Science, Innovation and National Growth

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Science, Innovation and National Growth

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Abstract:

This paper studies the effects of public research (publications) and innovation output (patents) on national economic growth with the help of a GMM panel regression including 114 countries. Effects on productivity growth and capital and labor inputs are distinguished. Furthermore, different time lags are examined for the various analyzed effects and two time periods as well as less and more developed countries are studied separately. The results confirm the effect of innovation output on productivity for more developed countries. Simultaneously, innovation output is found to have negative impacts on capital and labor inputs, while public research is found to have positive impacts on labor inputs.

Keywords: national growth, innovation, public research, growth

JEL Classifications: O11, O31, E10, C23

I. Introduction

In the literature on economic growth there is agreement that knowledge, technological advancement and industrial innovation are main drivers of economic growth. Since the path-breaking theoretical works by Romer (1986) and Lucas (1988) many works have shown empirically that R&D activities and innovations lead to economic growth (e.g., Cameron 1998, Coe & Helpman 1995, Goel et al. 2008, Madsen 2008, Akcomak & ter Weel 2009, Hasan & Tucci 2010, Madsen et al. 2010, Güloglu & Tekin 2012 and Nishioka & Ripoll 2012). Especially in developed countries research and innovations play a central role in the explanation of economic growth.

However, while the general relationship between research, innovation and growth is well documented, studies on the impact of public R&D expenditures on economic growth are rare (an exception is Goel et al. 2008). Governments contribute to R&D activities by subsidizing private R&D and by financing research within public research institutes and universities. The main aim of public research institutes and universities is the discovery of new knowledge and the publication of this knowledge, which makes it freely available worldwide. While public research does not in the first place intend to influence the economy, governments hope for impulses for the economy on the basis of public research. Various mechanisms exist that cause such an impact of public research on economic development. While plenty of studies exist that examine this impact on the level of firms and show that public research triggers innovativeness, productivity gains and growth in firms (e.g., Griliches & Lichtenberg 1984, Jaffe 1989, Acs et al. 1994, Audretsch & Lehmann 2005, Raspe & VanOort 2011 and Duschl et al. 2014), studies on the influence of public research on national economic growth provide a more mixed picture (Lee et al. 2011, Jaffe et al. 2013, Jin & Jin 2013 and Inglesi-Lotz et al. 2014). The impact of public research on economic growth seems to be more complex to detect on the national level.

This paper adds to the existing literature by studying the impact of innovation output (patents), which mainly reflects the outcome of private research and development activities, and scientific research (publications), which mainly reflects the outcome of public research activities, on growth. The paper goes beyond the existing studies in two main aspects: First, the effects of innovation and scientific research on growth are disentangled into the effects on productivity and the effects on production capacity in the form of changes in capital and labor inputs. Second, time lags in the effects of innovation and scientific research are explicitly considered and examined.

A standard GMM panel analysis with instruments is used on data for the years from 1974 to 2009 for 114 countries. Differences between less and more developed countries are repeatedly stated in the literature (e.g., Bond et al. 2010, Lee et al. 2011, Jaffe et al. 2013). Less developed countries show much lower innovation and scientific research activities. Therefore, various groups of countries are analyzed separately. In recent years more and more countries have begun to significantly contribute to the worldwide research activities, so that R&D expenditures have increased faster in developing countries than in developed countries in the last years (see, e.g., Lorenczik & Newiak 2012). As a consequence, the factors influencing growth change in time (Lu 2012). Therefore, two time periods, 1974 to 1991 and 1992 to 2009, are build and analyzed separately. Finally, patent data provides information on inventors as well as applicants, which allows to assign patents to countries on the basis of inventors or applicants. To answer the question of whether it is more important for national growth that innovations are developed or owned, both assignment principles are used and the results compared.

While no clear differences between inventing or owning innovations are found, clear differences are obtained between the groups of countries and between the time periods. Time lags of the effects are found to range between one and two years. Strong differences are found between the effects of innovation output and scientific research: While innovation output increases total factor productivity but decreases capital and labor inputs, scientific research increases innovativeness and labor inputs.

The reminder of the paper proceeds as follows. The next chapter contains the presentation of the underlying theoretical models, a discussion of the available empirical knowledge on the national, regional and firm level, and the deduction of the theoretical equations for the empirical estimation. The empirical approach and the used data is described in Chapter three. Chapter four contains the detailed presentation and discussion of the results. Chapter five concludes.

II. Theoretical background

II.1 Basic growth model

The usual approach for modelling the dependence of economic output (*Y*) on technology (*A*), capital (*C*) and labor (*L*) is a Cobb-Douglas function:

$$Y_{it} = A_{it} \cdot C_{it}^{\alpha} \cdot L_{it}^{\beta} \qquad (1)$$

with $\alpha+\beta=1$. Endogenous growth theory (Romer 1986, Lucas 1988, Romer 1990 and Aghion & Howitt 1992) has brought the attention to the importance of human capital and knowledge in the context of national growth. Human capital (*H*) is usually considered as an additional factor in the Cobb-Douglas function either as part of the labor term or as a factor on its own. Following the latter approach leads to:

$$Y_{it} = A_{it} \cdot C_{it}^{\alpha} \cdot H_{it}^{\gamma} \cdot L_{it}^{\beta}. \qquad (2)$$

Knowledge is usually assumed to be a major part of variable A_{it}. Therefore, activities, such as research and development, that increase the knowledge base of an economy enter the dynamics of A_{it}. Usual approaches (Jones 1995 and Young 1998) model the dynamics of technology (A_{it}) as a function of R&D inputs (R_{it}):

$$\frac{\dot{A}_{it}}{A_{it}} = \lambda \cdot R_{it}^{\sigma} \cdot A_{it}^{\text{theta}-1} \qquad (3a)$$

or

$$\frac{\dot{A}_{it}}{A_{it}} = \lambda \cdot \left(\frac{R_{it}}{Q_{it}}\right)^{\sigma} \qquad (3b)$$

where Q_{it} denotes the already reached product variety in the economy (see Madsen 2008 for a discussion and estimation of the two approaches). Madsen (2008) shows that Equation (3b) fits reality better.

