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THE HETEROGENEITY OF KNOWLEDGE AND THE ACADEMIC MODE OF KNOWLEDGE GOVERNANCE. ITALIAN EVIDENCE IN THE FIRST PART OF THE XX CENTURY[1]

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ABSTRACT. The academic system is an effective mechanism of knowledge governance that remedies to markets failure in the generation and dissemination of knowledge. The heterogeneity of academic knowledge with respect to economic growth however calls attention of the composition of knowledge generated by the academic system. This paper contributes the large literature on the university industry relations with the identification of the heterogeneity of academic knowledge with respect to economic growth and the analysis of its implication for the working of the academic mode of knowledge governance. It provides unique historic evidence on the differentiated effects of academic spillovers as proxied by chairs, distinguished by disciplinary field, on total factor productivity growth. The results shed new light on the differentiated impact of the different disciplines on economic growth. The increase in the number of chairs in engineering and chemistry contributed to total factor productivity growth more than any other discipline. This is consistent with the historic context characterized by the radical transformation of a backward agricultural economy into a highly industrialized and rich one. The results of this cliometric analysis call attention on the need to control and direct the composition of the bundle of types of knowledge generated by the academic system with the support of public subsidies.

KEY WORDS: KNOWLEDGE GOVERNANCE; SELECTIVE SPILLOVERS; UNIVERSITY INDUSTRY RELATIONS; TFP.

JEL CODE: O33

1. INTRODUCTION

Knowledge is essential for the efficiency of an economic system. The increase of efficiency of an economic system can only take place as a result of the increase in the amount of knowledge used as intermediary input for the production of all other goods. Knowledge is a very special economic good characterized by an array of

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highly idiosyncratic characteristics such as non-exhaustibility, non-appropriability, non-divisibility and hence cumulability, complementarity and fungibility. Moreover the generation of new knowledge necessarily impinges upon the use of existing knowledge as an intermediary input. Hence knowledge is at the same time an output and an input (Nelson, 1959; Arrow, 1962; David, 1993; Antonelli, 2008).

Such characteristics typically lead to market failure and because of inefficient allocation of property rights, resources and incentives, the system risks experiencing either the tragedies of commons or the opposite tragedies of the anticommons. In this context the governance of knowledge emerges as an institutional remedy to market failure (Ostrom and Hess, 2006).

Knowledge governance consists in the set of rules, procedures, modes and protocols that organize the generation and the use of knowledge in an economic system. It includes a variety of institutional factors including hierarchical coordination within firms and public institutions, and, most importantly, transactions-cum-interactions. The working of knowledge governance mechanisms, at each point in time, within each economic system, can be seen as the spontaneous result of a systemic process of polycentric governance where the interaction between a myriad of actors is able to implement the emergence of structured and viable modes of coordination that are able to complement or substitute the imperfect allocation of property rights: knowledge governance mechanisms change across time as the architecture of its elements is the object of different forces that act in diverse relations and reflect the changing weights within the system.

The renewed attention to the role of universities as a central mechanism for knowledge governance in advanced economies is the result of recent changes in the knowledge governance of the advanced economies. Since the decline of the corporate mode of knowledge governance a large consensus has emerged that the academic system is also and primarily a major engine of economic growth. Additional public resources have been invested with increased expectations and in the public discourse the role of the academic system has been stretched considerably adding new functionalities and new responsibilities. The academic system is now expected to contribute economic growth with a role that is well beyond the traditional training functions and the contribution to cultural activities. Our paper explores precisely the foundations of such an extended and enlarged role of the academic system.

The central aim of the paper is to show that the historic analysis of the pre-corporation mode of knowledge governance, based upon the university as the central mechanism for knowledge governance, can provide basic guidance to articulate a selective support to the academic system in the new, emerging open innovation mode. Indeed also in the first part of the XX century in most advanced economies the university held a central role, working as a dedicated tool to support the generation and dissemination of knowledge when and where large corporations were lacking.

The Italian evidence of the first 60 years of the XX century confirms that the university played a key role in the process of industrialization and rapid economic growth experienced by an economy characterized by the small and medium size of its firms. However the Italian example also shows that only a subset of scientific disciplines was actually able to provide effective knowledge externalities to the rest of system.

Such results confirm that knowledge is not homogeneous: on the opposite it should be regarded as a highly differentiated bundle of different knowledge items. The appreciation of the intrinsic disciplinary heterogeneity of academic knowledge with respect to economic growth, confirmed by the historic example, has important consequences for knowledge governance: public support to the academic system should take into account the differentiated effects of the different disciplines.

The rest of the paper provides in section 2 an analysis of the recent shift from the corporate mode of knowledge governance to the open innovation model at the heart of which the university-industry relations play a central role. Section 3 explores the strengths and weaknesses of the academic mode of knowledge governance and articulates the main hypotheses on the effects of the heterogeneity of academic knowledge with respect to economic growth in section. Section 4 presents an empirical analysis of the effects of the evolution of the Italian academic system, as measured by the changing stock of chairs, distinguished by scientific field, on productivity growth in the first part of the XX century. The conclusions summarize the main results and put them in perspective.

2. THE CHANGING ORGANIZATION OF KNOWLEDGE GOVERNANCE

Economic history documents the emergence and implementation of different forms of knowledge governance to remedy the failure of markets for knowledge. These different knowledge governance mechanisms are alternative institutional solutions that have emerged through historic time by means of recursive processes of interactions and structural changes to better organize the complexity of knowledge interactions and support the creation and exploitation of knowledge externalities according to the changing knowledge infrastructure of the system.

For quite a long time, since the early decades of XX century, advanced economic systems relied upon the corporate model. The corporate model of knowledge governance, was first identified by Joseph Schumpeter (1942) as the major institutional innovation introduced in the US. It was characterized by large corporations able to rely upon internal markets and hierarchical interactions in the generation of new technological knowledge. Corporations were able to engage in the systematic performance of research activities with the creation and active implementation of intra-muros R&D, hiring skilled scientists and implementing long-term research programs. The strength of the corporate model lies in twin capability to: i) generating efficiently new knowledge building upon the accumulation of competence based upon learning processes and its recombination with formal research activities, and ii) valorizing internally stocks of existing knowledge with systematic strategies of knowledge exploitation based upon diversification and internal provision of funds for the generation of new knowledge. Diversification provided, at the same time, the opportunities to increase the scope of application and to increase the breadth and diversity of knowledge units that could enter the recombinant generation of new knowledge process. The corporate model appeared for quite long time especially effective in the organization of internal financial markets where extra-profits stemming from the previous generation of knowledge and the related introduction of innovation could overcome the serious problems of financial markets in the provision of finance to fund the generation of new knowledge and the introduction of innovations. The effective intra-muros management of the interactions between production, marketing, internal finance and research seemed for quite a long time the best way to securing the allocation and the direction of resources for the generation and use of appropriate quantities of knowledge. The success of the corporate model of knowledge governance put the university aside pushing it towards the specialization in didactic activities and research in basic science. Corporations funded and performed the bulk of applied research, intramuros.

