THE HETEROGENEITY OF KNOWLEDGE: UNIVERSITY-INDUSTRY RELATIONS AND THE EVOLUTION OF KNOWLEDGE GOVERNANCE. THE ITALIAN EVIDENCE IN THE FIRST PART OF THE XX CENTURY[1]

Cristiano Antonelli, Dipartimento di Economia, Università di Torino & BRICK Collegio Carlo Alberto.

Claudio Fassio, Dipartimento di Economia, Università di Torino & BRICK, Collegio Carlo Alberto

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 analysis impinges upon an original data-base on the evolution of the size and the disciplinary composition of the stock of academic chairs in Italy in the years 1900-1959. The results confirm the contribution of academic knowledge to economic growth and the positive effects of the public support to the academic system. At the same time they 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; SPILLOVERS; UNIVERSITY INDUSTRY RELATIONS; TOTAL FACTOR PRODUCTIVITY GROWTH; LONG TERM ECONOMIC GROWTH.

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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 highly idiosyncratic characteristics such as non-exhaustibility, non-appropriability, non-divisibility and hence cumulability and complementarity. 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 input characterized by non-appropriability and cumulability (Nelson, 1959; Arrow, 1962).

Such characteristics typically lead to the well-known case of the commons where, because of the limits to the identification of an efficient allocation of property rights, the system risks experiencing either the tragedies of commons or the opposite tragedies of the anticommons. In this context the governance of knowledge is a central issue (Ostrom, 1990; 2005, 2010; 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 that qualify the architecture of relations, ranging from the extremes of pure transactions to pure interactions, 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 (Antonelli, 2011; Ostrom, 2010).

The renewed attention to the role of universities as the central mechanism for knowledge governance in advanced economies is the result of recent changes in the knowledge governance of the advanced economies (Leisyte, Horta, 2011). The central aim of the paper is to show that the university had been already the central mechanism for knowledge governance, before the emergence and widespread diffusion of the corporate model of knowledge governance. The university is back to center stage role that characterized most advanced economies in the first part of the XX century 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 the key role of the university in the process of industrialization and rapid economic growth experienced by an economy characterized by the small and medium size of its firms.

The analysis of the role of universities in the early stages of Italian industrialization enables to grasp the differences in the contribution to economic growth of academic disciplines. This in turn confirms 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, has important consequences for knowledge governance. Public support to the academic system should take into account the different 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. The foundations of the academic model of knowledge governance are elaborated in section 3 that also presents the research strategy. The following 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 the total productivity growth experienced by the Italian economy 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. These different knowledge governance mechanisms can be considered 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 (Arthur, Durlauf, Lane, 1997; Lane, 2009).

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 research and development activities, 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 the performance of didactic activities on the one hand and basic science, on the other. The bulk of applied research was mainly implemented by corporations, intramuros.

The discontinuity brought about by the introduction of the new gale of information and communication technologies and later of biotechnologies called attention upon the limitations of the corporate model. 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 corporation is afflicted by the non-invented-here syndrome and the high costs of absorption of external knowledge. The corporate model excelled in directing technological change towards incremental advances, but failed in taking advantage of new radical scientific and technological breakthroughs. When the direction of technological knowledge exhibits significant discontinuities and sudden change in directions, the corporate model can suffer dramatically. 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, 1962, 1977, 1990; Antonelli and Teubal, 2010).

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 has called attention on alternative modes of knowledge governance. The open innovation model has been consolidating in the US after the new information and communication technological 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; Chesbrough, Vanhaverbeke, West, 2006).

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 (Etzkowitz Leydesdorff, 1997; Branscomb Kodama Florida, 1999; Henderson Jaffe Trajtenberg, 1998).

Actually, however, the academic model is far from being new. As a matter of fact it preceded the corporate model 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 (Meyer-Thurow, 1982; Geuna, 1999).

The role of the new equity based finance 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; Antonelli, Teubal, 2010).