Empirical studies of economic growth usually focus on the growth of the logarithm of output or GDP per capita as dependent variable. To this end, Equation (2) is transformed into:

$$\Delta\ln\left(\frac{Y_{it}}{P_{it}}\right)=\Delta\ln(A_{it})+\alpha\cdot\Delta\ln\left(\frac{C_{it}}{P_{it}}\right)+\gamma\cdot\Delta\ln(H_{it})+\beta\cdot\Delta\ln\left(\frac{L_{it}}{P_{it}}\right) \tag{4}$$

with P_{it} denoting the number of inhabitants and Δ standing for the difference between the value at time $t+1$ and the value at time t.

Equation (3b) can be transformed into

$$\Delta\ln(A_{it}) = \ln\left(\lambda\cdot\left(\frac{R_{it}}{Q_{it}}\right)^{\sigma}+1\right) = \ln(\lambda)+\ln\left(\left(\frac{R_{it}}{Q_{it}}\right)^{\sigma}+\frac{1}{\lambda}\right).$$

Given that Q_{it} is proportional to L_{it} (see Madsen 2008) and, thus, can be approximated as being proportional to P_{it}, and assuming that σ is approximately 1, the following equation results:

$$\Delta\ln(A_{it}) \approx \ln(\lambda)+\sigma\cdot\ln\left(\frac{R_{it}}{P_{it}}+x\right). \tag{5}$$

Similar equations are used in empirical studies (e.g., Coe & Helpman 1995 and Bilbao-Osorio & Rodriguez-Pose 2004). However, in these approaches a parameter x does not occur. Interestingly, this parameter can be interpreted in two ways. First, it can be simply seen as a mathematical necessity resulting from the mathematical formulation of the dependence between research and technological development. Without x no R&D activities would imply an infinitely large decrease in A_{it}. Second, if countries benefit from knowledge spillovers from other countries and all countries benefit in the same way from some knowledge 'in the air', such effects could also be reflected by x. Studying spillovers in detail is beyond the scope of this paper and has already been done in the literature (e.g., Coe & Helpman 1995, Glass et al. 2013). However, the approach taken here automatically considers spillovers that affect all countries to the same extent.

Inserting Equation (5) into Equation (4) results in:

$$\Delta\ln\left(\frac{Y_{it}}{P_{it}}\right) = \ln(\lambda)+\sigma\cdot\ln\left(\frac{R_{it}}{P_{it}}+x\right)+\alpha\cdot\Delta\ln\left(\frac{C_{it}}{P_{it}}\right)+\gamma\cdot\Delta\ln(H_{it})+\beta\cdot\Delta\ln\left(\frac{L_{it}}{P_{it}}\right). \tag{6}$$

Equation (6) builds the basis for the empirical analysis below, but in the following further equations are deduced for the factors in Equation (6) from empirical findings.

II.2 Research, innovation and growth

R&D activities are seen as the main driver of technological progress. Therefore, many studies in the field of economic growth examine the impact of R&D activities on growth or total factor productivity (e.g., Coe & Helpman 1995, Goel et al. 2008, Madsen 2008, Madsen et al. 2010a and Nishioka & Ripoll 2012). The results show that R&D inputs explain GDP growth and growth in total factor productivity. However, while some studies find only clear results for R&D inputs but not for patents (Madsen 2008, and Madsen et al. 2010a), other studies find positive effects for patents or for both (Akcomak & ter Weel 2009, Hasan & Tucci 2010 and Güloglu & Tekin 2012). Güloglu and Tekin (2012) find that R&D expenditures cause innovation success in the form of patents, which, in turn, cause economic growth. This seems to be a natural causal chain.

The usual measures for R&D expenditures include private and public expenditures. Focusing on public research activities leads to a less clear picture. Goel et al. (2008) distinguish federal, non-federal and defence R&D expenditure and find that federal R&D has a higher impact than non-federal R&D on growth. Other studies use publication activities to measure academic research output and estimate their impact on national economic growth (Lee et al. 2011, Jaffe et al. 2013 and Inglesi-Lotz et al. 2014). While Jaffe et al. (2013) find a significant relationship between publication output and economic growth, Lee et al. (2011) and Inglesi-Lotz et al. (2014) find no or little evidence for such a relationship.

In contrast, there are many studies that examine the effects of public research on a regional or firm level. All of them find a positive impact of public research activities on the innovativeness, productivity or growth of nearby firms (e.g., Griliches & Lichtenberg 1984, Jaffe 1989, Acs et al. 1994, Audretsch & Lehmann 2005, Schlump & Brenner 2010, Raspe & VanOort 2011, Broekel & Brenner 2011 and Duschl et al. 2014). Therefore, the literature on local effects clearly suggests that public research has positive impacts on innovation activities in the private sector and enhances productivity and growth there.