The discontinuity brought about by the introduction of the new gale of ICTs and later of biotechnologies called attention upon the limitations of the corporate mode. The corporate model seemed more and more unable to grasp the new technological opportunities. The main limitation of the corporate model was found in the resistance and lack of interest with respect to the external sources of technological knowledge. The non-invented-here syndrome and the high costs of absorption of external knowledge undermine the corporate model that excelled in directing technological change towards incremental advances, but failed in taking advantage of new radical scientific and technological breakthroughs. The main weakness of the corporate model can be identified in the high risks of errors of exclusions. Corporate managers are better able to select incremental innovations that build upon internal knowledge cumulability, avoiding the inclusion of 'lemons', but less ready to grasp new opportunities that emerge in scientific fields that are far away from their competence too much based upon the experience acquired by means of internal learning processes (Chandler, 1977).

The decline of the corporate model as the core of an effective knowledge governance mechanism and the need to extend the scope of the search process so as to include new emerging opportunities in new scientific fields has called attention on alternative modes of knowledge governance. The open innovation model has been consolidating in the US after the ICT revolution and seems to be especially viable for science based technologies. The open innovation model recognizes the central role of universities as the main locus for generation of both scientific and technological knowledge, specifically for its wide range of search directions that can be implemented and assessed. Countries and regions with a strong academic and scientific infrastructure have an advantage in the introduction of science-based technologies especially when and where the start-up-venture capitalism mechanism can complement the academic generation of knowledge as an effective tool for its economic exploitation and further dissemination (Chesbrough, 2003).

In the new open innovation mode of knowledge governance the academic system is back to the center stage. The role of the new equity based finance however marks a major difference of the new open model of knowledge governance with respect to the academic model at work in Europe in the first part of the XX century. In the old model the provision of funds for the exploitation of scientific knowledge was based on the credit provided by banks. In the new model, exploitation is based upon equity provided by venture capitalism and eventually, by means of mergers and acquisitions of the start-ups publicly traded in the stock exchange markets, by corporations. This difference has major implications in terms of the viability of the screening process. The university provides a large and differentiated supply of new possible avenues for extracting technological knowledge from a variety of scientific advances. The structured provision of equity, organized on venture capitalist companies and sequentially on the working of the stock exchanges increases the chances of a polycentric inclusion of the most promising areas for technological exploitation. The crucial difference between the two funding system is found in the asymmetries of creditors which can only participate into losses with no tools to share the profits on the successful ventures, with respect to shareholders that bear the risks of the losses but can cash the profits (Stiglitz, Weiss, 1981).

Besides the clear differences with respect to the funding mechanisms, the new open model of knowledge governance puts again the university-industry relations at the center of the generation of new knowledge. The return to the academic model of knowledge governance and its increasing role within the new systemic approaches to innovation policies solicit the investigation of its analytical foundations and calls renewed attention on the possible sources of both success and failure (Fagerberg, Sapprasert, 2011).

3. STRENGHTS AND WEAKNESSES OF THE ACADEMIC MODE OF KNOWLEDGE GOVERNANCE

The recent wave of investigations upon the open innovation model has called renewed attention to the university as the main source of knowledge externalities that spill in the system and provide firms with the low-cost access to knowledge as an intermediary input into the recombinant generation of technological knowledge (Jaffe, 1989; Feldman, 1994; Rosenberg and Nelson, 1994).

As a matter of fact the open innovation model of knowledge governance is based upon the centrality of the university as the dedicated institution for the generation and dissemination of generic knowledge with a wide scope of application and high levels of fungibility. Firms rely on universities for the provision of generic knowledge that they can eventually use in the recombinant generation of specific knowledge and sequentially for the introduction of innovations (Jaffe, 1989).

Actually, however, the academic model is far from being new. As a matter of fact it preceded the corporate mode as it was very much in place in Europe since the late XIX century in economic systems characterized by small firms. In Europe a public academic system was already in place, building upon the heritage of the medieval universities, and played a central role in the rapid growth of the European economy. The European public academic system was actively supported by the states and yet the interactions between the academic system and the business community were quite strong, as a large case study evidence confirms (Geuna, 1999).

The public university system can be regarded as an institution that reconcile the conflicting proprietary incentives necessary to fund and perform the generation of knowledge with the non-appropriability conditions that are necessary to secure its timely dissemination and un-limited use as an input into the generation of further technological knowledge. This result is made possible by the role of the state as an intermediary that collects taxes from economic agents and provides funds to the university. The university in turn provides incentives to researchers to generate and disseminate knowledge. Academic knowledge can be widely disseminated by means of publications, specific interactions between scholars and firms, mobility of trainees.

The academic mode of knowledge governance can be a very effective mechanism of knowledge governance as it makes it possible at the same time to incentive the generation of knowledge, favoring the use of knowledge as an intermediary input into the recombinant generation of new knowledge and its use into the economic system as an intermediary input for the introduction of innovations. From this viewpoint the academic mode of knowledge governance seems especially suited to exploit the special characteristics of knowledge as an output and an input (David, 1993).

The increasing role of the academic system within the open innovation mode of knowledge governance has called attention upon its possible weaknesses. The literature has identified the limits of the actual dissemination of the knowledge generated by universities as one of the main weaknesses of the academic mode. Publications risk to performing very poorly as the exclusive vector of the knowledge generated in academia. The actual enrollment by firms of PhDs rarely matches the necessary role of interface between the academic and the business community. The need for closer interactions and actual transactions between the academic and the business system has been made clear. A variety of mechanisms have been advocated and put in place to try and remedy the risks of poor dissemination and consequently poor use of academic knowledge in economic activities.

While much attention has been paid to put in place mechanisms that could favor the actual interaction between the academic and the business community and the creation of effective channels of dissemination of academic knowledge externalities, lesser attention has been paid to assessing the actual congruence of the knowledge generated by universities with its actual exploitability by the business system. The identification of the heterogeneity of knowledge and the analysis of its implications for the effective working of the academic mode of knowledge governance has received so far little attention. Actually much of the analysis has been based upon the tacit assumption that knowledge is homogeneous (Aghion, Dewatripont, Hoxby, Mas-Colell, Sapir, 2009).

However as a growing literature has shown, knowledge cannot be any longer regarded as a homogenous bundle: its components differ widely in terms of appropriability, cumulability, exploitability and fungibility. Some types of knowledge can be better appropriated than others for their high levels of tacitness. Fungibility and exploitability differ because of the varying levels of basicness. The levels of cumulability change according to the indivisibility and complementarity with the existing stocks of knowledge. Finally, looking at its fungibility it seems stronger the distinction between knowledge as final good and knowledge as an intermediary good. The latter deserves indeed public support much more than the former (Trajtenberg et al. 1997)

The working of the university as an elegant mechanism for improving the governance of knowledge, as an intermediary good, can be questioned by the intrinsic heterogeneity of knowledge across disciplines. As long as knowledge is supposed to be homogeneous, in fact, the university can be seen as an effective institutional remedy to failure of markets to allocate the correct amount of resources to the generation of knowledge and eventually to the growth of the economies. However as soon as the intrinsic heterogeneity of knowledge is appreciated the working of the academic system, as an institutional remedy to market failure needs major qualifications. The composition of the bundle of different knowledge items becomes a central issue. Because of the lack of appropriate signalling devices, able to inform decision makers about the excess supply or demand of specific knowledge items, universities can keep generating types of knowledge that firms do not actually need.

In standard markets, prices perform the central role of signals that convey information about the actual costs of producers and needs of customers and stir entry and exit decisions making adjustments possible so as to favor the crossing of demand and supply schedules around equilibrium levels. In the traditional design of the university-industry relations very little attention is paid to implementing signaling devices that make it possible to firms to inform universities about the types and kinds of knowledge that are actually necessary to improve their performances.

