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ACADEMIC KNOWLEDGE AND ECONOMIC GROWTH: ARE SCIENTIFIC FIELDS ALL ALIKE?

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ACADEMIC KNOWLEDGE AND ECONOMIC GROWTH: ARE SCIENTIFIC FIELDS ALL ALIKE?[1]

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ABSTRACT

The aim of the paper is to contribute the debate on the accountability of the academic system. To this it grafts the recent advances of the economics of knowledge into the economics of the academic system. The paper elaborates and tests the hypothesis that there are different types of academic knowledge that exert different effects on economic growth. The recent advances of the economics of knowledge enable to appreciate the differences among types of academic knowledge in terms of appropriability, fungibility and cumulability, field of application and with respect to the specificities of the generation process. Building upon these bases, distinctions can be made between knowledge in hard sciences, social sciences, humanities and medical sciences. The hypotheses are tested on OECD data about the numbers of university graduated students in the years 1998-2008 in 16 countries with a simple production function. The results stress the differences in the output elasticity of each discipline and confirm their wide differences in the capability to contribute economic output. The policy implications are important: public support to the academic system, advocated to support economic growth, should not be spread uniformly across academic disciplines but rather focus the academic fields that are better able to contribute economic growth.

KEY WORDS: GRADUATE STUDENTS, TYPES OF KNOWLEDGE, KNOWLEDGE EXTERNALITIES, OUTPUT ELASTICITY OF KNOWLEDGE TYPES.

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1. INTRODUCTION

The paper elaborates and tests the hypothesis that there are different types of academic knowledge that exert different effects on economic growth. The aim of the paper is to contribute the debate on the accountability of the academic system grafting the recent advances of the economics of knowledge into the economics of the academic system. Section 2 shows how the recent advances of the economics of knowledge enable to appreciate the differences among types of academic knowledge in terms of fungibility and cumulability, field of application and with respect to the specificities of the generation process. Building upon these bases, relevant distinctions can be made between knowledge in humanities, social sciences, hard sciences and medical sciences. Hard sciences are likely to contribute most to economic growth as they feed the eventual introduction of technological innovations. The role of social sciences can be fully appreciated as soon as their role in feeding organizational innovations is properly identified and highlighted and, in turn, the crucial role of the latter in economic growth is acknowledged . Academic knowledge in medical sciences is likely to have a narrow scope of application. Academic knowledge in humanities seems to lack the basic ingredients to contribute directly economic growth. In order to provide a first tentative test of these hypotheses section 3 presents an econometric approach, using OECD data about the stock of graduated university students in the years 1998-2008 in 16 countries. A simple production function is tested to measure the differences in the output elasticity of each of these stocks. The results confirm that academic disciplines display wide differences in their capability to contribute economic output. The conclusions summarize the result and highlight the policy implications. As lomg as the academic system is considered to play a central role in fostering economic growth, a careful scrutiny is necessary, in order to understand which are the academic fields that are better able to contribute economic growth. Public support to the academic system should not be spread uniformly across academic disciplines but rather focus these specific fields.

2. THE ANALYSIS

2.1 THE ANALYTICAL FRAME

There is large consensus that the academic system plays a central role in economic growth as the provider of both the formal training that cumulates into human capital and the flow of inventions that feed the innovation process.

Together with learning by doing and learning by using, academic training helps building human capital that, like fixed capital, increases labor productivity and commands a specific revenue (Schultz, 1960; Becker, 1962a, 1975). The research on the role of human capital has followed typically a macroeconomic path paying much attention to the contribution of the different endowments of schooling experience to economic performances in terms of output and total factor productivity growth (Carnoy and Marenbach, 1975; Hanushek and Woessmann, 2008; Di Liberto, Pigliaru, Chelucci, 2011).

The appreciation of the role of the academic system to economic growth has been characterized by substantial evolution through time. In the traditional approach academic research was regarded as an important factor to sustain total factor productivity growth only indirectly. In the traditional approach the academic system was regarded as the institutional locus dedicated to generating new scientific knowledge that might be eventually used by firms to generate additional technological knowledge that would possibly translate in the introduction and diffusion of technological and organizational innovations that increase the total factor productivity of the production process (Feller, 1990).

It must be stressed that this approach builds upon the implicit assumption that scientific knowledge is an intermediary input, i.e. an input itself into the production of other goods. The analysis is directed towards the identification of the role of knowledge from a production-side perspective, while little attention is paid to its role in consumption. However in some cases academic knowledge might as well be considered as a final good, i.e. the result of a generation process that is aimed at increasing directly the satisfaction of final consumers. In the literature discussed so far instead a larger supply of knowledge would increase the satisfaction of consumers only indirectly, as it helps the production process of other goods, including other final goods.

In this paper we will mainly refer to the concept of knowledge as an intermediary product, however such assumption should be acknowledged since it has important implications for the evolution of both the economics of knowledge and the economics of the academic system.

The arrovian contributions to the economics of knowledge provided the explicit foundations of the analysis of knowledge as an intermediary input. The early identification of the major limitations of knowledge as an economic good, such as non-appropriability, non-divisibility, non-rivalry in use, non-exhaustibility of knowledge and the consequent market failures, with high risks of undersupply, provided the traditional approach with the necessary tools to introduce a political economy of knowledge. The early economics of knowledge articulated the need for a strong public policy to remedy the intrinsic risks of undersupply and advocated the opportunity of a systematic public intervention on the supply side with the direct provision of public subsidies to the academic system (Dasgupta and David, 1987 and 1994).

The public support to the academic system and the build-up of a public academic system are advocated to balance the lack of incentives to generate knowledge. The basic argument can be synthesized as it follows. The public support would enable to implement a structured mechanism of institutional incentives by means of which talented and creative agents would be willing to publish and hence make publicly available the results of their cognitive efforts in order to be included in the academic system and receive a salary. The academic system becomes the provider of knowledge externalities to the rest of the economic system. The mechanism is likely to be effective as long as the expenses of the academic system, covered by public subsidies, are compensated, possibly more than compensated, by the positive effects of knowledge externalities spilling from the academic system to the rest of the economic system, in terms of an increase of the output levels (Antonelli, 2008a).

The progressive demise of the corporation of the central mechanisms for the generation and exploitation of technological knowledge lead to the appreciation of the role of the academic system as the engine of the generation of knowledge at large with the progressive fading of the distinction between scientific and technological knowledge. The academic system was more and more regarded as the institutional locus for the generation of technological knowledge (Mansfield, 1991, 1995; Mansfield and Lee, 1996).

The new centrality of the academic system has called increasing attention both in the economic and policy debate on the amount of both public and private resources devoted to support the academic system, its accountability in terms of the relationship between input and output and its organization (Nelson, Rosenberg, 1994).

More specifically we can identify a clear sequence in the debate. In this evolution the academic system first complemented and subsequently partly substituted the corporation as the main player in the generation of technological knowledge. The general consensus about the need to increase the amount of resources devoted to the academic system has progressively called more attention upon its accountability (Murphy, 1995). Much effort has been made to elaborate analytical tools and interpretative frameworks to better appreciate the actual output of the academic system (Cave, Weale, 1992; Cave, Hanney, Henkel and Kogan, 1997; Crespi, Geuna, 2008). This undertaking has been especially productive at the microeconomic level with important contributions that have made it possible to better appreciate the measures of academic output at the individual, departmental and university level (Johnes, 1988, 1990, 1992, 1997; Johnes and Johnes, 1993).

The organization of the academic system has also received much attention exploring whether the joint performance of research and training were more productive than the specialization. Increasing attention has been paid to assess whether the dissemination of academic knowledge could be left to traditional tools such as the publication of scientific papers and the enrollment of Phds in productive activities in the economic system, or better implemented strengthening the direct interactions and possibly transactions between the academic system and the business sector. Private funding of academic research has been more and more regarded as an effective tool to better appreciate the actual relevance of the academic output and to shorten the time lags between inventions and innovations (Geuna, 1999; Etzkowitz, Leydesdorff, 2000; Antonelli, Patrucco, Rossi, 2010).

The enquiry about the efficiency of the academic system has been directed mainly, if not exclusively, towards the assessment of its internal efficiency, as distinct from its general, or external efficiency. Much efforts, in fact, have been directed to identify new metrics so as to assess the quantity and quality of knowledge generated, in order to establish appropriate measures of the relationship between the amount of economic resources transferred to the academic system and the amount of knowledge generated (Auranen, Nieminen, 2010). Yet from an economic viewpoint it is not sufficient to assess the internal efficiency of the academic system in terms of the relationship between economic inputs and knowledge outputs. It seems in fact more important to assess whether the amount of knowledge –efficiently- generated by the academic system is actually useful to support economic growth.

Following this line of analysis it is clear that a major problem of coordination and composition may take place. The state provides subsidies to implement a public academic system to remedy to the –possible- undersupply of knowledge, but the academic system insists in the generation of knowledge that is not useful for economic growth. The mismatch between the objectives of public policy and its effects may become gradually evident and the consensus to a public academic system would decline, even if the academic system is able to generate efficiently large amounts of knowledge with a limited amount of public economic resources.

As long as knowledge is regarded as a heterogeneous intermediary input, the effects of the efficiency in its generation are relevant not only internally but also externally. The exploration of the composition of the knowledge generated by the public academic system and the actual assessment of its external efficiency become necessary. Only when the levels of both internal and external efficiency are high it is possible to support the hypothesis that the supply of knowledge generated by the public academic system is actually able to match efficiently the ‘correct’ levels of the derived demand for knowledge of the rest of the economic system.