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. THE ANALYTICAL FOUNDATIONS OF THE ACADEMIC MODEL OF KNOWLEDGE GOVERNANCE

The appreciation of the academic model of knowledge governance stems directly from the analysis of the unique characteristics of knowledge as an economic good. Knowledge, in fact, is a very special economic good, as it is at the same time an output and input characterized by non-appropriability, non-ehaustibility, a strong tacit component and cumulability. The new appreciation of the intrinsic characteristics of the generation of knowledge unveils the central role of recombination. New knowledge is the result of the recombinant integration of existing modules (Weitzman, 1996 and 1998; Arthur, 2009).

The idiosyncratic character of the recombinant generation of new knowledge makes the management of the conflicting incentives stemming from knowledge non-appropriability and knowledge non-exhaustibility and cumulability, respectively, very difficult. This context provides new ammunitions to regard the academic mode of knowledge governance as an institutional device that makes it possible to manage the knowledge commons (Arrow, 1969).

Non appropriability limits the incentives to the allocation of economic resources to its generation and impedes trade with the well-known risks of undersupply. A number of institutional mechanisms have been elaborated and implemented to cope with the problems engendered by non-appropriability. The introduction of intellectual property rights contributes to create incentives to the generation of knowledge and increases the possibilities for trade and hence division of labor with the well-known positive consequences in terms of specialization and hence increased efficiency.

Cumulability and non-exhaustibility, the second key characteristics of knowledge as an economic good, however dramatically limits the benefits of intellectual property rights. The systematic use of intellectual property rights characterized by exclusivity, such as patents, limits the dissemination of knowledge and its access to users. This limit has severe consequences has soon knowledge cumulability is taken into account.

Knowledge in fact is at the same time the output of an intentional process based on dedicated resources and an input into the generation of further knowledge. The limitations raised by exclusive intellectual property rights have direct negative consequences on the efficiency of the generation of new technological knowledge. Redundant duplication of efforts reduces efficiency and in some cases knowledge rationing caused by exclusive intellectual property rights may actually block the generation of new knowledge (Antonelli, 2008 and 2011).

The negative consequences of intellectual property rights are all the stronger the larger is the fungibility of knowledge, i.e. the wider is its scope of application. The limits to the use of knowledge as an input into the generation of new technological knowledge are all the stronger the more frequent is the use of that specific knowledge item for the generation of new knowledge. Intellectual property rights to knowledge items with a narrow scope of application have smaller negative consequences than intellectual property rights to knowledge items with a broad scope of application.

In this context the public support to universities can be thought as the result of a long term search process that has been taking place through historic times since the creation of the first university in Bologna geared towards the identification and construction of an institutional mechanism able to help solving the crucial problem of the management of the knowledge commons. The origin of the academic system dates back to the early medieval times. Since then, however, the academic system kept growing directing its evolution towards stronger and stronger levels of integration into the institutional organization of European countries with the identification of new functionalities and new roles in the active dissemination of knowledge to business firms and in the participation to their knowledge generation activities (Geuna, 1999; Geuna and Muscio, 2009).

The active support of the state to the creation and the development of the academic system and more generally of a public research systems can be understood as the result of the collective and sequential implementation of an institutional mechanism design able to overcome the problems raised by the characteristics of knowledge as an economic good and the limitations of intellectual property rights (Mansfield, 1991, 1995; Mansfield and Lee, 1996).

From this viewpoint the public university system can be regarded as an institution that reconcile the conflicting incentives necessary to fund and perform the generation of knowledge with the incentives 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 proves funds to the university. The university in turn provides incentives to researchers to generate and disseminate knowledge.

Together with the creation of human capital embedded with frontier competences in advanced scientific fields, the publication is the key device that makes the mechanism working. The allocation of tenures and salaries in general, by the university, is based upon the proofs of the scientific capabilities of the researchers, as documented by authored publications in scientific journals that are able to screen and assess whether the contribution is actually relevant and original and such able to increase the stock of knowledge. Publications perform the twin crucial role of carriers of the proof of the scientific capabilities and vectors of the new knowledge in the dissemination process. As soon as a new contribution is recognized as a source of scientific advance and as such is published in a scientific journal it is also made publicly available to all possible users.