Because knowledge can no longer be regarded as a homogeneous bundle, , it becomes important to assess which types of knowledge are actually able to generate effective knowledge spillovers that are able to support economic growth (Audretsch, Lehmann, Warning, 2004; Antonelli, 2008).

The appreciation of the heterogeneity of knowledge stresses the centrality of new signalling mechanisms that can appreciate the intrinsic differences across types of knowledge and academic disciplines. The role of the state as an intermediary that collects taxes and transfers them to the academic system where the resources are used to incentive both the generation and the dissemination of knowledge is no longer sufficient. Additional mechanisms are necessary to insure that the resources are directed towards the types of knowledge that are actually necessary and useful to the economic system for its recombinant transformation into technological knowledge and eventually innovations. The risks that universities are unable to generate the appropriate bundle of knowledge types are very high.

The identification of the heterogeneity of knowledge and more specifically the investigation about the possible heterogeneity of knowledge with respect to economic growth may have important implications for the design of more efficient mechanisms of knowledge governance. It allows to grasping the hidden effects of a new typical principal-agent problem. The university, as an opportunistic agent, may indulge in actions geared towards the generation and dissemination of types of knowledge that the business community is not likely to use and the state, as the principal, is not able to contrast.

In this context it becomes a central issue to assess whether all academic activities at large or only a selective group of scientific fields are actually able to supporting economic growth by means of the generation of effective knowledge externalities.

3.1 HYPOTHESES AND RESEARCH STRATEGY

The historic analysis of the role of the academic model of knowledge governance in an economic system that had not yet adopted the corporate model can provide important insights about the actual viability and the limitations of the academic system within the new open innovation mode of knowledge governance that is substituting the corporate mode as the key mechanism for knowledge governance. Of course an historical example cannot provide useful suggestions about which are the disciplines that today can provide useful knowledge for science based industries, but it can provide insights about the heterogeneous impact of different academic fields on economic growth.

In the first part of the XX century the Italian economy experienced a prolonged period of fast industrialization and economic growth that paralleled the evolution of the national academic system. At the end of the XIX century the Italian academic system however was already very strong with a long history of embedded participation to the articulation of the national economic and social system. Different waves of creation of universities took place ever since the establishment of Bologna, the first university in history, especially because of the active participation of the princes of the array of small regional states each of which attempted to increase its prestige and reputation establishing a high quality university.

Since the beginning of the XX century Italy experienced a fast growth and a radical transformation from a poor agricultural economic system into a strong industrial one and its academic system witnessed a strong evolution of the stock of chairs. The provision of scientific and technological knowledge was almost exclusively based upon the public university system as large corporations –and related R&D- were almost absent. University industry relations were very active and scholars of the public universities did participate actively to business activities typically on a professional consultancy base that was fully allowed by non-exclusive employments relations and supported by social approbation[2].

In this context the analysis of the evolution of the Italian public university system can be effectively proxied by the number of chairs. Their effect on economic growth can be appreciated testing the relationship between the increase in the number of chairs and total factor productivity (TFP) growth in the years 1900-1959. The use of chairs as an indicator of the levels of academic activity seems appropriate to catch the actual amount of knowledge externalities spilling from the academic system into the industrial one when we take into account the lack of alternative sources of evidence. It must be stressed that, differently from patents or publications, chairs are not a direct measure of academic output and hence their use as a proxy for knowledge spillovers has some limitations. Indeed chairs are first of all a cost figure, a measure of input, rather than output. However they share this feature with all expenses in R&D. Henceforth their use as an indicator shares the basic assumption, common to all R&D measures, that their marginal revenue is actually larger than their costs and that to a large extent spills in the economic system. However it must be stressed that, with respect to R&D measures, chairs display the great advantage to enabling a much finer grained analysis at the level of the scientific field of activity. Where R&D

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[2] A relevant source of information and examples related with this tight connection existing in Italy between entrepreneurs and universities can be found in the Biographical Dictionary of Italian Entrepreneurs, a multivolume work launched in 2001 by Enciclopedia Italiana and coordinated by members of the Economic History Institute at Bocconi University (Amatori, 2011). The volume provides a detailed case study evidence related with the analysis of the sources of technological knowledge that enabled the introduction of the key innovations in the first part of the XX century in Italy.

measures simply merge together expenses corresponding to research activities in heterogeneous fields, university chairs allow to distinguish among the disciplinary fields in which research is undertaken and to identify the specific impact of each of them on economic activities.

The accountability of chairs enables to test the hypothesis that selective academic spillovers played a central role in the rapid growth of the Italian economy. The detailed evidence provided by the disciplinary fields of each academic chair in fact makes it possible to test whether different academic disciplines yield differentiated flows of knowledge externalities and hence effects on the rates of growth of TFP (Audretsch Lehmann Warning, 2004).

The rates of increase of TFP of the Italian economy in the years 1900-1959 are the dependent variable. TFP levels, as it is well known, stem from the discrepancy between the expected levels of output produced in equilibrium conditions and the actual ones, historically experienced. Assuming constant returns to scale the discrepancy can take place only when knowledge generated by the academic system at a cost paid indirectly via the collection of taxes, can be used and used again by a multiplicity of secondary and derivative users as an input of both the recombinant generation of new knowledge and the introduction of innovations (Griliches, 1979).

In this case knowledge generated by the academic system enters the recombinant generation activities and the production functions of downstream users at cost that are far below the equilibrium ones. Each additional and derivative use increases the discrepancy between equilibrium conditions, valid for standard economic goods that tear and wear, are fully exhaustible, perfectly divisible and appropriable, and the specific conditions at which the repeated use of knowledge is possible (Andersen Rossi, 2011).

The historic evidence provided by the analysis of the performances of the different academic fields of the Italian academic system provides important elements to assess whether the contribution of academic knowledge is homogenous or, instead, some disciplines are better able to support economic growth than others. The accountability of chairs can test whether the generation of pecuniary knowledge externalities is homogenous across disciplines, or on the opposite, varies, with significant heterogeneity.

4. THE EMPIRICAL EVIDENCE

4.1. THE DATA

Our empirical analysis relies on an original database that comprehends for each year in Italy from 1901 to 1959 all the chairs disaggregated in five disciplinary fields, following the latest OECD classification (OECD 2006): Engineering and Technology

(ET - including chemistry and engineering), Social sciences (SS - sociology, economics and law), Humanities (HUM - arts and humanities), Natural sciences (NS - biology, physics and mathematics) and Medical and Health Sciences (MS). For the economic data we combined the series recently elaborated by Baffigi (2011) together with the Bank of Italy and by Broadberry Giordano and Zollino (2011) in their reexamination of the Italian economic growth in the XX century[3].