The two notions of internal and external efficiency would coincide only if knowledge were a homogenous good. As soon as we appreciate that knowledge is a composite bundle of a variety of different kinds of knowledge, the problem of the composition of the bundle becomes crucial. The academic system may generate too much of one kind of knowledge and too little of another. The system would suffer both from the undersupply of the relevant knowledge and the oversupply of knowledge that is not directly useful to support growth.

The assessment of the external efficiency of the academic system has been somewhat overlooked. In order to assess whether the public academic system is actually working as a complementary mechanism able to compensate for the undersupply of knowledge by the private sector it is in fact necessary to assess what is the relationship between the amount of public subsidies paid to the academic system and its revenue measured by the effects of knowledge externalities spilling from the academic system in terms of additional economic output.

As soon as we understand that knowledge is not a homogenous bundle of standardized items it becomes clear that its heterogeneity risks to undermine the working of the elegant arrovian mechanism and raises a major problem of coordination between the supply of knowledge by the academic system and the actual content of the derived demand expressed by the rest of the economic system.

The grafting of the recent advances in the economic of knowledge enables to contribute this debate from a different viewpoint. The economics of knowledge has made much progress in the appreciation of the variety of different types of knowledge. Knowledge is not homogenous. Knowledge differs on many accounts. Knowledge differs in terms of levels of appropriability, levels of cumulability, levels of fungibility or scope of applications, levels of compositeness. The generation of knowledge differs itself as it is not a general process that takes place at all time, all circumstances and with all kinds of knowledge. The role of tacit knowledge differs as well as the role of learning processes. Tacit knowledge and learning processes are more relevant in the generation of some kinds of knowledge than in others. In some circumstances the generation of knowledge consists mainly of the recombination of diverse and disperse knowledge inputs: this is typically the case of knowledge with high levels of compositeness. With high levels of compositeness the relevance of the complementarity among different units of knowledge and different possessors of knowledge is paramount. In other circumstances, when knowledge cumulability matters, the generation of knowledge is much influenced by vertical processes of diachronic implementation of basic knowledge inputs (Antonelli, 2008b).

The application of these tools to academic knowledge yields interesting results. Hard sciences such as physics, chemistry, biology, mathematics and the broad spectrum of engineering fields seems characterized by high levels of fungibility and appropriability. Their contribution to the eventual introduction of technological innovations is well documented and relies upon the wide spectrum of direct applications in production processes. The cumulability between scientific knowledge and technological knowledge is very high: inventions do feed innovations. Research and development activities (R&D) concern mainly if not exclusively hard sciences. The generation of technological innovations more and more impinges upon the advances in scientific knowledge. The role of codified knowledge produced by the academic system is ever increasing in the generation of technological knowledge, while the role of tacit knowledge generated in learning processes declines with the growing role of the science base of advanced technologies. The growing reliance of corporations upon academic laboratories to perform basic and applied research in hard sciences has the effect to increase the overlapping between sheer academic activities and corporate R&D. The appropriability of technological knowledge stemming from scientific advances in hard science is relatively high and sufficient to provide adequate incentives to implement the applied research and the development activities that are necessary to actually exploit technological knowledge. As a consequence all advances of academic knowledge in hard sciences are most likely to exert a strong and direct effect on economic growth (Stephan, 2011).

Social sciences play a central role in the introduction of organizational innovations. The introduction of more efficient and effective methods of conducting business companies encompassing a broad array of activities ranging from corporate management practices, marketing, advertisement, industrial relations and finance relies upon the advances in academic knowledge in social sciences. Research activities aiming at the introduction of organizational innovations are poorly appreciated by R&D statistics. Never the less a large evidence constructed by business schools confirms the key role of social sciences as the provider of organizational knowledge that helps improving the efficiency of production processes in all industries and sectors of economic activity (Evangelista, Vezzani, 2010; Van Reenen, 2011). As a matter of fact the fungibility of social sciences appears to be even higher than the fungibility of hard sciences as the scope of application of organizational innovations includes not only the high-sectors but also the traditional fields of activities where technological innovations are less relevant for the conduct of business activities. The appropriabilty of organizational innovations and new business methods is quite low, but organizational innovations require such large amounts of tacit and highly localized knowledge and competence on the specific conditions of the firms and the types of organization to which they apply, to make it hard for uncontrolled spillovers to leak to third parties. As a consequence incentives to try and exploit the advances in social sciences are not negligible (Stephan, 1996; Foray, 2004).

Medical sciences are clearly most relevant from a social viewpoint as they feed the introduction of new medical practices and pharmaceutical products that help fighting diseases, stretching the duration of life and improving its quality. Yet the scope of application is narrow as it is limited to the health industry. The likelihood that advances in medical sciences affect directly economic growth seem lower also for the institutional setup of the health industry that in most countries is organized as a public service with specific accountability rules that reduce the possibility to appreciating their economic effects (Grebel, 2011).

Finally, human sciences seem to be characterized by low levels of direct fungibility. The notion itself of advances in academic knowledge in humanities is debatable. The knowledge generation activity in humanities seems characterized by high levels of recombination where a large tradition of notions and concepts is continually reorganized into new frames. The appropriability of advances in humanities is very low and does not provide sufficient incentives to private undertakings to invest resources to try and exploit it. The direct application to economic activities of such advances concerns mainly cultural and entertainment industries, but also in this case the public support to these activities makes it harder to establish their real contribution in terms of value added.

Furthermore the case of human sciences calls for a critical attention to the implicit assumption that knowledge is an intermediary input and not a final good. As a matter of fact knowledge in human sciences may be regarded as a final good that consumers are eager to acquire simply because culture increases the quality of life, and not because it provides competitive advantages in the labour market. From this viewpoint it would become necessary to discriminate between the cases in which human sciences can be considered as a final good and the cases in which they should be regarded as an intermediary input.

Going one step forward within this perspective it becomes also clear that considering knowledge as a final good -at least to some extent- has important implications in terms of causality. It might be argued in fact that the consumption of knowledge (specifically knowledge in human sciences) increases as a consequence of the increase of revenue and not the other way around, where the increase in the generation of knowledge is expected to affect the levels of output and revenue. In the case of human sciences hence the basic assumption of knowledge as an intermediary input should be taken into account when analyzing the effects of this type of knowledge on the economic performances of countries.

The intrinsic characteristics of the four types of knowledge described so far differ substantially. Their analysis supports the general hypothesis that knowledge is not a homogenous good. On the opposite it is a highly differentiated bundle of types, with different scope of application. Building upon these bases it seems possible to move away from the effort to analyze the internal efficiency of academic departments in terms on the relationship between input and outputs measured in terms of the amount of knowledge generated with given investments, towards an original approach to measure the external, rather than the internal, efficiency of the academic system.

The analysis carried out enables to try and assess the external efficiency of academic knowledge, that is to implement the effort to try and measure the differentiated effects of the different types of knowledge on economic growth. The different kinds of knowledge identified can be considered as different intermediary inputs that enter the production process via: A) the different types of human capital that increase labor productivity and hence output that they concur to generate and B) most importantly the inventions that they help producing with the final effect of the introduction of specific innovations that foster total factor productivity growth and hence output.

2.2. THE RESEARCH STRATEGY

The grafting of the new tools of the economics of knowledge and the new understanding about the relationship between the two classic notions of invention and innovation helps to elaborating a clear set of hypothesis.

Our first and main hypothesis is that knowledge cannot be any longer considered as an undifferentiated basket of a homogenous good. Knowledge differs in many ways, in terms of generation, use and exploitation. The plural, knowledges –types of knowledge-, should replace the singular, knowledge.

We want to explore here the differences across types of knowledge in terms of direct effects on economic growth and we put forward the hypothesis that the advances in hard sciences and social sciences are likely to exert a stronger effect on economic growth than the advances in medical and human sciences.

The identification of the impact of each academic field on the economic performances of a country is extremely difficult from an empirical viewpoint, since it is likely that such effect will interact with many other variables (such as the institutions, the cultural environment, the industrial specialization of a country) and will apply with differentiated lags. However our aim here is to provide a first tentative measurement, keeping our analysis at a very simple level, in order to check first of all for the presence of differences among disciplines in their impact on economic growth.

Our approach enables to regard the empirical information about the graduation of university students as a reliable indicator of the variety of both the different types of human capital and the different types of research infrastructure of an economic system. Our approach enables to exploit a source of data that has received so far little attention.

The stock of students who graduated in the academic system can be considered a reliable proxy of both the amount of dedicated and specific human capital that flows into the economic system and the size of the academic system that provides tuition and training to the students. Hence the relative size of the stock of students should also measure the stock of scholars that provide teaching and the quality and size of the infrastructure of the academic system that enrolls the students. As we assume that teaching and research are strictly associated at the graduate level we can argue that the size of graduate students seems a good indicator that provides a reliable proxy both for the specific characteristics of the human capital that is likely to enter the system and for the stock of the research infrastructure of an economic system.

The stock and the flows of graduate students can be regarded as a reliable proxy for the stock of the scientific infrastructure into which their learning activity takes place even after taking into account the possible differences in the size (and the cost) of the infrastructure that is necessary across disciplines. It might be argued in fact that the tuition and participation into research activities of a student in chemistry and engineering might involve much a larger amount of resources than the tuition and participation into research activities of a student in human sciences. However it must be stressed that the density of academics to graduate students does not vary across disciplines. Furthermore, the capital intensity varies very little if libraries are properly accounted as a form of capital (and related variable costs) that is primarily necessary for social and human sciences, while equipments and laboratories are mainly used by hard and engineering sciences. Moreover some hard sciences use very low levels of machinery and equipments such as it is the case of mathematics and informatics.

