. Nevertheless, it is useful to compare the results to other innovation indicators to not jump to conclusions. Figure 11 shows the HP filtered trend of the multifactor productivity in the United States and the top 25 economies. The limited time span

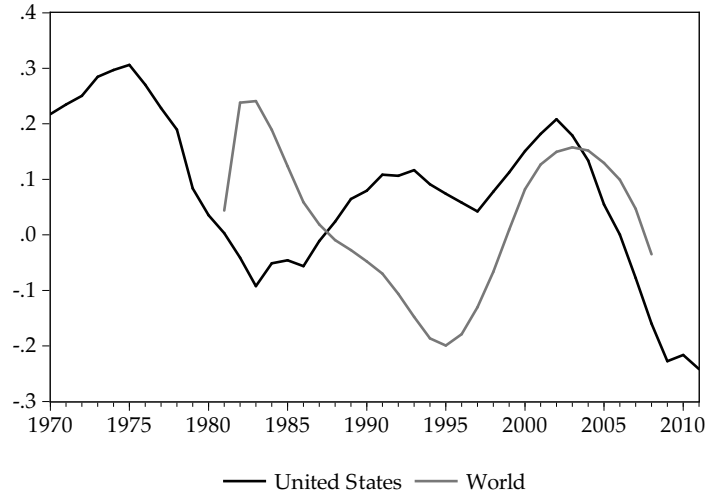
Figure 10: Innovation index, USA, 1790-2011



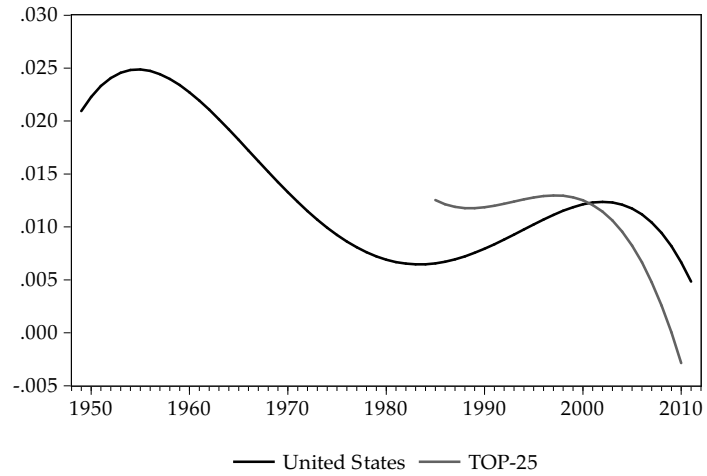
The dating of the GPT is based on HAUSTEIN und NEUWIRT (1982), VAN DUIJN (1983), SILVERBERG und VERSPAGEN (2003) and GORDON (2012). The timing of the emergence of the railroad refers to the invention of the rolled rails, while the steam locomotive has been developed in 1824.

Source: US PATENT AND TRADEMARK OFFICE (2013) and own calculations.

Figure 11: Innovation activity in the United States, the top 25 and the World
 Innovation activity: US vs. World (Polynomial)



Multifactor productivity (HP trend)



Source: OECD (2013a, 2013b), BUREAU OF LABOR STATISTICS (2013),
 WORLD INTELLECTUAL PROPERTY ORGANIZATION (2013) and own
 calculations.

refers to the availability of data. As both indicators illustrate a strong negative trend, the downturn strengthens around the year 2000. The short recovery period around 1980 is also very similar to the evolution of $\Lambda(t)$. At large, the development of the multifactor productivity in the United States and the top 25 confirm the hypothesis that innovation activity has declined since the early 2000s.

GORDON (2012) argues that faltering innovations currently lead to a slowdown of the US growth rate. Our results strongly support this assumption. Yet, the consequences for growth in the top 25 and Germany are alarming. NIKULAINEN and KULVIK (2009) provide some evidence from Finland that nanotechnologies have the potential to be widely applicable and to influence the economies similar to recent GPTs. YOUTIE et al. (2008a, 2008b) also come to the conclusion that nanotechnology may be a breakthrough innovation with long-run growth potentials. Figure 10, however, illustrates that the effects of such a new technology emerge only with a significant time lag. Even if nanotechnological applications were already marketable - which is highly questionable - the diffusion process would take years to exert positive effects on long-run growth.