In order to compute the TFP for the Italian economy we rely on a typical Cobb-Douglas production function at the country-level, in which output (Y) is measured by the time series of national GDP in 2010 constant prices, as provided by Baffigi (2011), the stock of fixed capital (K) is the net capital stock in the total economy in 2010 constant prices provided by Broadberry et al. (2011) and labor (L) is represented by the time series of full-time equivalent workers in the total economy (Broadberry et al, 2011). α and β are the output elasticity of capital and labour and we further assume constant returns to scale:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} \qquad (1)$$

Where $\alpha + \beta = 1$

The series provided by Baffigi and Broadberry et al. do not include the aggregate value of wages, so that we cannot compute the aggregate labor and capital shares on the basis of the data. We stick to the usual values β=0.6 and α=0.4 (Gollin, 2002). TFP is computed as it follows:

$$\ln A_t = \ln Y_t - \alpha \ln K_t - \beta \ln L_t \qquad (2)$$

Figure (1) displays the time series of the yearly growth rates of TFP, obtained through the explained procedure, fully consistent with those estimated by Broadberry et al. (2011). As for the academic system Figure (2) provides evidence of a positive trend between 1901 and the beginning of WWI. After WWI the number of chairs decreases substantially, returning to the levels of the beginning of the century. At the beginning of the 30's the number of chairs reached the pre-war levels. After the WWII, chairs increased steadily with a structural transformation of the academic system towards the modern academic standards.

The analysis of the shares of chairs for each discipline (See Figure 3) highlights that medicine faculties kept for the whole period a position of absolute predominance. Chairs in social sciences increased steeply at the beginning of the Thirties, while the share of chairs in humanities increased especially after WWII, during the overall

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[3] An appendix that provides an accurate description of how the database has been built is available on request.

expansion of the system. Engineering and Technological sciences (including engineering and chemistry), exhibit a constant and positive growth. Conversely chairs in Natural Sciences such as mathematics physics and biology display a constant negative trend. The decline is especially evident at the beginning of the 30's, and during the accelerated growth experienced during the 50's.

Summing up, the analysis of the first 60 years of the XX century in Italy shows a progressive shift, started at the beginning of the century and ended during the 30's, which increased the centrality of Engineering and Technology Sciences (chemistry, engineering), at the expense of more theoretical sciences (mathematics, physics, natural sciences). Social sciences (economics, statistics, sociology) gained momentum especially during the 30's. Conversely, in the growth of the second post-war period the share of chairs in engineering and chemicals and management-related disciplines remained quite stable, while human sciences experienced a positive increase.

4.2. THE ECONOMETRIC STRATEGY

According to our central assumption, the level of TFP is affected by the knowledge spilling from the academic system and specifically from the chairs of each of the disciplines considered:

$$A_t = cET_t^{\gamma_1} SS_t^{\gamma_2} HUM_t^{\gamma_3} NS_t^{\gamma_4} MS_t^{\gamma_4} e^{u_t} \qquad (3)$$

Where A indicates the level of TFP, c is a constant, u is a idiosyncratic error term, ET stands for Engineering and Technology (chemistry and engineering), SS indicates Social Sciences (sociology, economics, law), HUM is for Humanities (arts, humanities), NS is for Natural Sciences (biology, physics, mathematics) and MS stands for Medical and Health Sciences.

We can estimate equation (3) after a log transformation into equation (4):

$$\begin{aligned} \ln A_t &= \ln c + \gamma_1 \ln ET_t + \gamma_2 \ln SS_t + \gamma_3 \ln HUM_t + \\ &\gamma_4 \ln NS_t + \gamma_5 \ln MS_t + v_t \end{aligned} \qquad (4)$$

Figures (2) and (3), provide the check for the presence of unit roots and confirm that the "academic" variables do not display any stationary behavior. Table (1) presents the results of a Dickey-Fuller test (D-F) which examines the null hypothesis that the series are I(1), with the critical values (CV) at the 10 per cent level: the results indicate that we cannot reject the hypothesis that the time series are integrated of order 1. We then transform equation (4) in first differences:

$$\Delta_1 \ln A_t = \ln c + \gamma_1 \Delta_1 \ln ET_t + \gamma_2 \Delta_1 \ln SS_t + \gamma_3 \Delta_1 \ln HUM_t + \gamma_4 \Delta_1 \ln NS_t + \gamma_5 \Delta_1 \ln MS_t + \Delta_1 \nu_t \quad (5)$$

Where Δ_1 stands for the change of each variable from year t-1 to year t.

Table (2) shows the two tests to assess the stationarity of the series. It is generally accepted that the Dickey–Fuller test has little power, thus we introduce another and more robust test, Kwiatkowski, Phillips, Schmidt and Shin (1992), that takes the opposite approach: it tests the null hypothesis that the series are stationary, against the alternative of non-stationarity. The rejection of the null hypothesis in the Dickey-Fuller test therefore corresponds to the non-rejection of the null hypothesis in the test by Kwiatkowski et al. (1992). Table (2) shows that the first differences of the series under consideration are surely stationary at the highest confidence level. We can hence estimate equation (5) with the normal OLS estimator.

We took into account some possible sources of endogeneity of the variables in our model, as well as some problems related with the nature of the residuals. As regards endogeneity, we believe that our estimates are not affected by problems related to reverse causality: a shock at time t of TFP might affect the increase or decrease of the number of chairs in each discipline only in future periods, but not on the contemporary rate of change. Therefore we do not expect the dependent variable to affect the correlation between $\Delta_1 \ln X_t$ and $\Delta_1 \varepsilon_t$. We then consider the independent variables as past and present exogenous.

In order to avoid the risks that the possible exclusion from our model of variables which do affect the growth of TFP, might lead to serial correlation of the residuals of our estimation, and hence to incorrect standard errors, we run a test for the presence of autocorrelation of the residuals. We also dedicate a part of our estimation procedure to test the more appropriate time lag to include in the regressions: it is not straightforward to understand with which time lag the externalities spilling from the academia towards the growth of TFP occur (Adams, 1990; Encaoua, Hall, Laisney, Mairesse, 2000). Finally in order to account for the possibility that the exclusion of variables that affect both the growth of TFP and which are also correlated with the growth of the different type of chairs might lead to a typical problem of omitted-variable bias that would affect the coefficients and standard errors of the academic variables, we use lagged values of the independent variables..

4.3 THE RESULTS

Table 3 presents the results of the test of the baseline specification of our model, as expressed in equation (5), with the contemporaneous rates of growth of the dependent and independent variables: ET (Engineering and Technology) has a positive and significant coefficient. The growth rates of the other disciplines display non-significant (and negative) values. MS (Medical and Health Sciences) show a moderate and positive coefficient, although not significant. To check whether different values of α and β affect our estimates, in column (2) the dependent variable is the growth rate of TFP calculated holding $\alpha = 0.3$, instead of 0.4 (as in the previous specification). The results do not change, reassuring about the robustness of our estimate with respect to the procedure used in order to calculate TFP.

In column (3) we also include the lagged value of the dependent variable in order to control for cyclical dynamics of the growth of TFP that might affect the results obtained so far: also in this case however there are no significant changes in the signs and the magnitudes of the coefficients.

Finally, given that the only positive and significant coefficient is ET (Engineering and Technology), we try and investigate which of its components is more related to the growth of TFP: whether the growth rate of the number of chairs in chemistry or in engineering. The results in column (5) show that, when we discriminate between chemistry and engineering, we find that only the growth rate of the chairs in engineering displays a positive and significant coefficient, while the coefficient of chemistry is positive but not significantly different from zero.

As anticipated, we also need to check for the presence of autocorrelation among the residuals of the estimated models. We are especially concerned that if $\Delta_1 v_t$ follows an $AR(1)$ process, due to some omitted variable in the model, the standard errors of the independent variables might be downward biased, thus leading to wrong conclusions about their significance (Greene, 2008). Having included the lag of the dependent variable we cannot rely on the normal Durbin-Watson tests for the detection of serial correlation (Dezhbaksh, 1990), furthermore the Durbin-Watson dos not perform well in small samples. Therefore we employ the Breusch-Godfrey test, which performs well in small samples and in dynamic models (Breusch, 1978; Godfrey, 1978). The results reject the hypothesis of serial correlation of first order and provide robustness to our significance tests.