While public research primarily intends to increase the knowledge base, private R&D efforts are taken in order to produce innovations, mainly process and product innovations. These innovations can have two kinds of effects (Freeman et al. 1982, Antonucci & Pianta 2002, Hall et al. 2008 and Harrison et al. 2008; an overview on the evidence for different effects is given in Dachs & Peters 2014): Product innovations extend the range of available goods and are claimed and found to lead to employment increases, while process innovations increase productivity and are claimed and to lead to employment decreases. However, some studies find a less clear relationship between innovation and employment changes with a dependence on many other factors (Capello & Lenzi 2012). Furthermore, the time structure is usually not explicitly considered in these studies. Process innovations lead to productivity increases, which in the first run lead to a decrease in employment. However, as a consequence of higher productivity, the following increase in competitiveness might well lead to output growth, which in turn leads to employment growth in the medium run. Therefore, the results for process innovations are not conclusive. In the case of product innovations, studies on the firm level clearly find a positive impact on firm growth (Banbury & Mitchell 1995, Del Monte & Papagni 2003 and Yang & Lin 2007). Hence, it can be assumed that new products lead to an increase in output and, therefore, also in the used capital and labor inputs.

As mentioned above the temporal structure of these relationships is usually not explicitly considered in studies on national growth. On the firm level some studies exist: Ravenscraft and Scherer (1982) find a time lag of four years between R&D investments and firm growth. Kafouros & Wang (2008) study the impact of R&D investments on the performance of firms for different industries and find mainly time lags between one and six years. Schimke and Brenner (2014) find highest evidence for effects of R&D investments on next year's firm growth, but also effects in later years. A distinction between product and process innovations is missing in this literature. Hence, it can only be concluded that time lags in this context can be expected to range between one and six years. Considering the effects of innovations on labor inputs, negative effects can be expected to be rather immediate while positive effects can be expected to take somewhat longer to establish.

Since product and process innovations cannot be distinguished in the empirical analysis, it has to be assumed that all innovations measured by patents on a country level somehow represent a mixture of product and process innovations. The following hypothesis on the national level reflects the above arguments:

Hypothesis 1:

> *a) R&D expenditures impact on innovation output and, through this, indirectly influcence output growth.*
>
> *b) Innovation output has an immediate positive impact on productivity.*
>
> *c) Innovation output has a delayed (one to six years) positive impact on output growth, which comes along with capital and labor increases.*
>
> *d) The effect of innovation output on labor inputs is unclear, but should be rather negative in the short run (rather one to three years) and rather positive in the medium run (rather three to six years).*

This hypothesis is in line with the findings by Güloglu and Tekin (2012), who find that R&D activities positively affects innovation output and innovation output leads to growth.

As stated above, while knowledge is seen as an important factor in theoretical growth theories, the impact of scientific research on national economic growth does not clearly show up in empirical studies (Lee et al. 2011, Jaffe et al. 2013 and Inglesi-Lotz et al. 2014). Outside of the national growth literature the effects of scientific research are comprehensively studied and well-documented. Many studies give an overview on the various mechansims that underlie these effects (e.g., Fritsch & Slavtchev 2007). Four mechanisms are relevant in the context of this paper.

First, scientific research leads to knowledge that can be used in R&D activities. On the one hand, the results of scientific research are usually published and, hence, they are available worldwide. On the other hand, many studies have shown that knowledge is sticky and diffuses locally (Anselin et al. 1997, Beise & Stahl 1999, Adams 2002 and Bottazzi & Peri 2003). Hence, it can be expected that scientific research has a positive effect on national R&D activities and innovation outcomes. Since it takes some time for firms to use the published knowledge in their research activities and generate innovation output, a time lag can be expected. Finardi (2011) finds a time lag of three to four years.

Second, public research is often involved in private R&D activities either through contracted research or through collaboration. Most of these interactions take place within countries. This leads to the same prediction as the argument before: Public research should increase innovation outcomes. Again a time lag can be expected because public research supports R&D activities in firms in this case and above it has been argued that R&D activities of firms take time to result in innovations.

Third, researchers increase their competences and skills during their work in scientific research institutions and universities. Quite a share of these researchers move to companies after working some time in public research and transfer the obtained knowledge and skills to the private sector. Hence, it can be expected that scientific research has an impact on the human capital that is utilized in production activities in a country. Unfortunately, national statistics are only able to reflect human capital that is obtained in training and education programs and not human capital that is obtained in the form of experience on the job. Therefore, it is not possible to measure this kind of human capital. Nevertheless, scientific research can be seen partly as investment into human capital.

Fourth, the literature shows that public research contributes to the local entrepreneurial activity, especially in high-tech industries (e.g., Lowe 2002 and Djokovic & Souitaris 2008). New firms in this area are usually founded on the basis of new products, meaning that they enhance the product space. This should lead to an increase in output, capital and labor. Again some time lag can be expected because the establishment of a firm takes some time.

According to the above stated four effects, scientific research can be expected to have to following effects in the context of economic growth:

Hypothesis 2:

> *a) Scientific research triggers innovation with a time lag of some years (studies suggest a time lag of three to four years).*
>
> *b) Scientific research contributes to the building of human capital.*
>
> *c) Scientific research increases output, which comes along with capital and labor increases, with a time lag of a few years.*

The first effect is based on two mechanisms that are very well documented in the literature, so that this effect can be expected to be the strongest. The third effect should be the smallest because only a small share of all start-ups origin from public research.

II.3 Growth model including innovation and public research

As a final step of the theoretical discussion, the arguments from Section II.2 are included into the growth models from Section II.1. Three variables are used to reflect scientific research (K_{it}), R&D activities (R_{it}) and innovation output (I_{it}) in country *i* and year *t*.