The institutional combination of publication-cum-taxation embedded into the university makes it possible to reconcile the conflicting incentives. The prospect for the wages and eventually the tenure allocated by the university provides sufficient incentive of researchers to publish. The disclosure of the secret is compensated by the wages paid by the university. On the other hand economic agents are ready to accept the reduction in their income engendered by the dedicated taxation necessary to support the university as long as they are compensated by the economic value that can be extracted by the free access to the new knowledge generated by the scholars organized within the academic system (Antonelli, 2008).

The implementation of an academic system based upon the public support stemming from dedicated taxation of the final users of the knowledge generated and disseminated is especially relevant for knowledge with high levels of fungibility. The conflicting incentives between generation and dissemination for further uses is in fact especially strong for knowledge items that are likely to be sequentially used by many other agents. When fungibility levels are lower the allocation of intellectual property rights can provide the system with appropriate quantities of knowledge. This distinction is relevant as it identifies the types of knowledge in whose generation the university should specialize.

This interpretation of the university as the product of a long-term, collective process of search and implementation of an institutional design able to make possible the management of the knowledge commons has many important implications as it provides a general framework into which it is better possible to appreciating the array of specific details investigated by the recent spur of empirical work on the relations between university and industry.

The investigation into the performance of the university as a mechanism for managing knowledge commons and generating knowledge externalities actually able to providing essential knowledge externalities to the rest of the system is crucial for guiding its maintenance and possibly for the further implementation of its function.

According to the results of a large literature the relations between university and firms rely on a variety of communication channels, including both personal and institutional transactions and interaction mechanisms that are much wider and articulated than publications and tuition as effective carriers of scientific knowledge and vehicles for its dissemination and eventual use for the generation of new technological knowledge (Cohen, Florida, Randazzese Walsh, 1998; Cohen, Nelson, Walsh, 2002; Antonelli, Patrucco, Rossi, 2010; Rossi, 2010):

1) Academic patenting is an important vector of knowledge externalities together with the variety of different property right mechanisms that universities use to disseminate knowledge and stimulate its use for the generation of technological knowledge (Andersen, Rossi, 2011).

2) The direct participation of scholars to the exploitation of new knowledge with the creation of new firms helps increasing the effective use of knowledge to introduce innovations. Scientific entrepreneurship becomes a complementary communication mechanism between university and industry (Bania Eberts and Fogarty, 1993). The creation of start-up companies by students is an important vector of knowledge externalities (Åstebro, Bazzazian, Braguinsky, 2012).

3) The role of the direct – professional- relations between scholars as individuals and universities as institutions and firms is much more important than currently assumed. The employment relationships in universities is characterized in most cases by substantial non-exclusivity and the professor's privilege goes well beyond the right to patent including the right to earn professional fees. Non-exclusive employment relationship may affect the fragile combination of basic incentives: professional and personal transactions-cum-interactions in fact may favor the use of knowledge but inhibit exploration in wider and potentially more useful areas of investigation. Personal transactions and interactions between scholars and firms are one of the main vectors of dissemination and socialization of scientific knowledge especially for small and medium size firms (Etzkowitz, 1998; Perkmann and Walsh, 2008 and 2009).

4) The creation of markets for research services where firms outsource dedicated research activities to academic laboratories to perform 'extra-muros' research activities can be most beneficial to both parties. Firms benefit of the access to high level competence available at variable costs taking advantage of the sunk costs paid by the academic system so as to enhance an actual complementarity between their internal research strategies and the academic research activities. Universities may

increase their budget and receive important feedbacks about the effective relevance of their knowledge capabilities. It is clear that the share of the external funds earned on the markets for research services should not become so large to limit the freedom of universities to select the areas of investigation that look more relevant from a strict academic viewpoint. Excess reliance of academic activity on rent-seeking funding may compromise the central role of the university on the frontier of knowledge (Schartinger, Schibany, Gassler, 2001; Siegel, Waldman, Atwater, Link, 2003).