4 Conclusions: The explanation of the German growth crisis

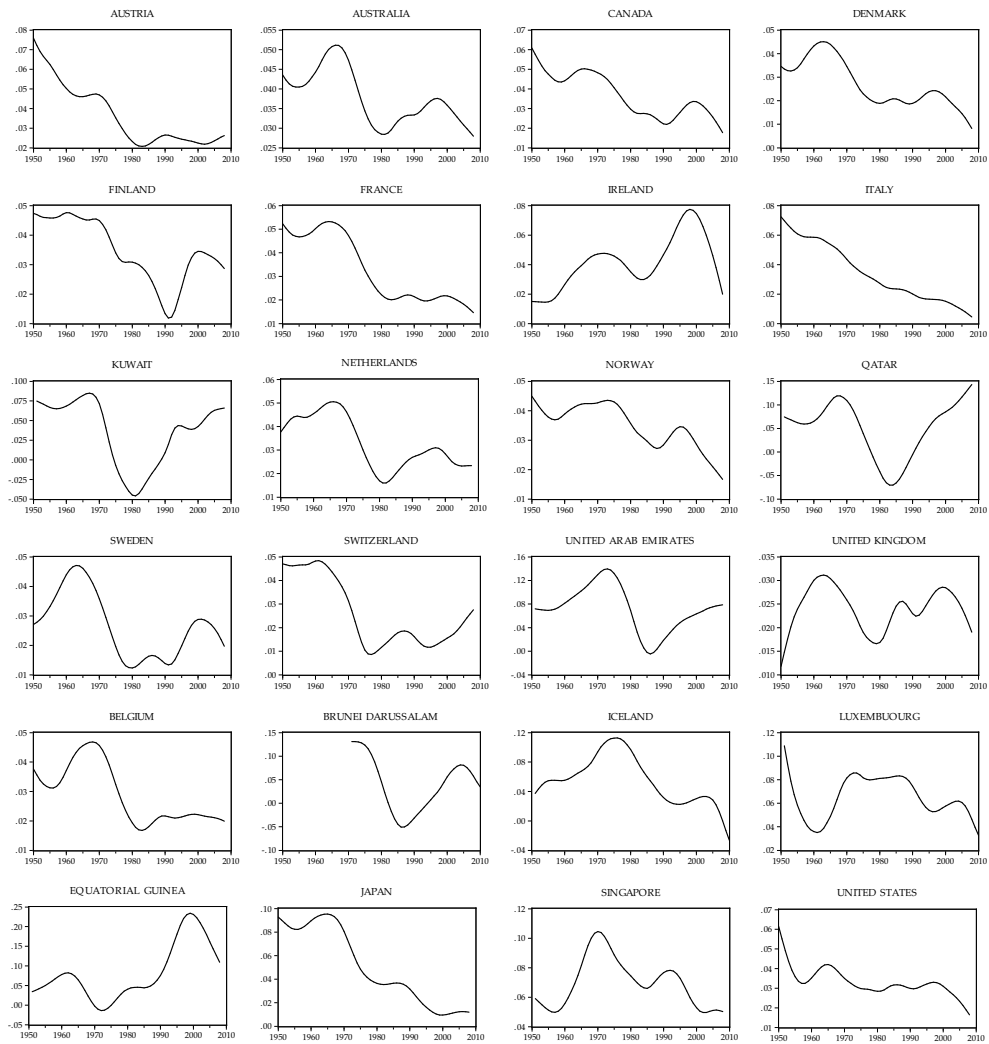
Considering the findings of this paper, we can summarize the explanation of the German growth crisis as follows: first, the high rates of per capita growth during the 1950s and 1960s must almost entirely be attributed to convergence. As these effects expired in the early 1970s, the German growth rate significantly declined and settled down at a more or less stable level at about 2 percent per year. Economists long considered this rate as the German steady state growth rate of income. Yet, it turns out that this rate refers to a period in which technical knowledge evolves above average. As the innovation activity declined by the year 2000, so did the growth rates. There is much evidence that the global economy runs out of radically new ideas that enable the creation of new growth-boosting capital goods, their improvements or varieties. The positive effects of the ICT-revolution, mainly the internet, have vanished. As this reduces the growth of the technological front, the potential of factor productivity increases and the creation of new or improved capital goods declines. This leads to a general decline in growth rates across all developed countries. The growth crisis may be amplified by some developments that currently take place in the world economy. PHILIPPON (2010) and BOLTON et al. (2011) for example find that a financial sector that is too large in relation to the real economy might depress economic growth by attracting too many talented people and thus leading to misallocations. The huge increases of the financial sector in the past decades thus may also contribute to the growth crisis to some extent, while the major part of the slowing income increases must be attributed to a lack of new ideas.

Yet, considering the case of Germany, there is a further alarming development: human capital turns out to exert a strong influence on growth, partly because it operates as a direct input factor in the production function, partly because it enables an economy to close the technological gap. Germany, however, severely lags behind the group of the top 25 in terms of human capital accumulation. Analyzing the test scores of PISA and TIMSS as well as the cognitive skills measured by HANUSHEK and WOESSMANN (2012), Germany is clearly behind the mean value. The demographic development is an occasion to suspect that human capital increases in the future will be even lower.