Hypotheses 1a and 1b state that R&D activities increase innovation output and that innovation output, in turn, leads to technological advancement. This implies that the R&D expenditures in Equations (3a), (3b) and (5) have to be replaced by the innovation output (I_{it}). As a consequence, Equation (6) reads

$$\Delta \ln\left(\frac{Y_{\mathrm{it}}}{P_{\mathrm{it}}}\right) = \ln(\lambda) + \sigma \cdot \ln\left(\frac{I_{\mathrm{it}}}{P_{\mathrm{it}}} + \mathrm{x}\right) + \alpha \cdot \Delta \ln\left(\frac{C_{\mathrm{it}}}{P_{\mathrm{it}}}\right) + \gamma \cdot \Delta \ln(H_{\mathrm{it}}) + \beta \cdot \Delta \ln\left(\frac{L_{\mathrm{it}}}{P_{\mathrm{it}}}\right). \qquad (7)$$

The arguments above imply that innovation output (Hypothesis 1c) and public research (Hypothesis 2c) have a somewhat delayed impact on output growth. However, this output growth is connected to growth in capital and labor, because new products are generated. Hence, the effects stated in Hypotheses 1c and 2c do not alter Equation (7).

According to the above arguments, innovation output depends on R&D activities (Hypothesis 1a) and public research (Hypothesis 2a) in the past. Furthermore, the growth literature as well as the literature on regional innovation systems usually assume that human capital matters for innovation output. The usual Cobb-Douglas formulation of the knowledge production function is used here (Griliches 1979). Assuming that the already reached level of innovation output might matter, the change in innovation output can be written as

$$\Delta \ln\left(\frac{I_{\mathrm{it}}}{P_{\mathrm{it}-1}}\right) = \mu_I \cdot \ln\left(\frac{I_{\mathrm{it\text{-}1}}}{P_{\mathrm{it}-1}}\right) + \mu_R \cdot \Delta \ln\left(\frac{R_{\mathrm{it\text{-}a}}}{P_{\mathrm{it}-a}}\right) + \mu_H \cdot \Delta \ln(H_{\mathrm{it}}) + \mu_K \cdot \Delta \ln\left(\frac{K_{\mathrm{it\text{-}b}}}{P_{\mathrm{it}-b}}\right), \qquad (8)$$

where *a* and *b* stand for the time lags of these effects and μ_I, μ_R, μ_H, and μ_K are parameters.

Besides the effects on technological advancement, Hypothesis 1c implies that innovations also lead to an extension of the production capacities, implying increases in capital and labor. In the case of labor this effect might be counterbalanced by technical labor substitution (Hypothesis 1d). Of course, innovations do not literally increase capital and labor, but according to the arguments above innovations motivate firms to enlarge their production capacities. The same effect is stated for public research above (Hypothesis 2c). Hence, it can be expected that the relative increase in capital depends on innovation success or public research before:

$$\frac{\Delta\frac{C_{\mathrm{it}}}{P_{\mathrm{it}}}}{\frac{C_{\mathrm{it}}}{P_{\mathrm{it}}}} = \nu_C \cdot \frac{I_{\mathrm{it}-a}}{P_{\mathrm{it}-a}} + \eta_C \cdot \frac{K_{\mathrm{it\text{-}b}}}{P_{\mathrm{it}-b}}, \tag{9}$$

where ν_C and η_C are parameters and *a* and *b* stand for the time delays of these effects.

Similar to the above statements on capital inputs, it has been argued above that innovation and knowledge creation also influence labor inputs (Hypotheses 1c, 1d and 2c). The predictions on whether the impacts are positive or negative and about the time lags of these impacts are more complex than in the case of capital inputs. Nevertheless, a similar model is used:

$$\frac{\Delta\frac{L_{\mathrm{it}}}{P_{\mathrm{it}}}}{\frac{L_{\mathrm{it}}}{P_{\mathrm{it}}}} = \nu_L \cdot \frac{I_{\mathrm{it}-a}}{P_{\mathrm{it}-a}} + \eta_L \cdot \frac{K_{\mathrm{it\text{-}b}}}{P_{\mathrm{it}-b}}, \tag{10}$$

where ν_L and η_L are parameters and *a* and *b* stand for the time delays of the effects. Different time delays have to be tested in the empirical analysis.

III. Methods

III.1 Econometric approach

In recent years it has become common in the empirical economic growth literature to use panel GMM regressions (e.g., Hasan & Tucci 2010, Güloglu & Tekin 2012 and Museru et al. 2014). This approach allows to test for causality with the help of instrument variables. Furthermore, it allows for an easy inclusion of time lags. Thus, it perfectly fits the intention of this paper. All panel GMM regressions are conducted with time and country fixed effect.

The regression equations are directly taken from the above theoretical considerations. This means that the Equations (7), (8), (9) and (10) are estimated. The equation system contains some of the variables as dependent as well as independent variables. Hence, alternative options would be the use a VAR approach. However, since the theoretical considerations lead to clear expectations for the dependencies and their time lags and instrument variables allow for testing causality, a separate estimation of the equations seems adequate.

As usual, lagged variables are used as instruments. To check the robustness of the results, the estimations are repeated including other variable as instruments, such as export and import rates. The significant results remain robust, so that the basic estimation with lagged variables as instruments are presented and discussed below.

Since the relationships between the variables include time lags, using lagged variables as instruments might bias the results. Therefore, the robustness of the results is also checked by reducing the instruments to lagged variables with larger time lags. Some results change significantly, implying that they are not robust. This holds for some regressions with one-year time lags in the independent variables. However, in all those cases two-year time lags lead also to significant results, explaining the problems with two-year lagged instruments in the one-year lag regressions. Below, only the results for the robust, most significant time lags are presented and discussed.