The use of the stock of graduated students enables to bring together the stream of research on human capital with the stream of research on the accountability of the academic system into an integrated economic approach where both traditions of investigation can enrich each other. The appreciation of the differences among scientific fields with respect to their direct contribution to economic growth in fact has direct application and implication to appreciating the differences in terms of specific human capital. If knowledge is no longer all alike, human capital also differs with respect to economic growth, in terms of specific knowledge content.

The differentiated effects of these sciences upon economic growth can be tested using a OECD data base that provide the figures for the numbers of students graduating in the academic system of the leading 16 advanced countries for the years 1998-2008.

The notion of knowledge indivisibility put forward by Arrow (1962) plays a central role in the identification of the correct functional form of the relationship between inputs and outputs. Knowledge indivisibility implies not only the cumulability of different vintages of knowledge across time, but also that the different kinds of knowledge are strongly complementary at the same time. Knowledge indivisibility, in other words, has important implications both diachronically and synchronically. Complementarity means that at each point in time the generation of each knowledge field relies upon the current and past acquisitions of the other fields. In order to incorporate this feature in our empirical investigation we chose to adopt a Cobb-Douglas production function. Although such a specification does not allow to explicitly test for complementarity (see Milgrom, Roberts, 1995; Mohnen, Röller, 2005), it still requires its inputs to be non-perfect substitutes, which can be considered as a satisfactory proxy for complementarity *tout court*. No knowledge field indeed can be brought to zero without harnessing the possibility to generate new knowledge at large.

We hence introduce a Cobb-Douglas production function to estimate the output elasticity of the stock of students enrolled in the different scientific fields, as it follows:

$$Y = K^a L^b HS^c SS^d MS^e HU^f \quad (1)$$

Where K stands for the stock of capital, L for labor, HS for the stock of students graduating in hard sciences, SS for the stock of students graduating in social sciences, MS for the stock of students graduating in medical sciences, and HU for the stock of students graduated in humanities. The exponents a, b, c, d, e, f measure the output elasticity of the production factors considered.

Our hypothesis is that c differs from d that differs from e and f. More specifically we expect that $c \geq d > e \geq f$.

3. THE EMPIRICAL ANALYSIS
3.1 DATA AND DESCRIPTIVE EVIDENCE

In order to be able to investigate the relationship between the heterogeneous stock of knowledge, dispersed among the different disciplines, and the aggregate economic performances of countries, we chose to take advantage of the UNESCO-OECD-Eurostat (UOE) database[2], which collects education statistics from many of the OECD member countries: specifically we used the database "Graduates by field of education". This database allows to obtaining the number of graduates in each scientific discipline for each country and in each year for the time period 1998-2008.

We are hence able to track the evolution of the number of students graduating in each year in every broad category of disciplines. For the purpose of our analysis we apply the main categories we identified in the previous section, and we also distinguish, within the category "hard sciences", between engineering-related disciplines and scientific ones. We could identify five main fields: graduates in engineering-related disciplines (including proper engineering courses and architecture), graduates in scientific disciplines (including life sciences, physics, mathematics, statistics and informatics), graduates in social sciences (social and behavioral sciences, journalism and communication, business and administration and law), graduates in humanities (including arts, humanities, and education-related courses) and medical sciences (medicine, health-related courses and social services)[3].

Based on the data availability of this source of data we combined such database with some economic variables, which would allow to analyze the relationship between the educational variables and the economic performances of countries. Specifically we collected from OECD-STAN (STructural ANalysis database) data on the value added of the total economy, the real (net) stock of capital[4] and the number of employees

[2] The database is available online on OECDSTATS.org

[3] See the Appendix A for a detailed description of the disciplines included in each of these broad categories.

[4] Since the OECD-STAN database was lacking some of the time-series of net capital stocks, we integrated the OECD data with those proceeding from the Groningen "Total Economy Growth Accounting Database" (this is the case for

engaged. From OECD-ANBERD (ANalytical Business Enterprise Research and Development database) instead we collected the yearly expenditures for the total economy in Research and Development activities. We finally deflated all the monetary measures by the Purchasing Power Parity deflator, in order to obtain comparable measures. We also retrieved information on the total population of each country from the OECD Population Statistics, in order to be able to compare countries on the basis of the ratio between the number of graduates and the total population.

The countries included in our database were chosen according to the availability of complete series of education-related data and economic variables[5]. Our final selection yielded a fairly balanced panel with 16 countries and 11 years, in Appendix A the construction and the composition of the database is explained in more details.

INSERT GRAPH 1 ABOUT HERE

A first interesting feature of our database concerns the total number of graduates (as a share of the total population of a country) and their rate of increase over time. In Graph (1) we plot the two variables on the axes of the diagram: on the ordinates is reported the average ratio -over the period 1998-2008- of the total number of graduates over the total population; on the axis instead is the average yearly growth of graduates within the same time interval.

As Graph (1) clearly shows Anglo-Saxon countries display on average higher shares of graduates over the entire population and also experience a continuous increase of the number of graduates over the last ten years (especially Australia and New Zealand). In Continental Europe the higher share of graduates is held by France, which appears to be very similar to the United States, both in terms of share of graduates and in terms of the growth of their number.

In a median zone are Mediterranean countries such as Italy, Spain, Portugal and Greece, with some slight differences among them. Specifically Italy and Portugal display a higher growth of graduates in the selected period, while Spanish numbers are slightly decreasing. Greece displays a lower share of graduating students on the total population, while the high growth of graduates over time displayed in the graph is partially due to the missing observations for some years (the same problem partly exists for Portugal, see Appendix A).

Greece and Portugal), from the EU KLEMS Database (United States and Japan). Swiss net capital stocks have been retrieved from the online time-series available at Swiss Statistics.

[5] The 16 selected countries are: Austria, Australia, Belgium, Czech Republic, France, Germany, Greece, Hungary, Italy, Japan, New Zealand, Portugal, Spain, Switzerland, United Kingdom, United States. Korea is included only in the descriptive statistics, since it lacks data on capital stocks and hence could not be included in the regressions.

Among the two former-socialist European countries included (Hungary and Czech Republic) we do not find many similarities for what concerns the growth of graduates over time: while Hungary displays a moderate growth, in Czech Republic the number of graduates has increased steadily at an average yearly growth rate of almost 15%, hence denoting a process of rapid expansion of the total mass of students in the country.

The countries which belong to the German-speaking area in Europe, instead, display quite low shares of graduates over the entire population: this is mainly due to the co-existence of professional schools (*Fachhochschulen*) which are not classified as university-level degrees, but which attract many students after secondary schools. The graph also shows that in these countries the rate of increase of the number of graduates is larger than in the rest of Europe and of the Anglo-Saxon countries, hence denoting the existence of a process of convergence of these countries towards the educational model which is widespread in the rest of the advanced capitalistic countries.

Finally, looking at the data concerning East Asian countries, such as Korea and Japan, we do not identify any peculiarity with respect to the rest of the countries, both countries are placed in a medium range as concerns the shares of graduates over the population. What is clear anyway is that Korean university system has been more dynamic than the Japanese one, with an average yearly growth rate higher than 5%.

Educational fields

Our main interest anyway lies in the heterogeneity of the stock of knowledge that each national educational system creates through the university system. We are hence interested in the specific features and dynamics of the single disciplines and in the possibility to make comparisons across countries. In the next graphs we report the relative shares of graduates belonging to the five main aggregates of disciplines previously described (engineering, scientific disciplines, social studies, humanities and medicine) and the rate of increase of the number of graduates in each field over time in the specified period (1998-2008)[6].

In Graph (2) are reported the relative shares and the rates of increase of the graduates which obtained their degree in engineering and scientific disciplines. As for the graduates in engineering-related disciplines (see the figure on the left of the graph) the first evidence concerns the very high shares of the Korean and Japanese systems (respectively 26% and 21% of all graduates in these countries belong to engineering or architecture faculties). This evidence is even more striking when considering that

[6] Greece and Portugal display some missing data which do not affect the average levels of the share of the graduates of each discipline with respect to the other countries, but may amplify the average yearly growth rates which, in some cases, simply consist in the mean of two or three periods and not of the entire period 1998-2008. In the text hence the growth rates of these two countries will not be analyzed in depth.

the percentages of graduates which belong to the engineering fields in these two countries are more than two times the shares displayed by a country such as the United Kingdom (9%).

INSERT GRAPH 2 AND 3 ABOUT HERE

Behind the East-Asian countries there is a large group of European countries in which the upper bound is represented by Germany[7] and Czech Republic and the lower bound is formed by France and Belgium. Mediterranean countries are in a middle range within this group of countries, with the exception of Greece, that shows quite lower shares (less than 10%). As in Graph (1) the English-speaking countries represent a quite coherent set, displaying very low shares of graduates in this field and without showing any tendency towards an increase over time of the number of students graduating in these disciplines.

The aggregate features of the graduates in engineering fields happen to stick very closely to the industrial structures of the countries analyzed. It is not difficult to identify among the countries with the higher shares of engineering graduates those who also display an industrial specialization drawing heavily on manufacturing activities. In order to show this more clearly we report in Graph (3) the average shares over the years of engineers among the graduates of each country together with the shares of manufacturing activities on the GDP of the same countries in the same time interval.

The results are quite striking: countries whose economies are more specialized in the manufacturing sector also invest more in the formation of graduates in the engineering fields (this is the case for Japan and Korea, but also for Germany and Italy), while countries such as United States and United Kingdom, which have recently shifted to a service-based type of economy, show lower shares of graduates in these fields.