The combination of human capital and innovations explains the German situation quite well: the backlog in human capital leads to - at best - mediocre growth rates within the sample of the 25 richest countries of the world. However, the group of developed countries in turn struggles with the absence of radically new ideas, leading to a decline in the innovation activity and thus to a decline in long-run growth. Increasing human capital would enhance German growth and improve the position in the group of developed countries. Yet, this potential is restricted to the evolution of the technological front. As the innovation index suggests that improvements and variations of existing goods currently require great effort, the incentives to invest in entirely new technologies are likely to rise. Nanotechnology is already regarded as a new GPT with profound economic potential. If the effects of such a basic invention reach the economies after some time delay, growth rates similar to those between 1970 and 2000 are easily possible. Yet, a prosperous phase similar to the 1950s and 1960s in Germany still remains utopian in the future.

Appendix

Figure A.1: Trend in growth rates, top 25, 1950-2010, HP filter
(lambda=100)

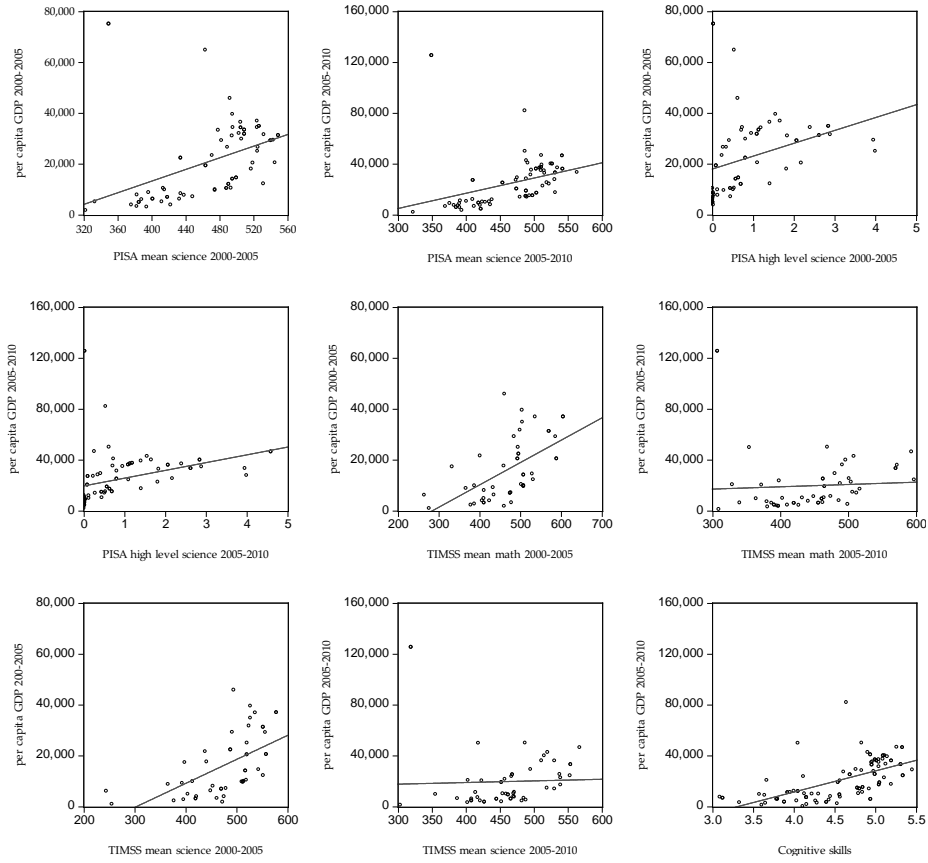


Source: HESTON et al. (2012), MADDISON (2013) and own calculations.