III.2 Data

As usual in the literature data from the Penn World Table (PWT8.0) and World Development Indicators (World Bank) is used. In addition, data is derived from the Patstat database as well as the Web of Science. As usual in the literature oil exporting countries are excluded from the analysis (e.g., Bond et al. 2010). In total data on 114 countries for the years from 1974 to 2009 is utilized.

Several existing studies show that the relevance of various factors for growth differs between countries (e.g., Bond et al. 2010, Lee et al. 2011, Jaffe et al. 2013) and in time (Lu 2012). Therefore, two periods of time are build, including the years 1974-1991 and the years 1992-2009. Quite a number of countries in our sample (especially in Eastern Europe) are founded in the years 1991 or 1992, so that the second time period includes their development while the first time period is restricted to all countries that exist for a longer time. Furthermore, three country groups are build:

- less developed countries: all countries with a GDP per capita below 5,000 US$ (in 2000)
- medium and well developed countries: all countries with a GDP per capita above 5,000 US$ (in 2000)
- most developed countries: all countries with a GDP per capita above 20,000 US$ (in 2000)

Each combination of country group and time period is analyzed separately, so that six different data sets are analyzed. The following provides a detailed description of the used variables.

Output (Y): As usual in the literature output-side real GDP at current PPPs is used as a measure for economic output. The data is provided in the Penn World Table.

Capital (C): As usual in the literature capital stock at current PPPs is used as a measure for capital. The data is also provided in the Penn World Table.

Labor (L): The number of persons engaged multiplied by the average annual hours worked by persons engaged provides the total labor input. Both required numbers are part of the Penn World Table. However, the Penn World Table contains a lot of missing values for the average annual hours worked. Using this variable reduces the number of countries that can be studied to 33 and for some of them the time period would be reduced. Therefore, the number of persons engaged is used as a proxy for the labor input and the average annual hours worked are ignored.

Human capital (H): The Penn World Table contains an index that approximates the human capital per person on the basis of years of schooling and returns to education. This value is used to reflect human capital in each country.

Population (P): The population of each country is given in the Penn World Table.

Innovation output (I): As usual, patent data is used to estimate innovation output. It is well-known and discussed in the literature that patent data only represents a certain share of the total innovation actitivity (see, e.g., Smith 2005). However, it is the only measure that is available comprehensively. The European Patent Office provides the most comprehensive database on patents: the Patstat database. This database contains all patents applications from over 100 countries, so that it provides nearly worldwide coverage. All inventors and applicants are listed and for most of them a country code is given. Here, the Patstat database (October 2013 release) is used and all patents are assigned to countries according to the country codes of the inventors and applicants. If the inventors or applicants are located in different countries, patents are assigned partly. Each entry in the patent database is counted as one, independent of whether the same patent occurs several times in the database because it is applied for at various patent offices. Patents that are applied for at several patent offices are assumed to be more important, which justifies the multiple count. The total number of patents increases with time. While part of this increase reflects the fastening of technological development, other parts are caused by changes in patent regulation, firms strategies, data quality and the like. Therefore, I_{it} is defined as the share of all patents in year *t* that originate from country *i*. It takes usually between 1 and 3 years for patents from their application until they are listed in patent databases. Therefore, the number of patents in the used database decreases tremendously for the years 2010 and later. Hence, the patent numbers are reliable for the years until 2009. The variable I_{it} is calculated in two variants: In the first version, $I^{(i)}_{it}$, the country assignment reflects the addresses of inventors, in the second version, $I^{(a)}_{it}$, the country assignment reflects the addresses of applicants.

R&D expenditures (R): The World Development Indicators contain, at least for some countries, the total expenditures (private and public) for research and development as a share of GDP. These values are used to approximate research activities.

Scientific research (K): R&D expenditure data is dominated by private expenditures, although it also contains public research activities. The World Development Indicators contain data on the number of researchers and scientific publications. However, this data is restricted with respect to the countries and time period covered. Therefore, data on the number of publications from each country in each year is directly taken from the Web of Science. While the Web of Science contains only few journals in the years before 1973, the coverage is good from 1973 onwards. A simple count of the number of publications in each year for which at least one author comes from the considered country is used. The coverage of the Web of Science increases with time. Therefore, in each year the country counts are divided by the total number of publications in this year.

IV. Results and discussion

Above four equations, (7), (8), (9) and (10), are deduced from theoretical considerations. The following subsections contain the empirical investigations of these equations.

IV.1 Innovation output and growth

In order to estimate Equation (7), data on Y_{it}, C_{it}, L_{it}, H_{it}, $I^{(i)}_{it}$ and $I^{(a)}_{it}$ is required. This data is available for 114 countries and for the years from 1974 to 2009. The two variables measuring the innovation output, $I^{(i)}_{it}$ and $I^{(a)}_{it}$, are highly correlated, so that they cannot be included in the analysis simultaneously. Therefore, two separate models (Model 1 and Model2) are run, each including only one of these two variables. Furthermore, the term for innovation output contains an unknown parameter *x*. This parameter is varied until the optimal value (leading to the highest significance of the respective term) is found. Only the results for this optimal choice of *x* are presented.

In the basic models, which includes all 114 countries and the complete time period, no significant influence of innovation output is found. Only the usual variables, capital, labor and human capital, influence the growth of the economy according to the results. This contrasts the positive effect that was expected. Analyzing the different data sets separately leads to heterogenous results listed in Tables 1 and 2.