When these different interaction and dissemination channels of academic knowledge externalities are appreciated, it seems more and more evident why the academic mode of knowledge governance can be a very effective mechanism of knowledge governance. 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 not only as an output and an input, but more precisely its twin characteristics of a dual intermediary input, both in the generation of new knowledge and in the production of other goods.

The advantages of the academic mode of knowledge governance appear very strong at times of scientific discontinuity that require long-range search provided that the search for new avenues for the generation of knowledge is kept wide by the variety of interest and activities of heterogeneous communities of scholars.

At the same time the academic mode of knowledge governance seems especially apt to enhance the exploitation of the non-exhaustibility and cumulability of knowledge. The academic mode of knowledge governance based upon the free dissemination of the results of the research activity enhances the dissemination of knowledge that can be used and used again with little if no wear and tear and beyond the limits of property rights. For these reasons the academic mode of knowledge governance is likely to affect directly the rates of total factor productivity growth.

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. The literature has paid little attention to the heterogeneity of knowledge. Actually much of the analysis has been based upon the tacit assumption that knowledge is homogeneous (Aghion, Dewatripont, Hoxby, Mas-Colell, Sapir, 2009).

The working of the university as an elegant mechanism for improving the governance of knowledge 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. As it is well known, market failure stems from the lack of incentives and the limits of markets transactions and funding generated by the well-known idiosyncratic characteristics of knowledge as an economic good. The state acts as intermediary between the supply and the demand of knowledge, with the collection of taxes and its transfer to the academic system where they provide the basic incentives to the generation and the dissemination of knowledge. Publications perform at the same time the basic role of tools for scholars to obtain a salary and a vector of knowledge dissemination in the system.

As soon as, however, 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. The lack of appropriate signaling devices, able to inform decision makers about the excess supply or demand of specific knowledge items, risk to have negative consequences. Universities can keep generating types of knowledge that firms do not 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.

The appreciation of the heterogeneity of knowledge stresses the centrality of this signaling mechanism. The role of the state as an intermediary that collects taxes and transfers them 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.

The identification of the heterogeneity of knowledge, as an immediate consequence makes it possible to grasp 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.

3.1 HYPOTHESES AND RESEARCH STRATEGY: ACADEMIC CHAIRS AND TOTAL FACTOR PRODUCTIVITY GROWTH

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 its actual viability and its limitations. 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 had taken 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 felt the need to increase its prestige and reputation establishing a high quality university. Since the beginning of the XX century the Italian academic system witnessed a strong evolution of the stock of chairs that made the academic system stronger. In that part of the XX century Italy experienced a fast growth and a radical transformation from a poor agricultural economic system into a strong industrial one. The provision of scientific and technological knowledge was almost exclusively based upon the public university system as the activities of research and development of large corporations 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.

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 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 consider the historic approach and the lack of alternative sources of evidence (Antonelli Crepax Fassio, 2012).

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

The rates of increase of total factor productivity of the Italian economy in the years 1900-1959 are the dependent variable. Total factor productivity 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.

The discrepancy cannot be justified by sheer research and development expenditures as their allocation should be made in equilibrium conditions where their marginal costs equal their marginal revenue. 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; 1992).

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 that are 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.

From this viewpoint the academic mode of knowledge governance enables to increase the generation of pecuniary knowledge externalities. The academic mode of knowledge governance in fact empowers the positive effects of knowledge non-exhaustibility and cumulability. At the same time the detailed sources upon which our analysis impinges, 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 takes advantage of an original database, recently built through the collection of official national bulletins on education published by the Italian Ministry of Education (Antonelli Crepax Fassio, 2012). The data collection comprehends the overall number of University chairs and the identification of five broad disciplinary fields at the national level for the years going from 1901 to 1959. In this way we are able to measure the total number of professors and assistant professors working in the Italian university in the period under consideration classified by each of the disciplinary fields identified. For each year we have the total amount of chairs in five disciplinary fields: applied sciences (AS - including chemistry and engineering), social sciences (SS - sociology, economics and law), human sciences (HUM - arts and humanities), other natural sciences (ONS - biology, physics and mathematics) and medical sciences (MS).