Graph (2) also reports (in the right diagram) the data concerning the scientific disciplines. In this case the results are quite different when compared with the previous graph and the sets of countries, which displayed similar behaviors, do not show similar patterns anymore. First of all it must be noticed that France, Germany and United Kingdom display the highest shares of students graduating in these fields of science: France shows the highest share, but does not display any positive rate of growth, while the other two countries are slightly lower in terms of shares, but show positive rates of growth of the number of graduating students.

[7] As for Germany it is worth stressing that the country is also a common destination for international students willing to enroll in engineering programs (see “Education at a Glance”, 2011, OECD): this might eventually raise even more the proportion of graduates in these fields in Germany.

The set of English-speaking countries is not homogeneous anymore: United States exhibit a lower percentage of graduates in these fields when compared with United Kingdom, Australia and New Zealand. Also Mediterranean countries show divergent patterns: while in the case of Greece and Portugal the shares are quite high and also the rates of change are strongly positive over the time-period selected, Italy and Spain instead have quite low shares of students graduating in scientific disciplines and furthermore the trends are sometimes stable (Spain) or even negative (Italy). As for the East-Asian countries, again Korea shows higher shares of students in these discipline and higher rates of change with respect to Japan, which, together with Hungary, represents the lowest bound for all the countries analyzed both in terms of relative shares and in terms of growth of graduates over time.

INSERT GRAPH 4 ABOUT HERE

Graph (4) reports the data concerning social sciences and humanities. As regards social sciences (in the left diagram) the first general observation concerns the higher shares of graduates in all countries, when compared to the other disciplines. While in the previous fields most commonly the values oscillated between 10% and 20% of all graduates, in the social sciences case in most of the countries the share of graduates in these disciplines is comprised between 30% and 40%. Graph (4) shows how in this category of educational fields the United States hold the absolute primacy with an average value of more than 40% of the students who graduate in these fields[8]. Among large countries Japan, France and Italy display the highest shares of graduates in these disciplines, together with other smaller countries such as Austria, Belgium and Switzerland. The Anglo-Saxon countries in general have quite high shares (see also Australia and New Zealand), although United Kingdom shows quite lower values, especially if compared with United States. It is worth notice that Germany and Korea, two of the countries in which industry plays a major role (recall Graph 3), display the lowest shares of graduates in these fields, although these have increased quite steadily in the last ten years.

When looking at the right diagram in Graph (4), which considers graduates in humanities, it becomes quite evident how most of the countries with low shares of graduates from social science appear to have instead more graduates in humanities. This is especially clear with Germany and Korea, who display the highest shares of graduates from these fields, showing high rates of growth as well (especially in the case of Germany). Also United Kingdom is among the countries with the highest proportion of graduates from these disciplines. On the contrary United States, Italy, Austria, Australia and Switzerland show quite lower percentages, somehow suggesting that the two areas can be considered as broad substitutes. There are

[8] A possible explanation of this fact lies on the high number of international students that chose United States for their formation: according to OECD statistics (Education at a Glance, 2011, OECD) on average international students are strongly represented in social sciences, business and law. This could be the reason why an open system such as the American one would exhibit high shares of graduates from these fields.

anyway exceptions to this structure, as in the case of France and Japan, which display high shares in both fields. Anyway in the case of France the number of graduates in Humanities has been decreasing over time in the period considered here. A quite singular case is represented by Spain which is the only country in which both number of graduates from Social Sciences and Humanities are decreasing over time[9].

INSERT GRAPH 5 ABOUT HERE

In the case of medical sciences, as shown in Graph (5), the first feature to be noticed is the general increase over time of the number of graduates in these disciplines in all countries. As the OECD itself states (Education at a Glance, 2011, OECD) this trend is partly due to the progressive professionalization of nursing and to the demand for highly specialized medical care. Only Italy and Germany appear to have almost stable numbers of graduates in these fields, the rest of the countries always display positive rates of growth. In particular it is possible to notice a quite well-defined structure according to which the countries with the lowest shares of graduates in the medical disciplines are also the ones where the growth of graduates over time is higher (see for example France, Japan and Korea), thus denoting a general process of convergence across countries.

3.2. THE MODEL

In order to give a rough proxy of the effect that the endowments of knowledge in different disciplines have on the aggregate performances of economic systems we chose to measure the output elasticity of the number of graduates in each different field. As we previously said we consider graduates as an indirect measure of the resources dedicated to their formation, hence of the supply of knowledge provided by the different national university systems. We assume to face a typical Cobb-Douglas production function as follows:

$$Y_{it} = AK_{it-1}^{\alpha} L_{it-1}^{\beta} HS_{it}^{\gamma_1} SS_{it}^{\gamma_2} MS_{it}^{\gamma_3} HU_{it}^{\gamma_4} RD_{it-1}^{\delta} e^{(u_i + \lambda_t + \varepsilon_{it})} \qquad (2)$$

where, on the left-hand side is the value added of the total economy (expressed in real terms and in Purchasing Power Parities dollars) while among the independent variables we include the standard material inputs (capital stocks –again expressed in PPP dollars– and labor, i.e., employment) and the number of graduate students from each of the disciplines we identified previously: Hard Sciences (HS), Social Sciences (SS), Medical Sciences (MS) and Humanities (HU). As a further control we also include the PPP-deflated expenditures in Research and Development (RD). Since the late years of the XX century the academic system and the business sector have much increased their interactions, with an increasing flow of research outsourcing based

[9] This is due to partial decrease of the total number of graduates in Spain after 2003, see Table A.2 in Appendix A.

upon long-term contracts and even spot transactions from corporations to academic departments that perform research activities funded by corporations. Hence R&D activities impinge more and more upon the same academic research infrastructure. The inclusion of R&D expenditures enables to check whether the effects of the new academic outsourcing influence our estimates and enable to specify in which academic fields they are stronger. As we said we decided to adopt a Cobb-Douglas specification in order to proxy the synchronic indivisibility of knowledge (complementarity among different types of academic knowledge) with the non-perfect substitution of the inputs of our model. We want to estimate the impact of each of these factors on the aggregate labour productivity, hence we take logs and transform our model into the following:

$$(y_{it} - l_{it-1}) = a + \alpha(k_{it-1} - l_{it-1}) + \gamma_1(hs_{it} - l_{it-1}) + \gamma_2(ss_{it} - l_{it-1}) + \\ + \gamma_3(ms_{it} - l_{it-1}) + \gamma_4(hu_{it} - l_{it-1}) + \delta(rd_{it-1} - l_{it-1}) + u_i + \lambda_t + \varepsilon_{it} \qquad (3)$$

where small letters stand for logarithms. All the coefficients are expressed in terms of labour intensity and the error term is composed of three parts, u_i, λ_t, ε_{it} that represent respectively a firm specific, common stochastic and idiosyncratic shock.

We chose to implement fixed effects for the estimation of this model: as said previously a great difficulty in assessing the impact of different fields of academic knowledge relies on the multiple variables that might interact with knowledge itself, such as the institutional environment, the entrepreneurial culture or the industrial specialization of a country. All these factors are likely to be correlated with the variables of interest of our model: hence adopting fixed effects should allow to take into account the unobserved heterogeneity at the country level. At the same time using fixed effects allows to avoid any assumption about the correlation between the regressors and the individual effect u_i.

We also took into consideration the potential problems of endogeneity of the material inputs (capital and labour), hence their correlation with the idiosyncratic error ε_{it}. Although in macro panel we cannot consider the choices regarding the levels of output, labour and capital as the result of a simultaneous decision by a single individual/entrepreneur (which would hence make the regressors endogenous) (Griliches, Mairesse, 1998), we still need to consider the possibility that a shock a time t in the level of GDP of the economy influences the choices about the levels of investments (capital) and employment (labour) in the same period. We hence decided to use one-year lagged levels of both material inputs, in order to avoid endogeneity. We decided to do the same also for the expenditures in R&D.

As for the "educational" variables, regarding the number of students graduating each year in the different fields of study, we have no reason to assume any correlation between the error term ε_{it} and these variables: the graduation of students in fact is anything but a decision depending from the contemporaneous economic conditions, but rather the final outcome of a choice generally undertook 3-5 years before. Things would have been different, had we used the number of enrolled students, in that case exogenous economic shocks might affect the contemporaneous decision of students to enroll into the university (and in which discipline) or enter the labour market.

Using the stock of graduate students should also prevent the potential problems of simultaneity that arise when we depart from the assumption that academic knowledge is an intermediary input and we allow knowledge to be also a final good, able to increase the satisfaction of its consumers. Indeed it could be the case that the growth of the overall wealth in an economic system might induce a greater share of students to study some specific subjects (specifically those related to human sciences) for their own cultural interest and not in order to improve their job opportunities. When knowledge is considered as a final good it becomes likely that the more a country is rich the more students can allow themselves to choose university degrees on the basis of their interests, not for the effect that these might have on their careers. In such a case we would then face a problem of reverse-causality: the growth of income would influence the choices concerning the discipline, with a clear positive correlation between the error term and the students in disciplines such as human sciences. However also in this case using the stock of graduating students allows us to exclude this possibility: the growth of the GDP could only influence future levels of the stock of graduates.

Even if we are not particularly worried about the possible endogeneity of the "educational" variables, we chose to include in the estimations also the lagged levels of these variables: the reason is that we want to control whether the effect of these variables on the total value added of the economy applies with some lags. If we consider these variables as proxies of the human capital that enters the productive system, then it would be reasonable to expect a natural lag between the incorporation of the mass of graduates into the labour market and its effect on the aggregate economic performances. We also want to check whether using lagged values changes substantially the coefficients.