Table 1:

Panel GMM regressions for national growth 1974-1991 (Equation (7)) (p-values in brackets)

Variable	Model 1 $Y_{2000}/P_{2000}<5.000$	Model 2 $Y_{2000}/P_{2000}<5.000$	Model 1 $Y_{2000}/P_{2000}>5.000$	Model 2 $Y_{2000}/P_{2000}>5.000$	Model 1 $Y_{2000}/P_{2000}>20.000$	Model 2 $Y_{2000}/P_{2000}>20.000$
$log(Y_{it-1}/P_{it})$	**-.185** (.0064)**	**-.230*** (.0008)**	**-.190*** (.0000)**	**-.192*** (.0000)**	**-.208*** (.0000)**	**-.152*** (.0001)**
$\Delta log(C_{it}/P_{it})$	.070 (.7848)	-.038 (.8839)	**.720*** (.0000)**	**.669*** (.0002)**	**.745*** (.0003)**	**.670** (.0011)**
$\Delta log(L_{it}/P_{it})$	.044 (.6649)	.059 (.5855)	.160 (.2600)	.128 (.3525)	.254 (.2870)	.194 (.3849)
$\Delta log(H_{it})$	**4.105* (.0399)**	**4.096* (.0302)**	-.874 (.1913)	-1.021 (.2539)	-.619 (.2504)	-1.573 (.1143)
$log(I^{(a)}_{it}/P_{it}+x)$	77.72 (.2362) x=.01		.015 (.3719) x=.00002		**.040** (.0020)** x=.00001	
$log(I^{(i)}_{it}/P_{it}+x)$		8.280 (.2547) x=.005		-.0098 (.2233) x=.00001		.026 (.2795) x=.0001
Number of countries	46	46	55	55	31	31
Number of observations	633	633	836	836	484	484

In the first time period (1974-1991) economic growth in the poorest countries depends mainly on the development of human capital. In contrast, capital investments are the main drivers of economic growth in the more developed countries. Patents, as a measure of innovation output, matter only in the case of the most developed countries. Hence, the above hypothesis (Hypothesis 1b) is only confirmed in the first time period for the most wealthy countries. A straight-forward explanation is that only if a certain level of development is reached, a country's economy benefits significantly from innovation activity within the country.

The results for the second time period (1992-2009) support this claim: Innovation output shows a significant impact for all countries with a GDP per capita above 5.000 US$. Since all countries are, on average, more developed in the second time period, now the medium and well-developed countries benefit from innovation activities. One might also argue that in the other cases the amount of innovation activities – at least the number of patents – is too low to be important. However, it seems more plausible that a certain level of development is necessary for a country to benefit significantly from innovation activity in terms of increased total factor productivity.

Interestingly, innovation activity is not significant for the most developed countries in the second time period. According to the above interpretation, this would mean that countries that are very well-developed do not benefit from innovations anymore. This seems unlikely. Another possible reason is that innovation activities are quite stable and follow the overall development in these countries. Using past values as instrument variables assigns in such a case the causal reason the previous development and not to the increases in innovation output. This would mean that in very well-developed countries innovations are less often the trigger of strong economic development, but are in most cases part of the overall development. Similar arguments are put forward in the case of scientific research by Inglesi-Lotz et al. (2014).

Table 2:

Panel GMM regressions for national growth 1992-2009 (Equation (7)) (p-values in brackets)

Variable	Model 1 $Y_{2000}/P_{2000}<5.000$	Model 2 $Y_{2000}/P_{2000}<5.000$	Model 1 $Y_{2000}/P_{2000}>5.000$	Model 2 $Y_{2000}/P_{2000}>5.000$	Model 1 $Y_{2000}/P_{2000}>20.000$	Model 2 $Y_{2000}/P_{2000}>20.000$
$log(Y_{it-1}/P_{it})$	-.054 (.2559)	-.053 (.2794)	**-.218*** (.0004)**	**-.277*** (.0000)**	**-.362*** (.0000)**	**-.369*** (.0000)**
$\Delta log(C_{it}/P_{it})$	**.526*** (.0001)**	**.529*** (.0001)**	**.409*** (.0000)**	**.369*** (.0000)**	**.222* (.0135)**	**.230* (.0251)**
$\Delta log(L_{it}/P_{it})$	.095 (.4034)	.096 (.4012)	**.408* (.0190)**	**.335* (.0344)**	.103 (.6592)	.100 (.6641)
$\Delta log(H_{it})$	4.10 (.1140)	3.79 (.1351)	-.498 (.5817)	-.371 (.6557)	-.143 (.8473)	-.422 (.5705)
$log(I^{(a)}_{it}/P_{it}+x)$	.164 (.1682) x=.00005		**.158*** (.0008)** x=.0002		.021 (.2330) x=.00001	
$log(I^{(i)}_{it}/P_{it}+x)$		.344 (.2845) x=.0002		**.248*** (.0003)** x=.0005		.127 (.1488) x=.002
Number of countries	48	48	66	66	31	31
Number of observations	766	766	1012	1012	478	478

Another interesting question is whether it is more important for a country to contain many inventors or to contain those actors that own the patents (applicants). Our results are not decisive. In the first time period only the number of applicants shows a significant impact. In the second time period both, inventors and applicants, have a significant impact. Hence, there is more evidence for the relevance of owning innovations, but the results are not sufficient to draw a final conclusion on this.

The results for the other factors in the second time period partly confirm the findings for the first period. Capital investments are now significantly relevant for all country groups. In contrast, human capital developments are insignificant in all cases. This corresponds to the findings for the more developed countries in the first time period. In contrast to the first time period, labor input matters for the medium and more developed countries.