Beside these variables related to the academic system, we included in the database some key-economic variables measuring the country's economic growth in the time-span identified. Given the difficulty in obtaining precise estimates of the growth of economic variables in these years, we relied on new data recently provided by the work of Broadberry et al. (Broadberry, Giordano, Zollino, 2011), which update the previous estimates of Italian historical economic growth and use their time-series measures of real GDP, real net capital stock and full-time equivalent employment at the national level for the first 60 years of the XX century.

The final database obtained combines, for each year, the "academic" variables with these country-level economic aggregates and covers the period 1901-1959 with some missing data during the two World Wars (there are no data for the years from 1916 to 1921 and from 1944 until 1953) which leaves us with 43 observation altogether. In Appendix A a more accurate description of how the database has been built is provided.

What we are interested in is the effect of knowledge spillovers stemming from the academic system to the economy: we suppose that the growth of GDP that is not explained by the growth of labor and capital inputs depends also on the stock and on the typology of the academic knowledge available. According to the recent estimates by Broadberry et al., in the first half of the XX century Total Factor Productivity (henceforth TFP) growth explained between one third and two third of the overall growth of the economy (Broadberry, Giordano, Zollino, 2011). It seems reasonable then to assume that possible spillovers from the academic system towards the economic activities might affect the size of this "residual"[2].

In order to compute the TFP for the Italian economy we rely on a typical Cobb-Douglas production function at the country-level, assuming constant returns to scale:

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

Where $\alpha + \beta = 1$

We don't have accurate and reliable measures of the share of labour on GDP for the time period considered, given the difficulty in finding data on the aggregate value of

[2] Of course we must take into account that what is called Total Factor Productivity includes also many other unmeasured or mis-measured factors that influence the growth of GDP: here we will use TFP as a rough proxy of the capability of the system to increase its productivity.

wages. We hence decided to stick to the usual values that are found in the literature (Bernanke, Gurkaynak, 2001; Gollin, 2002), setting beta (the elasticity of labor) equal to 0.6 and alpha (the elasticity of capital) equal to 0.4. In order to check for the robustness of our results we also tested our econometric analyses with different values of labor and capital shares.

We then computed TFP in the following way:

$$\ln A_t = \ln Y_t - \alpha \ln K_t - \beta \ln L_t \tag{2}$$

In Figure (1) we display the time series of the yearly growth rates of TFP, obtained through the explained procedure. The growth rates are extremely similar to those obtained by Broadberry et al. (2011). After an initial period, between 1901 and 1912, in which the growth rates were quite stationary, the variability of the series increases at the beginning of WWI; after the downturn occurred during the war, the growth rates become continuously positive throughout the first half of the 20's and then decline at the end of the decade, during the Great Depression. In the first half of the thirties the growth rates are mostly negative, they improve only in the second half of the decade: however WWII coincides with a new downturn of TFP growth rates. After the war, during the 50's, TFP growth displays the highest values, with a sustained growth that lasted until the end of our period of observation. It must be stressed that, given the missing values present in the series of the academic chairs for the two time-spans 1916-1921 and 1944-1953, also the growth rates of TFP during those years are not included in our data. Even if this includes some gaps in the time series it also allows to excluding the extreme values (outliers) of TFP growth that we observe in Figure (1) during the two conflicts.

As for the academic system, our database allows to track the evolution of the total number of chairs in the Italian university system in the period 1901-1959 (see also Table A.2 for the precise number of chairs): as shown in Figure (2) there is evidence of a positive trend between 1901 and the beginning of WWI. After the end of WWI the number of chairs decreases substantially, returning to the levels of the beginning of the century. However already at the beginning of the 30's the number of chairs reached the pre-war levels. After the Second World War the number of chairs increased steadily and, although our dataset accounts only for the years up to 1959, it is clearly visible in this period a structural transformation and expansion of the academic system towards the modern educational standards.