Another issue related to our estimation procedure regards the number of lags that we should include into our specification: basically we want to check whether we should include further lags in equation (5). We then decided to adopt both Akaike and Bayesian Information Criteria in order to find the best specification of our model[4].

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[4] The results of Table 7 however tell us that, when we use one-year rates of change, the best specification remains the one with only the contemporaneous growth rate of the independent variables.

Robustness Checks

In order to provide further robustness to our results, and to take into account the problems of the identification of the correct time lag to consider when we measure the academic spillovers and the potential problems of omitted variables, we try two other strategies to estimate equation (5).

First we choose to use long differences (three-years growth rate) obtaining the following specification:

$$\begin{aligned}\Delta_3 \ln A_t &= \ln c + \gamma_1 \Delta_3 \ln ET_t + \gamma_2 \Delta_3 \ln SS_t + \gamma_3 \Delta_3 \ln HUM_t + \\ &\gamma_4 \Delta_3 \ln NS_t + \gamma_5 \Delta_3 \ln MS_t + \Delta_3 v_t\end{aligned} \tag{6}$$

Where Δ_3 stands for the change of the variable from year t-3 to year t.

Equation (6) takes into account the fact that the effects of the spillovers stemming from certain academic fields might need a longer time period to affect the economic system: using three years growth rates should allow to appreciate also this possibility.

The results in column (1) of Table (4) change slightly the previous picture: ET (Engineering and Technology) is not significant anymore, although it still keeps a positive coefficient of about 0.4. MS (Medical sciences) and NS (Natural Sciences) still have the coefficients and signs they had in the previous specification (respectively positive and negative effect), but again they are non-significant. Finally SS (social sciences) displays the usual negative sign, but in this new specification the coefficient is also significant at the 5% level. However we notice from the results of the Breusch-Godfrey test that the residuals are strongly affected by serial correlation.

Second, we try other specifications and again we distinguish in column (2) between chemistry and engineering. The results are very different from those obtained with the contemporaneous rates of change in Table (3): in this case only chemistry is positive and significant, while engineering is not significantly different from zero. Again we notice that the Breusch-Godfrey test on the existence of serial correlation among the residuals of the estimation rejects the hypothesis of no-autocorrelation.

The inclusion, among the regressors, of the lagged value of TFP growth (ΔTFP at time t-3) eliminates the problem of serial-correlation in the residuals and changes slightly the values of the other variables (SS is not significant anymore), but it does not affect the sign of chemistry, which remains positive and significant.

To account for the issue of the omitted variable bias we transform equation (6) into the following:

$$\begin{aligned}\Delta_1 \ln A_t &= \ln c + \gamma_1 \Delta_2 \ln ET_{t-1} + \gamma_2 \Delta_2 \ln SS_{t-1} + \gamma_3 \Delta_2 \ln HUM_{t-1} + \\ &\gamma_4 \Delta_2 \ln NS_{t-1} + \gamma_5 \Delta_2 \ln MS_{t-1} + \Delta_3 v_t\end{aligned} \tag{7}$$

In this case the contemporaneous rate of growth of TFP is regressed against the one-year-lagged long differences (two-years) of the academic variables. In such a way we are still taking into account the possibility that spillovers from the academia might need a certain lag to affect the economy, and we can exclude the possibility that exogenous shocks happening at time t could affect both the growth of TFP and the growth of the number of chairs. This typical omitted-variable problem would create a correlation between the error term and the independent variables and finally a bias in the coefficients of the academic chairs.

The specification of equation (7) allows us to avoid this risk. The results of Table (5) are fully consistent with those of Table (4). Again ET (Engineering and Technology) is not significant, but when we distinguish between chemistry and engineering we find that the former is positive and significant. The other coefficients are never significant. Also when we control for the existence of serial correlation among the residuals the Breusch-Godfrey test can never reject the null hypothesis of no-autocorrelation.

The last robustness check relates to the hypothesis that increasing the total number of academic chairs without distinguishing among specific fields would not necessarily lead to increases in TFP. We therefore try one last specification of equation (5) in which we simply aggregate all the chairs into one single variable:

$$\Delta_1 \ln A_t = \ln c + \gamma_1 \Delta_1 \ln(TOTAL - CHAIRS_t) + \Delta_1 v_t \tag{8}$$

Table (6) presents several test of this new specification in which the growth rates of the total number of chairs are regressed on the growth rates of TFP.

Columns (1) and (2) introduce the contemporaneous rates of growth of the total number of chairs and the second and third lags: the results show that, disregarding the number of lags included, the coefficients of the variable never differ significantly from zero. Furthermore we notice that the R-squared is extremely low, meaning that we are not explaining almost anything of the variance of the growth of TFP. The same results occur when the dependent variable is calculated with $\alpha = 0.3$. The R-squared and the sizes of the coefficients do not improve even when, as a further control, we include the lagged rate of growth of TFP in column (4).

In column (5) we use long differences (the growth rate of the last three years): also in this case the coefficient remains not significant and the results of the Breusch-Godfrey test also show that there is a significant problem of serial correlation in the error terms. Finally we estimate a modified version of equation (7), trying to take into account the issue of endogeneity. Also in this case the results do not change, the coefficient of the lagged two-years rate of growth of the independent variable is very close to zero and furthermore we detect the presence of autocorrelation through the test on residuals of the estimation.

Summing up we find that the large growth of TFP experienced by the Italian economic system in the first 60 years of the XX century is not explained by the rate of growth of the overall number of chairs in the Italian university systems. Conversely when we discriminate among the different disciplines we find that only the growth of chairs in applied sciences such as engineering and chemistry explains the growth of TFP, the other disciplines exhibit non-significant coefficients. Specifically we find that when we consider engineering and chemistry separately, chemistry is positive and significant with longer time lags, while engineering is significant with contemporaneous rates of change.

5. CONCLUSIONS

The recent literature on the mechanisms underlying the generation and exploitation of technological knowledge has witnessed a strong and increasing attention to the role of the academic system as the primary source of both scientific and technological knowledge for the economic system. The relations between universities and business firms have been investigated with detail and the role of a variety of characteristics of the interacting partners (ranging from their location to their respective size, age and specialization, the typology of contracts, their recurrence and duration) in supporting the capability of an economic system to increase the amount of knowledge being generated and used for economic purposes has been identified and appreciated.

The amount of public resources invested in the academic system raises an issue of public accountability that calls attention upon the criteria by means of which public resources are invested in the academic system across disciplinary fields. Here the contribution of an historic perspective is very useful. The academic system has been a pillar of the knowledge governance mechanisms for quite a long time.

As a matter of fact the new wave of interest in the role of the academic system is the direct consequence of the decline of the corporate model, introduced in the US in the first part of the XX century and diffused worldwide in the second part of the XX century. The corporate model dampened the role of the academic system as the primary governance mechanism for the generation and dissemination of technological knowledge. The corporation became the key player and the university was very much relegated to a com-primary role with increasing emphasis on its training role. The decline of the central role of the academic system in the generation of new knowledge paralleled the widespread diffusion of the corporate model.