IV.2 Public research and innovation output

In order to examine the factors that influence innovation output, a knowledge production function, Equation (8), is used. R&D expenditures, scientific research and human capital provide the inputs. Data on R&D expenditures is much less available than data on the other inputs. Hence, including R&D expenditures reduces the number of observations strongly (63 countries with 604 usable observations in total). In contrast to several studies in the literature (Bottazzi & Peri 2003, Madsen et al. 2010b and Güloglu et al. 2012), no significant results are obtained here. As a consequence, this paper focuses on the impact of scientific research and refers to the existing literature for the relationship between R&D expenditures and innovation output.

This allows to use the complete data set and to separate again between the time periods and the groups of countries. A reduced knowledge production function is estimated, excluding R&D expenditures (R_{it}) from Equation (8). Two dependent variables are examined: the number of patents with applicants from the country and the number of patents with inventors from the country. According to the considerations above, scientific research should matter with a time lag between one and six years. Therefore, all time lags between one and six years are examined and the one leading to the highest, robust significance for scientific research is presented in Table 3.

Table 3:

Panel GMM regressions for innovation output growth (Equation (8)) (p-values in brackets)

Variable	(1974-1991) Y_{2000}/P_{2000}<5.000	(1992-2009) Y_{2000}/P_{2000}<5.000	(1974-1991) Y_{2000}/P_{2000}>5.000	(1992-2009) Y_{2000}/P_{2000}>5.000	(1974-1991) Y_{2000}/P_{2000}>20.000	(1992-2009) Y_{2000}/P_{2000}>20.000
Number of countries	44	48	54	66	30	31
	Dependent variable: $\Delta log(I^{(a)}_{it}/P_{it})$					
$\Delta log(H_{it})$	**163.7** (.0041)**	2.36 (.9722)	.833 (.9326)	3.71 (.4142)	-15.34 (.2739)	5.42 (.2507)
$\Delta log(K_{it-1}/P_{it-1})$				.436 (.1935)		*.604 (.0642)*

$\Delta log(K_{it-2}/P_{it-2})$	.093 (.547)	.114 (.7448)	*.391 (.0765)*		.272 (.1898)	
Number of observations	139	395	669	947	420	463
	Dependent variable: *$\Delta log(I^{(i)}_{it}/P_{it})$*					
$\Delta log(H_{it})$	-9.84 (.8769)	65.67 (.1193)	-14.21 (.1386)	-.652 (.8952)	-13.24 (.2773)	*6.55 (.0599)*
$\Delta log(K_{it-1}/P_{it-1})$	-.166 (.4313)			.179 (.3362)		.511 (.2507)
$\Delta log(K_{it-2}/P_{it-2})$		-.109 (.7716)	**.400*** (.0008)**		**.237** (.0096)**	
Number of observations	133	362	646	932	408	459

Human capital is found to significantly matter only in the first time period for the less developed countries. However, in the second time period it just misses the significance level for the most developed countries. Hence, some evidence for the relevance of human capital is found, but the relevance is either weak or not very robust.

No significant results appear for scientific research in the case of the less developed countries. This is not surprising, because innovation output and scientific research activities are quite low in these countries and year to year fluctuations are comparably huge. Hence, two interpretations are possible: the numbers are too low for a statistical analysis or scientific research is not sufficiently advanced to contribute to the innovation output in these countries.

In the case of more developed countries two significant findings are obtained. Accepting a significance level of 10% would increase the number of significant results to four out of eight. Hence, an influence of scientific research on innovation output (Hypothesis 2a) is confirmed. This influence seems to be stronger in the first time period. Again, it might be the case that in this time period more countries have shown specific technological development, while in the latter time period science and technology follows more often the overall development (as also stated in Inglesi-Lotz et al. 2014). However, more research on this issue is necessary to make a final statement.

Most significant results are found for a time lag of two years. Hence, on the country level scientific research output (publications) increases take approximately two years to lead to increases in innovation output (patents). Furthermore, more significant results are obtained for the number of inventors than for the number of applicants as a dependent variable. Not surprisingly, public research seems to trigger first of all the invention capabilities in a country. This is, at least partly, driven by the fact that public research itself contributes to the innovation output, often without acting as an applicant on patents.

IV.3 Capital and labor input changes

Finally, it has been deduced above that innovation output and scientific research should also stimulate firms to change their use of capital and labor. As a consequence, there should exist relationships between innovation output and scientific research on the one side and capital and labor inputs on the other side on the national level.

Again, two time periods and three groups of countries are examined separately. The numbers of patents and publications are very low in the case of the less developed countries. As consequence, no significant results are obtained for these countries in any of the regressions, and in some cases the analysis is not even possible. Hence, only the results for the more developed countries are presented and discussed in the following.

The results for the growth of capital inputs, Equation (9), are presented in Table 4. Again, time lags of one to six years are tested for scientific research as well as innovation output. Table 4 presents for each data set only the combination of time lags that leads to the highest, robust significances.