3.3 THE RESULTS

Table (1) shows the results concerning the estimation of equation (3): in column (1) we introduced the number of graduates for each discipline, together with the material inputs, without including R&D expenditures. The estimates confirm our hypothesis concerning the coefficients of the number of graduates from the different disciplines: specifically we notice that hard sciences (HS) and social sciences (SS) display positive and significant coefficients (at the 1% level), while medical sciences (MS) and human sciences (HU) have negative and weakly significant coefficients. The negative coefficients might be partly surprising, anyway, as previously said, in the case of medical sciences the institutional set up of the health industry, organized in most countries as a public service, does not allow to obtain precise measures of their economic effects. Hence it could be the case that medical sciences enter the production function of the whole economy mainly as a cost, while we are not able to measure their (non-economic) benefit. In the case of human sciences, instead, the implicit assumption of our model, according to which knowledge enters the production function of other goods as an intermediary input, does not match well with the features of this specific field of study. In other words we expect knowledge in human sciences to affect the production process of other goods but also to increase the final satisfaction of the consumers of that specific knowledge, i.e. the students themselves. Since our proxy does not distinguish between these two types of effects and only the former is accounted for, we might be double-counting this variable.

Since the model is expressed in labour intensity we had to decide whether to impose or not constant returns to scale. We chose to check whether this constraint would affect the estimates, hence in column (2) we did not introduce the levels of employment, which control for the presence of diminishing or increasing returns to scale. The results do not change significantly between the two models: the coefficient of capital increases when constant returns to scale are imposed, but the coefficients of the educational variables remain largely unaffected.

Given the graphics analyzed in the previous section, we wanted to check as well whether some of the results could be somehow induced by some outlier: i.e. countries which might influence the overall results of the estimates. Specifically we wanted to test whether the coefficients for the social sciences depended from the inclusion in our sample of the United States, which in Graph (4) happened to display the highest share of graduates in social sciences. This might generate a problem since United States clearly are among the countries with the highest level of GDP per capita: in column (3) we hence excluded the observation from United States from our sample. Anyway the signs and the significance of the coefficients do not change, on the contrary the coefficient for social sciences becomes even higher than that of hard sciences, thus rejecting our hypothesis that United States would have boosted the coefficient of social sciences.

In column (4) we take advantage of the possibility of distinguishing, among hard sciences, between engineering-related disciplines and scientific ones (life sciences, physics, mathematics, statistics and informatics) and we include them separately, dropping the variable “hard sciences”. The results show a positive and highly significant coefficient for engineering graduates, while a positive but not significant coefficient for graduates from scientific disciplines. This confirms the more direct impact of engineering-related courses on the productivity levels, with respect to the role of scientific disciplines. These results call for stronger efforts to detail the analysis of the relations between knowledge and economic performances stressing the differences among academic disciplines in order to identify more homogeneous types of knowledge –and hence sets of disciplines– and their actual elasticity to the output of a country.

Finally in column (5) we assess the effects of the inclusion of R&D expenditures. Our assumption is that the expenses in R&D can be considered as a proxy of the overall investment of a country in research and science; we hence expect that the graduates from hard sciences and the R&D expenditures might proxy a similar measure, that is the overall national stock of human capital in scientific fields and of the research infrastructure of the academic system that is most likely to perform research activities funded by corporations. We expect then the inclusion of R&D to impact negatively the coefficient of hard sciences, since we might be measuring two times the same variable, as previously explained.

The results confirm our hypothesis: when R&D expenditures are included the elasticity of hard science drops substantially and, being still positive, it loses its significance. Conversely social sciences remain positive and significant.

Table (2) presents the results from the robustness checks we included, in order to control for the presence of some lagged effect of the variables concerning the number of graduates. As previously said, we want to control for the possibility that lagged levels of these variables might yield too different results.

Anyway Table (2) reassures us about the stability of the estimated output elasticities: the use of one year lagged levels doesn't affect the size of the coefficients, nor the sign and the significance. Only when we control also for R&D the coefficients drop, losing part of their significance. When we use two-years-lagged levels of the variables concerning the number of graduates, instead, we notice that only the coefficient of hard sciences remains positive and strongly significant, while that of social sciences becomes small and not significant anymore. The size of the other coefficients (medical and human sciences) are small and not significantly different from zero, thus confirming that the effects are more or less stable disregarding the lags chosen, but they lose their size as the lags increase: this is proven by the fact that when we include R&D among the explanatory variables the coefficients of the educational variables (twice-lagged) decrease in size and become not significantly different from zero.

4. CONCLUSIONS

The fading role of the corporation as the privileged locus for the accumulation and exploitation of technological knowledge has brought the academic system on the center stage of the analysis of the determinants of economic growth. The wide consensus on centrality of the academic system as the main engine of economic growth has called increased attention on its accountability. The centrality of the academic system calls for the allocation of increasing resources into the academic system to foster economic growth. This in turn calls for a closer scrutiny of the actual benefits stemming from their allocation. The allocation of more resources calls for more attention and feeds the increasing need to better assess their efficiency.

Much attention has been paid to increase the accountability of the academic system. Two distinct notions of efficiency apply in this context. Internal efficiency accounts for the relationship between inputs and outputs at the academic system level. Output here is measured in terms of standardized units of knowledge. External efficiency accounts for the relationship between the resources transferred to the academic system and their effects on the output of the economic system at large.

Much attention has been directed to assess the levels of internal efficiency with the elaboration and application of new tools to better measure the output of the academic systems in the effort to measure the amount and the quality of knowledge actually generated and transferred to the economic system. Lesser attention has been paid to assess the actual levels of external efficiency i.e. to measure the relationship between the amount of resources allocated to generate new knowledge and its eventual effects in terms of output growth in the system at large. The two notions of efficiency would coincide only if knowledge were a homogenous good. As soon as we appreciate that knowledge is a composite bundle of a variety of different kinds of knowledge, the problem of the composition of the bundle becomes crucial.

The risks of a mismatch between supply and demand are high. Some types of knowledge may engender lower levels of knowledge externalities than other. The economic system may demand more intensively some kinds of knowledge as an intermediary input than other.

The distribution of resources across scientific fields has received little attention and poor empirical investigation. Recent advances of the economics of knowledge enable to enter more directly into the intra-allocation of resources within the academic system. The notions of knowledge fungibility and knowledge cumulability on the one hand and the distinction between the types of knowledge that contribute the introduction of respectively technological and organizational innovations enable to articulate the hypothesis that knowledge is not a homogenous basket of an undifferentiated good. Knowledge differs on many counts. A crucial difference concerns the capability of the different types of knowledge to contribute economic growth according to their differentiated support to the introduction of innovations and the accumulation of differentiated types of human capital.

Our approach enables to make an original use of the figures for graduate students, a rich and detailed source of empirical evidence, widely available, that has been little used so far. The stock of graduate students can be considered as a reliable indicator of both the variety of types of human capital that are likely to flow into the economic system and of the variety of academic competences in terms of stock of scholars and size of academic infrastructure. To test the hypothesis, in fact we relied upon the stocks of graduate students in the economic systems of 16 OECD countries, in the years 1998-2008.

In order to provide a first possible measurement of the impact of each type of academic knowledge on the economic performances of a country, i.e. the degree of their external efficiency, we propose a very simple econometric approach in which we identify the output elasticity of four main academic fields, proxied by the number of students graduating in each of them. The results show that there are important differences in the contribution of these fields to economic growth: specifically hard sciences and social sciences, contribute more to economic growth, than, respectively, medical sciences and human sciences.

Both the approach and the results seem important. The proposed approach integrates the human capital and economics of higher education traditions of analysis that have grown apart. The former has been implemented with full-fledged economic approaches based to assess the effects of different endowments of human capital on the performances of countries, industries, regions and firms. The latter has privileged the microeconomic exploration of the knowledge output of the academic system and the assessment of its internal efficiency. The approach elaborated in this paper provides an integrated frame of analysis where the emphasis on the external efficiency of the academic system is focused and contribution of the different types of knowledge on economic growth is directly assessed.

The results shed some light on the crucial issue of the intra-academic allocation of the growing amount of resources devoted to the academic system as a whole. It seems more and more important to call attention on the differences among academic fields in terms of their actual capability to contribute economic growth. It seems no longer appropriate to call for more support to the academic system as an undifferentiated whole. The results of our empirical analysis, that might be considered as a first attempt to discriminate among different "knowledges" based upon the number of graduate students, call for future research directed to a finer grained and more rigorous assessment of the impact of the stocks of academic knowledge on the national or regional economic performances. It seems worth to explore and carefully assess which fields deserve more funding than others. More generally it is more and more clear that there is an emerging need to better direct the resources invested into the academic system, not only in terms of internal efficiency but also and mainly in terms of their actual fungibility to economic growth. It is no longer sufficient to claim that all kind of knowledge yields knowledge externalities: as a matter of fact some types of knowledge yield knowledge externalities that can be better exploited by the business sector than others. Public support should be increasingly directed towards the most productive types of knowledge rather than across the board of all disciplines

The policy implications are important: public support to the academic system, advocated to support economic growth, should not be spread uniformly across academic disciplines but rather focus the academic fields that are better able to contribute economic growth. Policy guidelines should be fine-tuned to this necessity and, on the demand-side, might introduce incentives for students to enroll in specific academic fields, for example through differentiated fees.