The decline of the corporate model of knowledge governance brought back the university to the center stage next to venture capitalism. The new centrality of the academic system, however, is not new. The academic system had been, through the XIX century and a large part of the XX century, especially in Europe, the pillar of a knowledge governance mechanism that had made possible fast rates of economic growth with the continual generation and effective dissemination of scientific knowledge.

The historic analysis of its performances and working mechanisms can help guiding the implementation of the open innovation mode. In this context it is most important to assess whether additional public resources should be invested to support the academic system at large or rather a selected disciplinary component, which is better able to actually support economic growth.

The use of academic chairs seems a reliable indicator of the characteristics of the academic system in terms of strength and disciplinary composition. The results of this study support its use for further investigations especially in regional and historic contexts that do not enable the use of other scientometric indicators.

The use of chairs provides important opportunities to measure the efforts and extent of activity of the academic system under investigation across disciplinary fields. The disciplinary account in turn enables the direct investigation of the actual knowledge externalities that are made available to the economic system by each scientific field. At a closer look the results of our empirical analysis confirm that in Italy knowledge externalities from the academic system to the economy stemmed only from the research activities undertaken in specific fields such as engineering and chemistry. The academic activities in these fields appeared to be able to provide support to the rapid industrialization of the Italian economic system, much better than other scientific disciplines. This result is important as it enables to add the scientific specialization as one more relevant specification to the analysis of the relations between university and the economic system.

More specifically, these results are important as they call attention upon the need to improve the working of the academic system as an efficient mechanism of knowledge governance. They apply specifically to knowledge as an intermediary good, and hence an engine of growth, crucial for the generation of further knowledge and its application in the production of other goods. It does not pretend to apply to knowledge as a final good: its pursuit may be assessed with other tools and in other analytical contexts.

The new evidence about the heterogeneity of knowledge suggests that it is no longer sufficient to increase the amount of resources transferred to the university to supporting economic growth. It is necessary to analyze and question the composition of the bundle of knowledge types generated and disseminated by the academic system. The risks of an agency problem for which universities may prefer to generate and disseminate types of knowledge that do not match the demand and the expectations of the firms are not negligible. The historic evidence upon the heterogeneity of knowledge and the different impact of the scientific field of activity on economic growth calls for a major effort to identify the scientific fields that are better suited –today- to contribute economic growth.

The close inspection and valorization of all indicators that enable the actual measure of the real use of knowledge generated by the academic system by the business sector become necessary to better direct the generation of knowledge and to help improving the composition of the bundle of knowledge so as to make it closer to expectations of the business sector. The range of indicators can include the citations of academic outputs such as books and articles by patents and essays produced in the business sector as well as the flows of contracts and professional transactions that take place between firms and academic institutions and individuals. The measures of the actual use of academic knowledge can substitute the signaling role of the –missing- prices for knowledge items so as to help the academic system to better assess the matching between the composition of the supply of spillovers and the actual needs of the business sector.

The creation of a comprehensive vector of information about the actual use of knowledge generated by the academic system can improve substantially the governance of knowledge. Its systematic use, in fact, can help the academic system and public policy at large, to reducing the principal-agent problem built into the academic system.

The systematic elaboration of comprehensive vectors of information about the actual use and the specific economic effects of the knowledge generated by the different disciplinary fields of each university and the academic system at large can help shrinking the room for the typical opportunistic behavior of indulging in the generation of knowledge that is not actually useful for economic growth while claiming and voicing support for the generic provision of additional public subsidies.

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Figure 1. The growth of TFP in Italy (1900-1960)

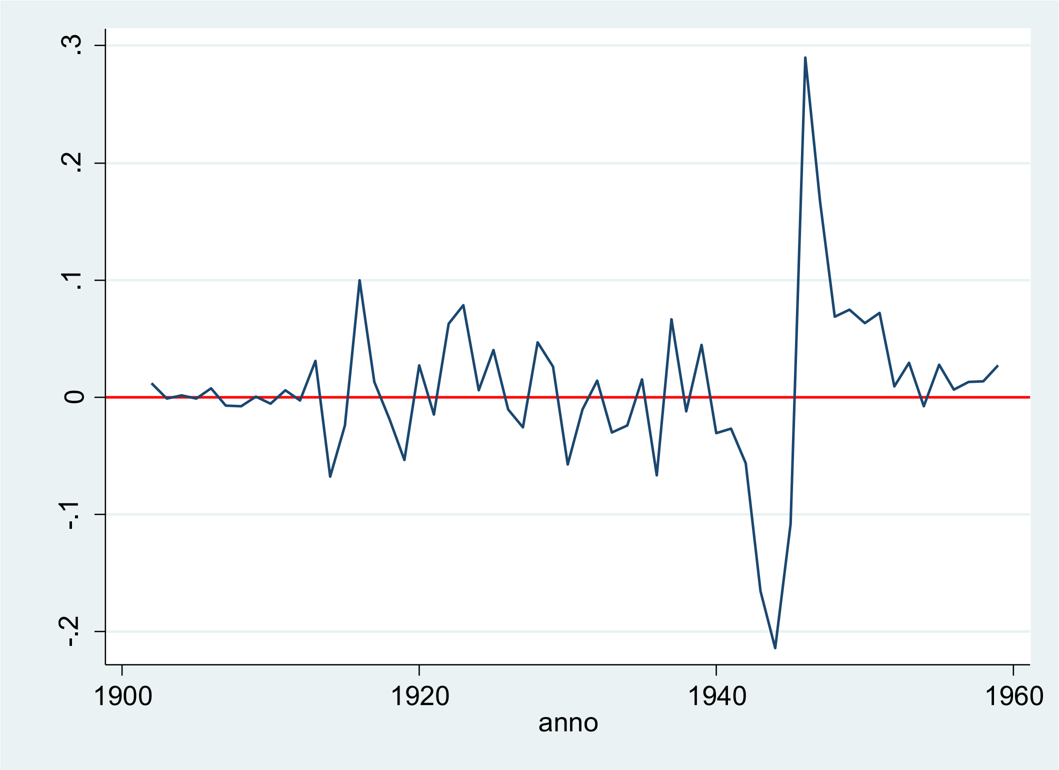

Figure 2. Total number of chairs in Italy (1900-1940 and 1900-1960)

Figure 3. The number of chairs in Italy, divided by disciplinary field (1900-1940 and 1900-1960)