Table 4:

Panel GMM regressions for capital input growth (Equation (9)) (p-values in brackets)

Variable	1974-1991 $Y_{2000}/P_{2000}>5.000$	1992-2009 $Y_{2000}/P_{2000}>5.000$	1974-1991 $Y_{2000}/P_{2000}>20.000$	1992-2009 $Y_{2000}/P_{2000}>20.000$
Number of countries	54	66	30	31
	Model 1			
K_{it-x}/P_{it-x}	3.17 (.9275) x=2	-114.9 (.1918) x=2	-1.16 (.9618) x=1	-36.70 (.5280) x=2
$I^{(a)}{}_{it-x}/P_{it-x}$	-8.06 (.1225) x=2	14.86 (.2985) x=2	-6.85 (.1070) x=1	13.02 (.3451) x=2
Number of observations	658	903	451	430
	Model 2			
K_{it-x}/P_{it-x}	27.12 (.5064) x=2	-107.9 (.2200) x=2	27.16 (.4138) x=2	-38.66 (.3542) x=1
$I^{(i)}{}_{it-x}/P_{it-x}$	**-12.39* (.0106)** x=2	16.29 (.3935) x=2	**-10.28* (.0151)** x=2	-7.65 (.7290) x=1
Number of observations	658	903	420	463

In contrast to the above hypotheses (Hypotheses 1c and 2c), a significant relationship results only for the number of inventors in the first time period and this relationship is negative. Hence, no effects of scientific research on capital inputs can be stated. The presence of many inventors seems to have a negative impact on capital investments in the first time period. This holds for the more developed countries as well as for the very well-developed countries. A potential explanation might be that in this time period inventive activities have triggered a shift away from capital-intensive production. Productivity gains (as found above) and shifts between industries might be responsible for this. The time lag for this effect is found to be two years.

Table 5 presents the results for labor input growth. As in the case of capital input growth, all time lags between one and six years are tested and the combination of time lags that leads to the highest, robust significances is presented.

Table 5:

Panel GMM regressions for labor input growth (Equation (10)) (p-values in brackets)

Variable	1974-1991 $Y_{2000}/P_{2000}>5.000$	1992-2009 $Y_{2000}/P_{2000}>5.000$	1974-1991 $Y_{2000}/P_{2000}>20.000$	1992-2009 $Y_{2000}/P_{2000}>20.000$
Number of countries	54	66	30	31
	Model 1			
K_{it-x}/P_{it-x}	23.36 (.2836) x=1	**61.89** (.0056)** x=1	*44.37 (.0577)* x=1	*41.02 (.0800)* x=1
$I^{(a)}_{it-x}/P_{it-x}$	**-5.75* (.0330)** x=1	4.09 (.6126) x=1	-3.43 (.3621) x=1	**-16.16* (.0258)** x=2
Number of observations	729	973	451	430
	Model 2			
K_{it-x}/P_{it-x}	11.51 (.6309) x=2	**68.72** (.0030)** x=1	*44.89 (.0661)* x=1	*24.95 (.0600)* x=1
$I^{(i)}_{it-x}/P_{it-x}$	-4.04 (.2822) x=1	.648 (.9354) x=1	-2.78 (.4291) x=1	**-16.29* (.0286)** x=1
Number of observations	671	973	451	463

The results for labor inputs are in line with the predictions above. First, scientific research has a positive impact on labor input growth as predicted in Hypothesis 2c. This impact is strongest for the medium and well-developed countries in the latter time period. However, weakly significant results are also found for most other data samples. The effect always (if it is at least weakly significant) appears with a time lag of one year. Hence, the above results suggest that scientific research indeed increases economic activity by triggering an increase in the labor used. This is an important message for policy, because economic growth on the basis of increases in employment is politically most desired and according to the results here can be reached by increasing scietific research.

In the case of innovation output a negative impact is expected in the short run due to replacement effects (Hypothesis 3d), while a positive impact is expected in the medium run (Hypotheses 3c and 3d). Some confirmation of the former effect is found: Higher innovation output decreases employment one or two years later. This effect is found for the number of inventors as well as for the number of applicants. Since patent activity is dominated by firms, we might interpret that firms, on average on the national level, use innovations to reduce labor inputs.

Interestingly, this effect is most significant for the medium and well-developed countries in the former time period and for the very well-developed countries in the latter time period. This does not provide a coherent picture, because in the former period rather the medium developed countries seem to be effected, while in the latter period rather the very well developed countries seem to be effected. More detailed studies on this seem to be require to draw a final conclusion.

A more delayed positive effect of innovations on employment is not found in the analysis here. Maybe this effect is too weak or too diffuse to be detected or it does really not exist.

V. Conclusions

This paper studies the contributions of innovation output (patents) and scientific research (publications) on economic growth on the basis of data on 114 countries. A number of interesting insights are provided. First, it confirms the well-established fact that innovations increase productivity and, thus, generate economic growth. This effect holds for the well developed countries while it is not significant for the less developed countries.

Second, public research is found to trigger innovation output two years later. Hence, the fact that scientific research supports private innovation activities, which is well-known from the literature on firms and regions, is confirmed here on the national level. Furthermore, a time lag of two years is identified for this effect and is found to be very robust between different data samples and variables used.

Third, the fact that innovations trigger growth through increases in production capacities, which is clearly confirmed in studies on the firm level, is not confirmed on the country level here. In contrast, higher innovation output seems to lead to a decrease in capital as well as labor inputs one to two years later. Hence, innovations seem to increase productivity but, at the same time, seem to decrease production capacities. While decreases in the capital used can be explained by shifts in the industrial structure, which might be desirable, losses in employment are a publicly unwelcome effect.

Fourth, while no effects of scientific research on capital inputs are found, clear evidence is gained for a positive effect of public research on labor inputs. Scientific research output (publications) seems to trigger employment growth one year later. This seems the most important message of this paper to policy makers: Scientific research appears to be an adequate way to foster employment growth.

However, this effect seems to be not similarly significant for all groups of countries. Further research on this issue is necessary to disentangle the effects and reasons. In this context, distinguishing various subjects of scientific research might provide addition insights. However, this goes beyond the scope of this paper and is left over for future studies.

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