Also when we look at the shares of chairs for each single discipline, as shown in Figure (3) and in Table (A1), we observe some specific trends during the 60-years period considered. First of all we notice that the number of professors and assistant professors belonging to the medicine faculties kept for the whole period a position of absolute predominance, holding on average more than 35% of the total number of chairs. However it must be stressed that no significant variation in these shares appears during the time span considered.

The chairs in social sciences increased steeply at the beginning of the Thirties, while the chairs in human sciences increased their share on the overall distribution of chairs especially after WWII, during the overall expansion of the system.

For what concerns applied and technical sciences (including engineering and chemistry), we observe a constant and positive growth of the chairs in these disciplines from the beginning until the end of our period of observation. A closer look, which distinguishes between engineering and chemistry, shows that while the former acquired more centrality in the university system already in the first decade of the XX century, the latter gained importance only after, at the end of the Twenties.

Conversely the number of chairs in other natural sciences such as mathematics physics and biology displays a constant negative trend. The decline is especially evident at the beginning of the 30's, but also during the accelerated growth experienced during the 50's by the whole system their role remained more marginal.

Summing up, the analysis of the first 60 years of the XX century in Italy displays a progressive shift, started at the beginning of the century and ended during the 30's, which increased the centrality of applied sciences, such as chemistry and engineering, at the expense of more theoretical sciences such as mathematics, physics and natural sciences. Also disciplines like economics, statistics and sociology gained momentum especially during the 30's. Conversely during the second post-war period we observe a diffused growth of the overall system. However such growth did not follow the pre-war dynamics: indeed the share of chairs in engineering and chemicals and management-related disciplines remained quite stable, with a positive increase, instead, of the human sciences.

4.2. THE ECONOMETRIC STRATEGY

As we said previously, in order to measure the effect of the knowledge spillovers stemming from the academic system to the economic system it seems proper to search for the effects of these spillovers inside the share of growth of GDP that is not explained by the growth of physical inputs, such as labor and capital: hence we choose TFP as the dependent variable of our models, calculated as shown in equation (2).

Assuming a Cobb-Douglas production function with constant returns to scale for the whole economy, as presented in equation (1) we hypothesize that the level of TFP is a multiplicative function of the numbers of chairs of each of the disciplines that we have identified:

$$A_t = bAS_t^{\gamma_1} SS_t^{\gamma_2} HUM_t^{\gamma_3} ONS_t^{\gamma_4} MS_t^{\gamma_4} e^{u_t} \tag{3}$$

Where A indicates the level of TFP, c is a constant, u is a idiosyncratic error term, AS stands for applied sciences (chemistry and engineering), SS indicates social sciences (sociology, economics and law), HUM is for human sciences (arts and humanities), ONS is for other natural sciences (biology, physics and mathematics) and MS stands for medical sciences.

In order to estimate equation (3) we take logs and transform it into the following:

$$\begin{aligned} \ln A_t &= \ln b + \gamma_1 \ln AS_t + \gamma_2 \ln SS_t + \gamma_3 \ln HUM_t + \\ &\gamma_4 \ln ONS_t + \gamma_5 \ln MS_t + \nu_t \end{aligned} \tag{4}$$

Before estimating equation (4) we need to check for the presence of unit roots: looking at Figures (2) and (3), the "academic" variables do not display any stationary behavior. In Table (1) are presented 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 as follows:

$$\begin{aligned} \Delta_1 \ln A_t &= \ln b + \gamma_1 \Delta_1 \ln AS_t + \gamma_2 \Delta_1 \ln SS_t + \gamma_3 \Delta_1 \ln HUM_t + \\ &\gamma_4 \Delta_1 \ln ONS_t + \gamma_5 \Delta_1 \ln MS_t + \Delta_1 \nu_t \end{aligned} \tag{5}$$

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

We run two tests to assess the stationarity of the series, as shown in Table (2). 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) (KPSS), 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). The results in Table (2) tell us 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 (Stock, Watson, 2007).

On the contrary we are worried that the 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. In order to avoid this problem we will specifically test for the presence of autocorrelation of the residuals.