Table T.1: Data sources

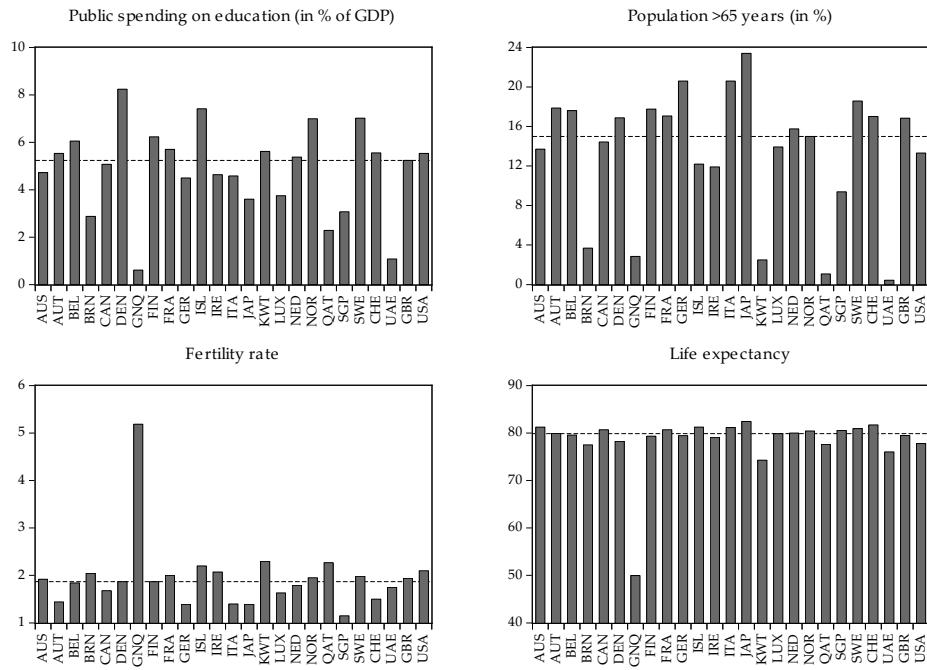
Variable	Data Source
dy/dt	HESTON et al. (2012)
LOG(CGDP)	HESTON et al. (2012)
SCHOOLY	BARRO and LEE (2010)
LIFEEX	WORLD BANK (2012)
LOG(FERT)	WORLD BANK (2012)
DEM	UTIP (2012), VANHANEN (2012)
OPEN	HESTON et al. (2012)
HOF	FREEDOM HOUSE (2011)
GOVC	HESTON et al. (2012)
SUB-SAHARA, LATIN AMERICA	Own calculations, classification of WORLD BANK (2012)
PAT	WORLD BANK (2012)
CIT	HALL et al. (2001)

Figure A.2: Schooling Quality and Growth



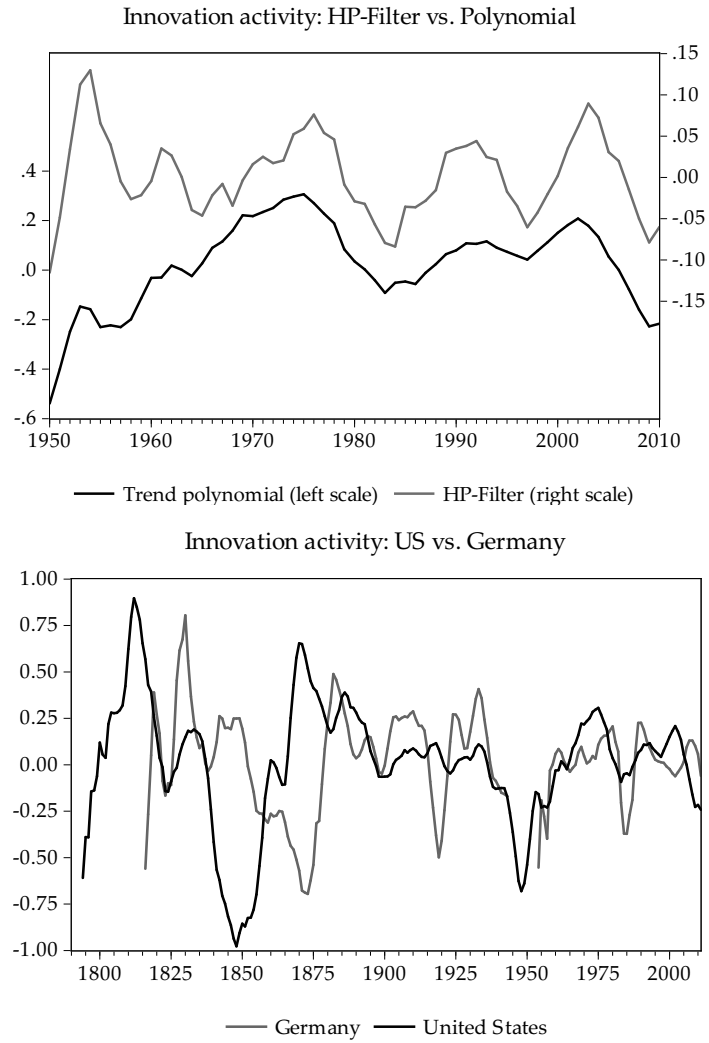
Source: HESTON et al. (2012), WORLD BANK (2013b), HANUSHEK and WOESSMANN (2012) and own calculations.

Figure A.3: Descriptive statistics on human capital, top 25 economies



Source: WORLD BANK (2013a) and own calculations.

Figure A.4: Innovation activity in the United States and Germany



Source: US PATENT AND TRADEMARK OFFICE (2013), FEDERICO (1964), WORLD INTELLECTUAL PROPERTY ORGANIZATION (2013) and OECD (2013a).

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