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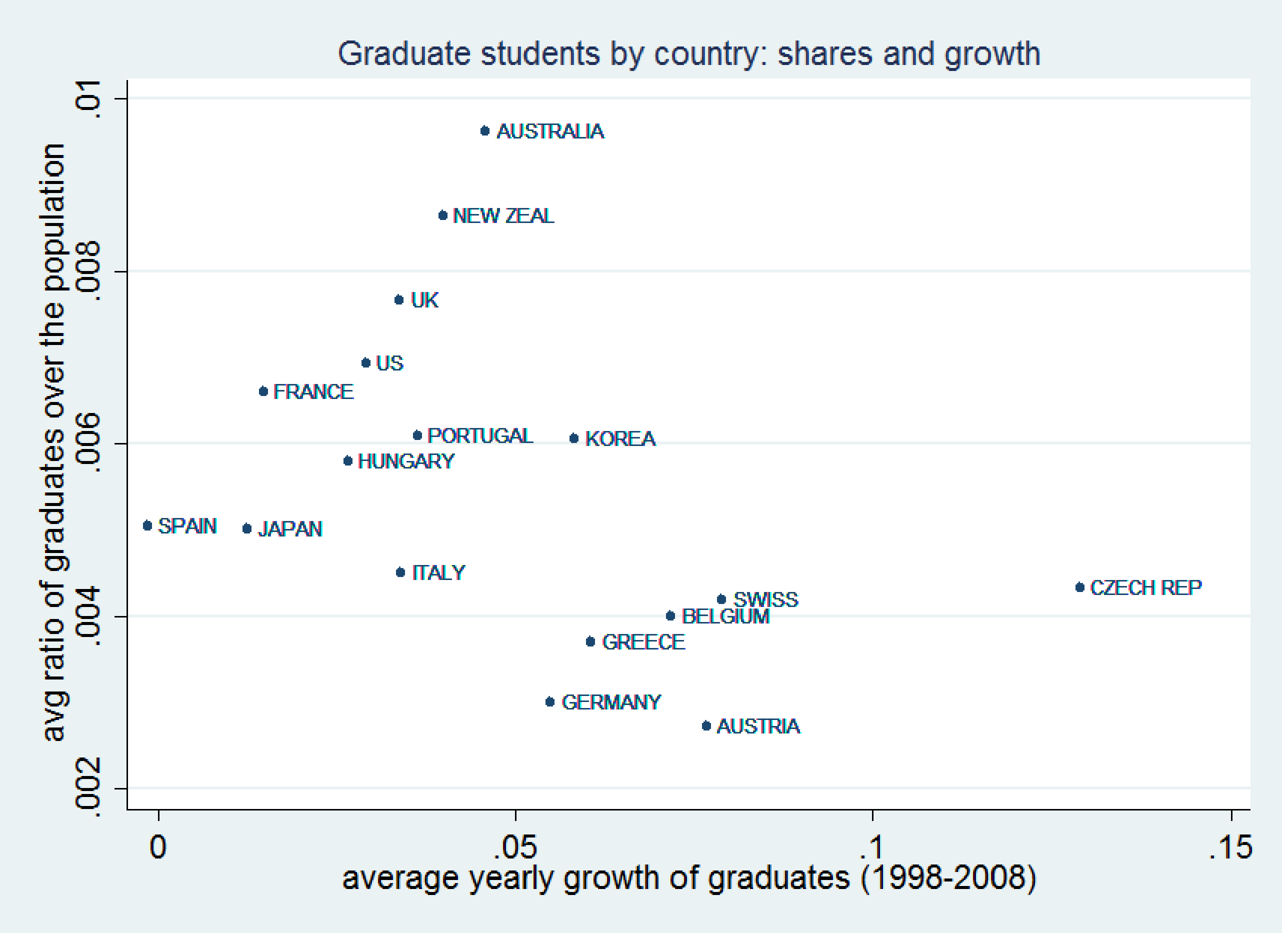
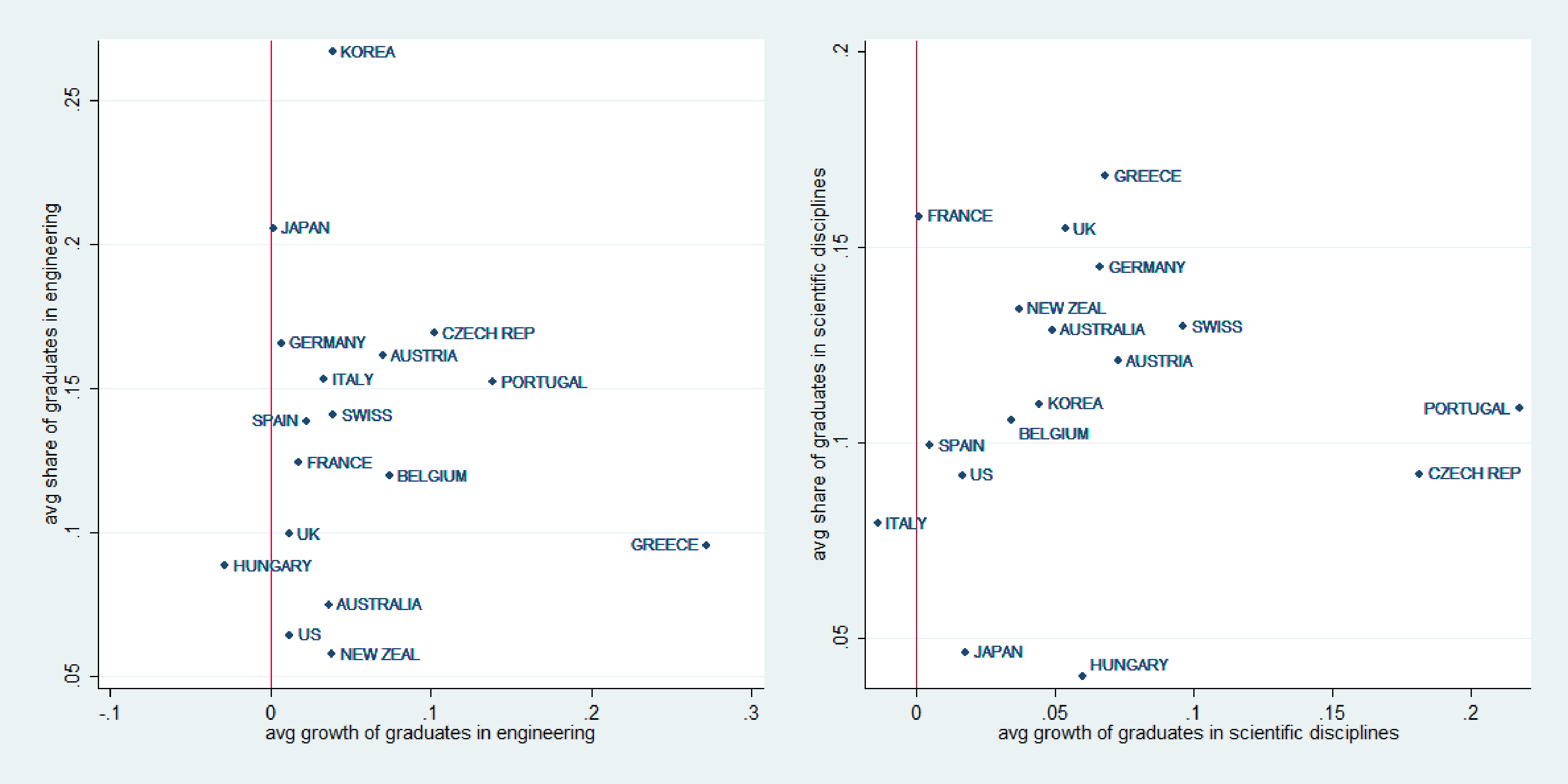
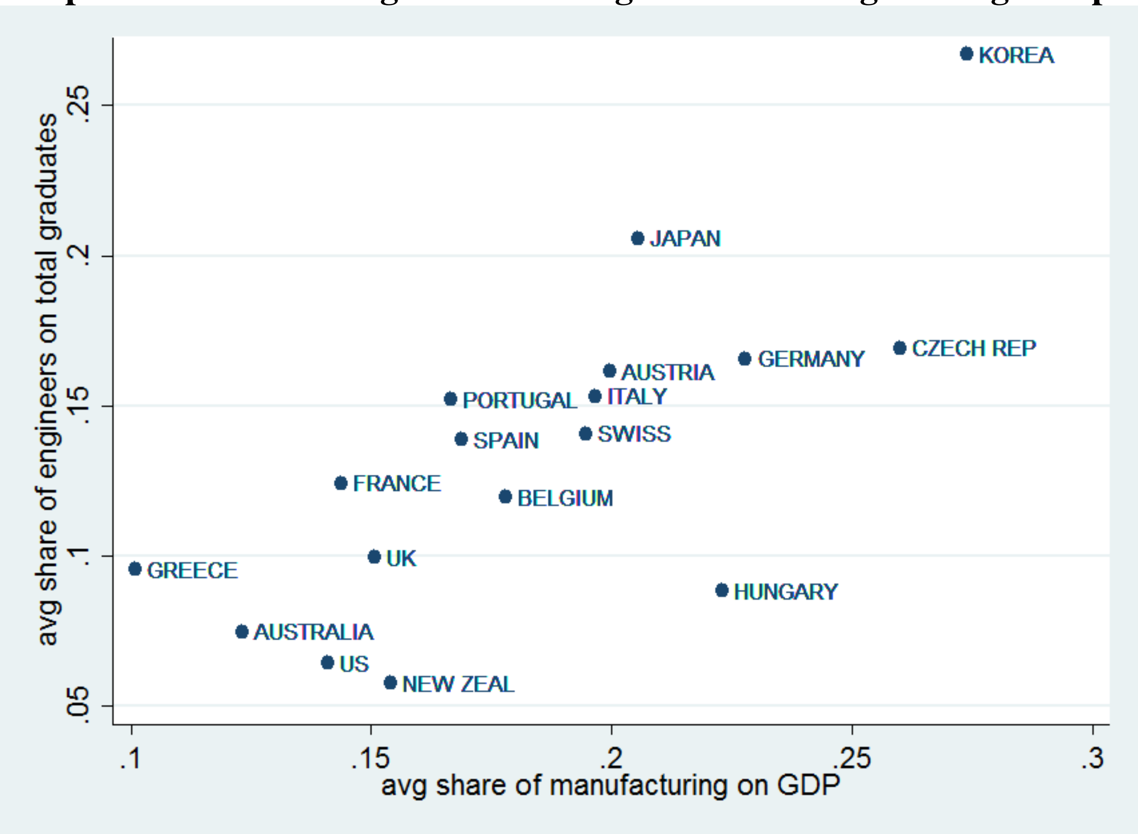
Graph 1: Total number of graduates per capita and rate of increase over time