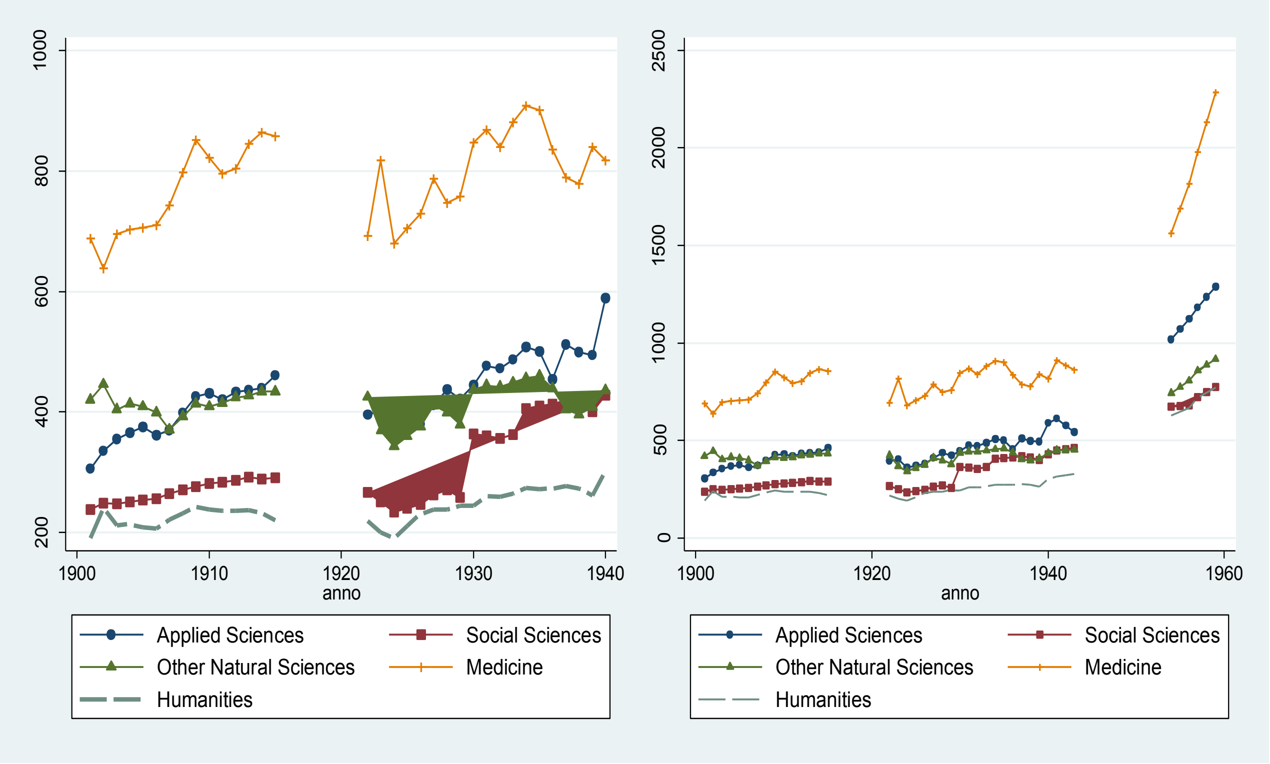

Table (1) Dickey-Fuller test on the levels of the variables

Variables	D-F	CV	
Engineering and Technology	0.421	-2.61*	I(1)
Social Sciences	0.681	-2.61*	I(1)
Humanities	1.022	-2.61*	I(1)
Natural Sciences	0.412	-2.61*	I(1)
Medical and Health Sciences	0.566	-2.61*	I(1)
TFP ($\alpha = 0.4$)	-1.834	-2.61*	I(1)
TFP ($\alpha = 0.3$)	-1.405	-2.61*	I(1)

* Critical values at the 10% level

Table (2) Dickey-Fuller and Kwiatkowski et al. test on the first differences of the variables

Variables	D-F	CV		KPSS	CV	lag order	
Engineering and Technology	-6.385	-3.66***	I(0)	0.111	0.119*	5	I(0)
Social Sciences	-6.522	-3.66***	I(0)	0.055	0.119*	4	I(0)
Humanities	-5.842	-3.66***	I(0)	0.078	0.119*	5	I(0)
Natural Sciences	-5.675	-3.66***	I(0)	0.080	0.119*	6	I(0)
Medical and Health Sciences	-5.777	-3.66***	I(0)	0.119	0.119*	6	I(0)
TFP ($\alpha = 0.4$)	-7.760	-3.66***	I(0)	0.071	0.119*	4	I(0)
TFP ($\alpha = 0.3$)	-7.743	-3.66***	I(0)	0.085	0.119*	4	I(0)

*** Critical values at the 1% level

* Critical values at the 10% level

Table 3. Estimation of equation (5)

Variables	(1) Δ1 ln(TFP_0.4t)	(2) Δ1 ln(TFP_0.3t)	(3) Δ1 ln(TFP_0.4t)	(4) Δ1 ln(TFP_0.3t)	(5) Δ1 ln(TFP_0.4t)
Δ_1 ln(HUM_t)	0.002	0.006	-0.068	-0.072	-0.069
	(0.136)	(0.139)	(0.163)	(0.166)	(0.168)
Δ_1 ln(NS_t)	-0.209	-0.211	-0.163	-0.165	-0.160
	(0.171)	(0.174)	(0.203)	(0.206)	(0.207)
Δ_1 ln(ET_t)	0.309**	0.310**	0.340**	0.341**	
	(0.136)	(0.139)	(0.144)	(0.145)	
Δ_1 ln(SS_t)	-0.208	-0.200	-0.198	-0.191	-0.196
	(0.129)	(0.131)	(0.134)	(0.136)	(0.138)
Δ_1 ln(MS_t)	0.107	0.117	0.069	0.083	0.077
	(0.111)	(0.113)	(0.140)	(0.142)	(0.147)
Δ_1 ln($CHEM_t$)					0.122
					(0.135)
Δ_1 ln(ENG_t)					0.202*
					(0.101)
Δ_1 ln($TFP\_0.4_{t-1}$)			0.211		0.209
			(0.201)		(0.206)
Δ_1 ln($TFP\_0.3_{t-1}$)				0.243	
				(0.202)	
Constant	-0.007	-0.005	-0.008	-0.007	-0.008
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Observations	40	40	37	37	37
Breusch-Godfrey test	0.082	0.278	1.442	1.195	1.398
Prob > chi2	0.775	0.597	0.229	0.274	0.237
R-squared	0.294	0.285	0.249	0.250	0.243

All models are estimated through OLS. The dependent variable is Δ1 ln(TFP_0.4t), with the elasticity of capital α=0.4, for the models in columns (1), (3) and (5). In the models in columns (2) and (4) instead the dependent variable is Δ1 ln(TFP_0.3t), with the eleasticity of capital α=0.3. The Breusch-Godfrey test reports the values of the chi-squared distribution and the p-values for the presence of serial correlation (the null hypothesis is the absence of serial correlation). Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4. Estimation of equation (6). Long differences.

Variables	(1) Δ_3 ln(TFP_0.4$_t$)	(2) Δ_3 ln(TFP_0.4$_t$)	(3) Δ_3 ln(TFP_0.4$_t$)
Δ_3 ln(HUM$_t$)	0.243	0.196	-0.159
	(0.212)	(0.206)	(0.161)
Δ_3 ln(NS$_t$)	-0.147	-0.201	-0.147
	(0.272)	(0.263)	(0.202)
Δ_3 ln(ET$_t$)	0.403		
	(0.249)		
Δ_3 ln(SS$_t$)	-0.376*	-0.382**	-0.119
	(0.193)	(0.185)	(0.134)
Δ_3 ln(MS$_t$)	0.142	0.157	-0.081
	(0.210)	(0.201)	(0.167)
Δ_3 ln(CHEM$_t$)		0.425**	0.392***
		(0.168)	(0.121)
Δ_3 ln(ENG$_t$)		-0.004	0.085
		(0.190)	(0.151)
Δ_1 ln(TFP_0.4$_{t-3}$)			0.317
			(0.362)
Constant	-0.010	-0.006	-0.020
	(0.020)	(0.019)	(0.018)
Observations	38	38	31
Breusch-Godfrey test	14.516	10.269	1.091
Prob > chi2	0.000	0.001	0.296
R-squared	0.464	0.520	0.365