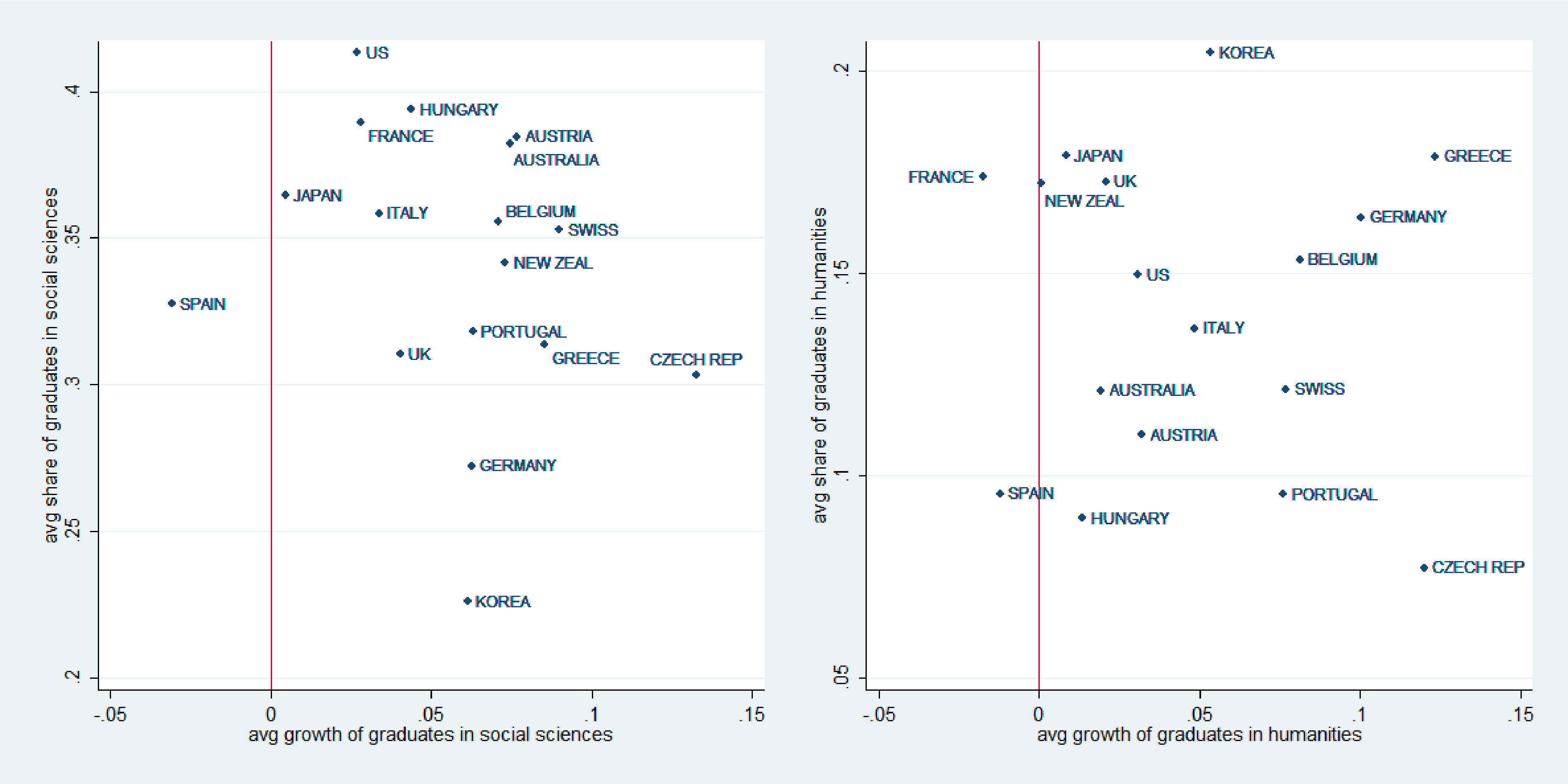
Graph 2: Engineering and Scientific Disciplines



Graph 3: Manufacturing and share of graduates in engineering disciplines



Graph 4: Social Sciences and Humanities



Graph 5: Health and Welfare

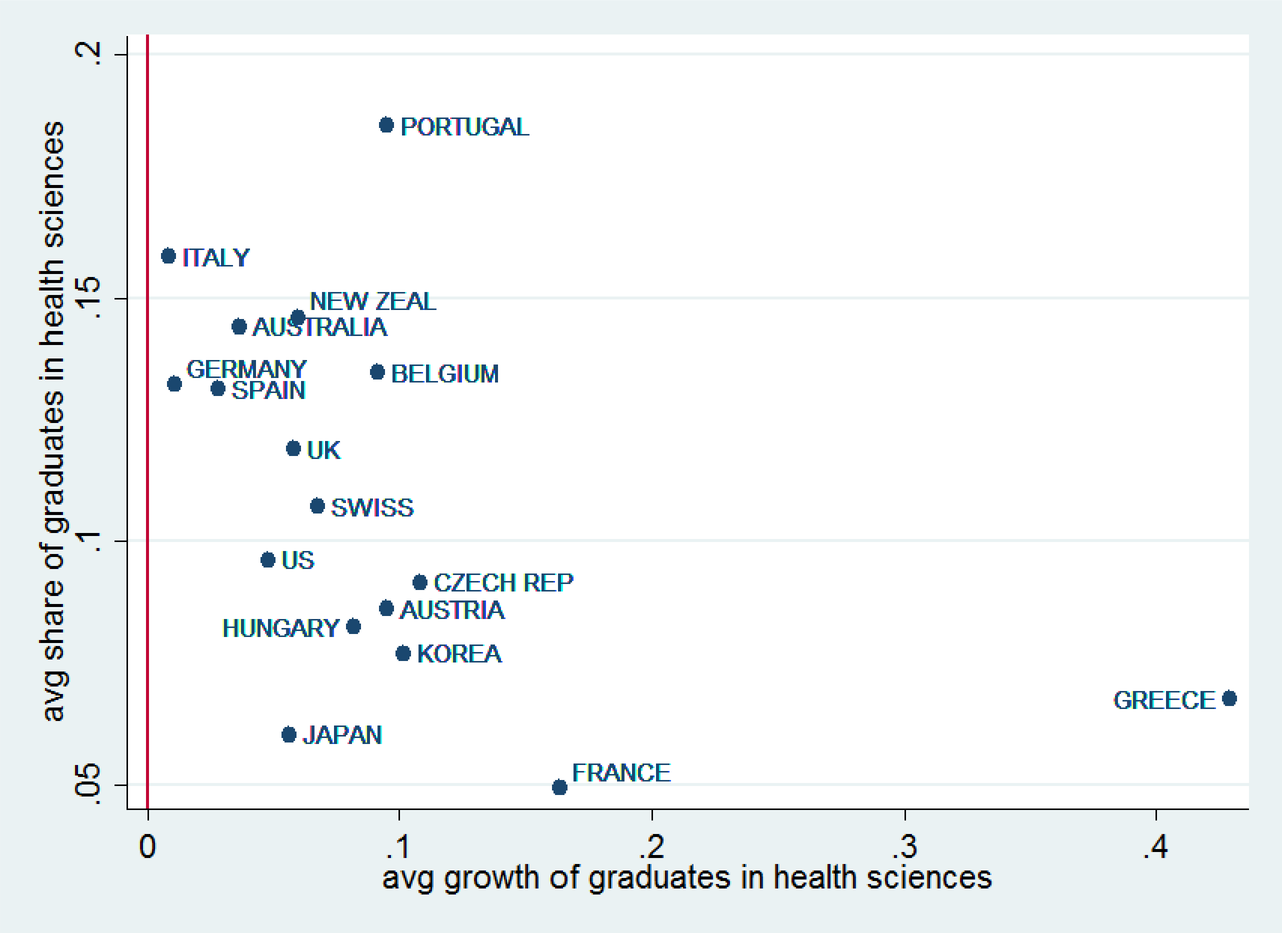


Table 1. Estimation results

Variables			no US	no HS	R&D
	(1)	(2)	(3)	(4)	(5)
$\ln(K_{it-1}/L_{it-1})$	0.595***	0.803***	0.864***	0.606***	0.419***
	(0.153)	(0.117)	(0.209)	(0.151)	(0.148)
$\ln(HS_{it}/L_{it-1})$	0.092***	0.081**	0.087**		0.039
	(0.034)	(0.034)	(0.035)		(0.034)
$\ln(SS_{it}/L_{it-1})$	0.085***	0.110***	0.096***	0.085***	0.070***
	(0.028)	(0.025)	(0.029)	(0.027)	(0.026)
$\ln(MS_{i}/L_{it-1})$	-0.026*	-0.023*	-0.032**	-0.039***	-0.012
	(0.013)	(0.013)	(0.014)	(0.014)	(0.013)
$\ln(HU_{i\,t}/L_{it-1})$	-0.044*	-0.035	-0.041*	-0.049**	-0.015
	(0.023)	(0.023)	(0.024)	(0.023)	(0.023)
$\ln(ENG_{it}/L_{it-1})$				0.088***	
				(0.026)	
$\ln(SCIENCE_{it}/L_{it-1})$				0.017	
				(0.019)	
$\ln(R\&D_{it-1}/L_{it-1})$					0.109***
					(0.028)
$\ln(L_{it-1})$	-0.270**		-0.165	-0.299**	-0.437***
	(0.131)		(0.142)	(0.129)	(0.128)
Constant	8.741**	1.956	3.754	9.128**	12.78***
	(3.560)	(1.400)	(4.381)	(3.509)	(3.450)
Observations	116	116	107	116	116
id	16	16	15	16	16
R-squared	0.802	0.792	0.798	0.812	0.833

The dependent variable is ln(value added$_{it}$ /L_{it-1}). All models are estimated with fixed effects and they include time dummies for each year. In Column (3) observations from United States have been excluded, in column (4) Hard Sciences (HS) have been disaggregated between Engineering Disciplines (ENG) and Scientific Disciplines (SCIENCE). In column (5) R&D expenditures have been included as further controls. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 2. Estimation results (lags)

Variables			2 lags	2 lags
	(1)	(2)	(3)	(4)
$\ln(K_{it-1}/L_{it-1})$	0.560***	0.383**	0.499**	0.344**
	(0.170)	(0.152)	(0.205)	(0.167)
$\ln(HS_{it-1}/L_{it-1})$	0.088**	0.058*	0.097**	0.053
	(0.035)	(0.031)	(0.049)	(0.040)
$\ln(SS_{it-1}/L_{it-1})$	0.079***	0.049*	0.051	0.026
	(0.028)	(0.025)	(0.036)	(0.030)
$\ln(MS_{it-1}/L_{it-1})$	-0.031**	-0.021	-0.031*	-0.019
	(0.016)	(0.014)	(0.018)	(0.015)
$\ln(HU_{it-1}/L_{it-1})$	-0.041	-0.026	-0.017	-0.009
	(0.025)	(0.022)	(0.030)	(0.024)
$\ln(R\&D_{it-1}/L_{it-1})$		0.143***		0.179***
		(0.027)		(0.029)
$\ln(L_{it-1})$	-0.355**	-0.569***	-0.403**	-0.680***
	(0.147)	(0.134)	(0.170)	(0.145)
Constant	10.49**	15.07***	12.12**	17.15***
	(3.992)	(3.574)	(4.698)	(3.881)
Observations	113	113	99	99
id	16	16	15	15
R-squared	0.780	0.836	0.733	0.828

The dependent variable is $\ln(\text{value added}_{it}/L_{it-1})$. All models are estimated with fixed effects and they include time dummies for each year. In Columns (1) and (2) educational variables are included with one year lag, in columns (3) and (4) educational variables are included with two years lag. In columns (2) and (4) R&D expenditures are included as further controls. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

APPENDIX A

The source of data for the number of graduates students is: “Graduates by field of Education”, UNESCO-OECD-Eurostat (UOE) data collection on education statistics, compiled on the basis of national administrative sources, reported by Ministries of Education or National Statistical Offices. In the following tables are listed the distinct disciplines and the criteria of aggregation used in order to obtain the variables included in the regression analysis.

Table A.1. Disciplines and categories included in the data

Broad categories	Disciplines	Courses
HUMANITIES (HU)	*140: Education*	141: Teacher training (ISC 141)
		142: Education science (ISC 142)
	200: Humanities and Arts	210: Arts (ISC 21)
		220: Humanities (ISC 22)
SOCIAL SCIENCES (SS)	*300: Social sciences, business and law*	310: Social and behavioural science (ISC 31)
		320: Journalism and information (ISC 32)
		340: Business and administration (ISC 34)
		380: Law (ISC 38)
HARD SCIENCES (HS)	*400: Science*	420: Life sciences (ISC 42)
		440: Physical sciences (ISC 44)
		460: Mathematics and statistics (ISC 46)
		480: Computing (ISC 48)
	500: Engineering, manufacturing and construction	520: Engineering and engineering trades (ISC 52)
		540: Manufacturing and processing (ISC 54)
		580: Architecture and building (ISC 58)
MEDICAL SCIENCES (MS)	*700: Health and welfare*	720: Health (ISC 72)
		760: Social services (ISC 76)
not included	*600: Agriculture*	
	800: Services	
TOTAL	*900000: Total over all fields of study*	

Source: UNESCO-OECD-Eurostat (UOE), “Graduates by field of Education”

Description of the variable “graduates”

“Graduates are those who successfully complete an educational programme during the reference year of the data collection. One condition of a successful completion is that students should have enrolled in, and successfully completed, the final year of the corresponding educational programme, although not necessarily in the year of reference. Students who do not complete the final year of an educational programme, but later successfully complete a recognised "equivalency" examination based on knowledge learned outside of the education system, should not be counted as graduates. Successful completion is defined according to the graduation requirements established by each country: in some countries, completion occurs as a result of passing a final, curriculum-based examination or series of examinations. In other countries, completion occurs after a specific number of teaching hours has been accumulated (although completion of some or all of the course hours may also involve examinations).” (Source: UNESCO-OECD-Eurostat (UOE))

Table A.2. Total number of graduates for each year and in each country

Country	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Australia	149768	155783	148502	165536	178041	192088	206140	228169	228396	233995	236627
Austria	16225	16068	17050	18625	18956	20441	22967	24770	26789	28181	34917
Belgium	..	..	32074	34023	35636	37040	38304	39683	40422	62224	56941
Czech Republic	22228	24173	29877	34951	36041	40272	46097	45670	60260	69657	80694
France	356186	362584	362369	367536	382661	412346	412346	463296	434586	412358	412730
Germany	213710	209598	204398	198203	199863	206365	219746	240092	310923	339543	369913
Greece	..	..	..	..	..	..	35779	41951	..	41185	45590
Hungary	43790	47964	59210	56681	60377	64336	63232	68570	63626	61125	57105
Italy	164567	174540	185979	195273	212153	241423	321284	373634	380010	394731	231082
Japan	592156	601633	607356	629634	637168	638548	646983	652432	665831	673641	671064
Korea	221956	233702	246393	273380	279017	293142	303559	305739	306524	317452	397497
New Zealand	26847	29534	31175	31571	31581	32154	37882	39459	41797	41973	39950
Portugal	..	..	52947	..	..	67353	56513	56901	58935	74407	80725
Spain	213829	230999	213585	217802	218884	216852	210603	202848	202642	199767	210577
Switzerland	22586	25792	26710	26440	..	27262	28547	31330	36812	40429	43784
United Kingdom	374582	383745	393400	425733	..	452708	..	498185	514135	521487	536723
United States	1716886	1739178	1819795	1837257	..	1987792	2089901	2153802	2223029	2279379	2343517

Level of education: 905160, Tertiary-type A and advanced research programmes; Programme destination: 900000, Total; Programme orientation: 900000, All educational programmes; Field of education: 900000, Total over all fields of study; Gender: 90: Total males+females

Table A.3. Correlation matrix between the variables used in the estimation of equation (3)

	$\ln(VA_{it}/L_{it-1})$	$\ln(K_{it-1}/L_{it-1})$	$\ln(L_{it-1})$	$\ln(SS_{it}/L_{it-1})$	$\ln(HS_{it}/L_{it-1})$	$\ln(ENG_{it}/L_{it-1})$	$\ln(SCIEN_{it}/L_{it-1})$	$\ln(MS_{i}/L_{it-1})$	$\ln(HU_{i\,t}/L_{it-1})$	$\ln(RD_{it-1}/L_{it-1})$
$\ln(VA_{it}/L_{it-1})$	1									
$\ln(K_{it-1}/L_{it-1})$	0.7479*	1								
$\ln(L_{it-1})$	0.3074*	0.2227*	1							
$\ln(SS_{it}/L_{it-1})$	0.1149	-0.0875	-0.0318	1						
$\ln(HS_{it}/L_{it-1})$	0.0584	0.0636	0.0724	0.5982*	1					
$\ln(ENG_{it}/L_{it-1})$	-0.1961*	0.0462	0.2194*	0.2557*	0.7277*	1				
$\ln(SCIEN_{it}/L_{it-1})$	0.2356*	0.0914	-0.0794	0.5907*	0.8112*	0.2166*	1			
$\ln(MS_{i}/L_{it-1})$	0.0349	-0.0543	-0.1551	0.6370*	0.4839*	0.2108*	0.5321*	1		
$\ln(HU_{i\,t}/L_{it-1})$	-0.0862	-0.2504*	-0.0315	0.8665*	0.7033*	0.3677*	0.6404*	0.6278*	1	
$\ln(RD_{it-1}/L_{it-1})$	0.6277*	0.6678*	0.6086*	-0.0999	0.1309	0.0938	0.1178	-0.2197*	-0.2387*	1