All models are estimated through OLS. The dependent variable is Δ_3 ln(TFP_0.4$_t$), with the elasticity of capital α=0.4. The Breusch-Godfrey test reports the values of the chi-squared distribution and the p-values for the presence of serial correlation (the null hypothesis is the absence of serial correlation). Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5. Estimation of equation (7). Lagged independent variables

Variables	(1) Δ_1 ln(TFP_0.4$_t$)	(2) Δ_1 ln(TFP_0.4$_t$)	(3) Δ_1 ln(TFP_0.4$_t$)
Δ_2 ln(HUM$_{t-1}$)	-0.049	-0.068	-0.161
	(0.138)	(0.129)	(0.136)
Δ_2 ln(NS$_{t-1}$)	0.084	0.049	0.066
	(0.158)	(0.149)	(0.144)
Δ_2 ln(ET$_{t-1}$)	0.096		
	(0.139)		
Δ_2 ln(SS$_{t-1}$)	-0.017	-0.026	0.051
	(0.122)	(0.114)	(0.119)
Δ_2 ln(MS$_{t-1}$)	-0.115	-0.151	-0.164
	(0.127)	(0.119)	(0.115)
Δ_2 ln(CHEM$_{t-1}$)		0.231**	0.174*
		(0.097)	(0.100)
Δ_2 ln(ENG$_{t-1}$)		-0.066	-0.056
		(0.094)	(0.091)
Δ_2 ln(TFP_0.4$_{t-1}$)			0.216*
			(0.125)
Constant	-0.004	-0.003	-0.003
	(0.010)	(0.009)	(0.009)
Breusch-Godfrey test	0.111	0.883	2.393
Prob > chi2	0.739	0.347	0.121
Observations	36	36	36
R-squared	0.032	0.184	0.262

All models are estimated through OLS. The dependent variable is Δ_1 ln(TFP_0.4$_t$), with the elasticity of capital α=0.4. The Breusch-Godfrey test reports the values of the chi-squared distribution and the p-values for the presence of serial correlation (the null hypothesis is the absence of serial correlation). Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6. Estimation of equation (8). Total number of chairs.

Variables	(1) Δ1 ln(TFP_0.4t)	(2) Δ1 ln(TFP_0.4t)	(3) Δ1 ln(TFP_0.3t)	(4) Δ1 ln(TFP_0.4t)	(5) Δ3 ln(TFP_0.4t)	(6) Δ1 ln(TFP_0.4
$\Delta_1 \ln(TOT_t)$	0.015	0.025	0.046	0.022	-	-
	(0.164)	(0.222)	(0.226)	(0.227)		
$\Delta_1 \ln(TOT_{t-1})$	-	-0.061	-0.043	-0.058	-	-
		(0.180)	(0.182)	(0.185)		
$\Delta_1 \ln(TOT_{t-2})$	-	-0.029	-0.008	-0.025	-	-
		(0.188)	(0.191)	(0.194)		
$\Delta_3 \ln(TOT_t)$	-	-	-	-	-0.022	-
					(0.174)	
$\Delta_2 \ln(TOT_{t-1})$	-	-	-	-	-	0.071
						(0.070)
$\Delta_1 \ln(TFP\_0.4_{t-1})$	-	-	-	0.029	-	-
				(0.262)		
$\Delta_1 \ln(TFP\_0.4_{t-3})$	-	-	-	-	0.043	-
					(0.371)	
$\Delta_2 \ln(TFP\_0.4_{t-1})$	-	-	-	-		0.658***
						(0.083)
Constant	-0.004	-0.007	-0.005	-0.007	-0.013	-0.003
	(0.007)	(0.010)	(0.011)	(0.011)	(0.015)	(0.005)
Breusch-Godfrey test	0.128	0.006	0.052	2.759	10.369	16.104
Prob > chi2	0.720	0.939	0.819	0.096	0.001	0.000
Observations	40	34	34	34	31	34
R-squared	0.000	0.006	0.003	0.006	0.001	0.671

All models are estimated through OLS. The dependent variable in columns (1), (2), (4) and (6) is Δ1 ln(TFP_0.4t), with the elasticity of capital α=0.4. In column (3) the dependent variable is Δ1 ln(TFP_0.3t), with the elasticity of capital α=0.3. In column (5) the dependent variable is the 3-years growth rate of TFP, Δ3 ln(TFP_0.4t). The Breusch Godfrey test reports the values of the chi-squared distribution and the p-values for the presence of serial correlation (the null hypothesis is the absence of serial correlation). Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * p<0

Table 7. Akaike and Bayesian Information Criteria on the correct number of lags to include in the specification of equation (5).

Variables	(1) $\Delta_1 \ln(TFP\_0.4_t)$	(2) $\Delta_1 \ln(TFP\_0.4_t)$	(3) $\Delta_1 \ln(TFP\_0.4_t)$
$\Delta_1 \ln(HUM_t)$	-0.068	-0.083	-0.131
	(0.163)	(0.183)	(0.251)
$\Delta_1 \ln(NS_t)$	-0.163	-0.217	-0.350
	(0.203)	(0.234)	(0.301)
$\Delta_1 \ln(ET_t)$	0.340**	0.375**	0.609***
	(0.144)	(0.154)	(0.210)
$\Delta_1 \ln(SS_t)$	-0.198	-0.167	-0.150
	(0.134)	(0.148)	(0.170)
$\Delta_1 \ln(MS_t)$	0.069	0.153	0.242
	(0.140)	(0.185)	(0.246)
$\Delta_1 \ln(HUM_{t-1})$	-	-0.217	-0.098
		(0.174)	(0.247)
$\Delta_1 \ln(NS_{t-1})$	-	-0.050	0.063
		(0.202)	(0.272)
$\Delta_1 \ln(ET_{t-1})$	-	0.139	0.186
		(0.174)	(0.218)
$\Delta_1 \ln(SS_{t-1})$	-	-0.004	0.098
		(0.152)	(0.185)
$\Delta_1 \ln(MS_{t-1})$	-	-0.064	-0.312
		(0.137)	(0.235)
F-test on $\Delta_1 ln(X_{t-1})$	-	*0.54*	*0.45*
p-value		*(0.746)*	*(0.804)*
$\Delta_1 \ln(HUM_{t-2})$	-	-	-0.020
			(0.222)
$\Delta_1 \ln(NS_{t-2})$	-	-	-0.088
			(0.237)
$\Delta_1 \ln(ET_{t-2})$	-	-	0.257
			(0.235)
$\Delta_1 \ln(SS_{t-2})$	-	-	0.139
			(0.171)
$\Delta_1 \ln(MS_{t-2})$	-	-	-0.108
			(0.168)
joint F-test on $\Delta_1 ln(X_{t-2})$	-	-	*0.41*
p-value			*(0.833)*
$\Delta_1 \ln(TFP\_0.4_{t-1})$	0.211	0.137	0.222
	(0.201)	(0.257)	(0.345)
Constant	-0.008	-0.008	-0.022
	(0.007)	(0.009)	(0.015)
Observations	37	37	34
Akaike Inform. Criterion	-129.652	-123.424	-106.360
Bayesian Inform. Criterion	-118.376	-104.093	-80.411
R-squared	0.249	0.322	0.456

All models are estimated through OLS. The dependent variable is Δ1 ln(TFP_0.4t), with the elasticity of capital α=0.4. Akaike and Bayesian Information Criteria are reported. Also reported are the F-statistics and p-values of a test of the joint significance of the academic variables with, respectively, one and two years lags. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1