Another relevant problem is related with the correct lag structure of the independent variables: it is not straightforward to understand with which time lag the externalities spilling from the academia towards the growth of TFP occur (Adams, 1990; Adams and Jaffe, 1996; Encaoua, Hall, Laisney, Mairesse, 2000). We will hence dedicate a part of our estimation procedure to test the more appropriate time lag to include in the regressions.

Finally 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. In order to account for this possibility we will use lagged values of the independent variables.

4.3 THE RESULTS

We start by presenting the baseline specification of our model, as expressed in equation (5), with the contemporaneous rates of growth of the dependent and independent variables: the results in Table (3) indicate that AS (applied sciences) has a positive and significant coefficient. The growth rates of the other disciplines display non-significant (and negative) values. MS (medical sciences) show a moderate and positive coefficient, although not significant. We also check whether different values of the elasticity of capital and of labor can affect our estimates: therefore in column (2) the dependent variable is the growth rate of TFP calculated holding the elasticity of capital equal to 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 AS (applied sciences), we try to 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 we said before, 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. The results, displayed in the Appendix in Table (A3) 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

The issue regarding the correct time lag to consider when we measure the academic spillovers and the potential problems of omitted variable, however, deserves some more consideration. In order to provide further robustness to our results we try two other strategies to estimate equation (5): first we choose to use long differences (three-years growth rate) obtaining the following specification:

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

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: first of all we notice that AS (applied sciences) is not significant anymore, although it still keeps a positive coefficient of about 0.4. MS (medical sciences) and ONS (other 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.

We then 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.

We include among the regressors also the lagged value of TFP growth (in this case the growth of TFP at time t-3) and we notice that this eliminates the problem of serial-correlation in the residuals. We also notice that the inclusion of this variable 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.

We then take into account the issue of the omitted variable bias and transform equation (6) into the following specification:

$$\begin{aligned}\Delta_1 \ln A_t &= \ln b + \gamma_1 \Delta_2 \ln AS_{t-1} + \gamma_2 \Delta_2 \ln SS_{t-1} + \gamma_3 \Delta_2 \ln HUM_{t-1} + \\ &\gamma_4 \Delta_2 \ln ONS_{t-1} + \gamma_5 \Delta_2 \ln MS_{t-1} + \Delta_3 \nu_t \end{aligned} \qquad (7)$$

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 time lag to affect the economy, and furthermore we also 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. As an example we could expect that an increase in public expenditure would increase the economic activity, thus determining a growth of TFP, but at the same time an increase of public expenditure might also determine a higher growth of tenures for university professors[3]. This

[3] The same would happen for a decrease of public expenditure: a very good example might be the financial crisis of 1929 which typically could have decrease the growth of TFP and the growth of academic chairs.

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. In Table (5) we see that the results are in line with those shown in Table (4). Again AS (applied sciences) is not significant, but when we distinguish between chemistry and engineering we find that only 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:

$$\Delta_1 \ln A_t = \ln b + \gamma_1 \Delta_1 \ln(TOTAL-CHAIRS_t) + \Delta_1 \nu_t \quad (8)$$

In Table (6) we present 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.

In column (1) and (2) we first introduce the contemporaneous rates of growth of the total number of chairs and then we add also the second and third lags: the results show that, disregarding the number of lags that we include, the coefficients of the variable are never significantly different 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 the elasticity of capital set to 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 resulting in not significant coefficients. Specifically we find that when we consider engineering and chemistry separately, we see that chemistry is positive and significant when we consider longer time lags, while engineering is significant when we include only the contemporaneous rates of change. A possible explanation of these findings might lie in the more theoretical nature of chemistry with respect to engineering, resulting in longer periods for the former before the knowledge spilling from the academia has an effect on the economic system. In the case of engineering, instead, the more applied nature of the discipline might explain the shorter lags needed to display an effect on the economy.

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 effectively generated and used has been identified and appreciated.

This new interest and the new evidence seem to forget the historic role of the academic system in the generation of technological and scientific knowledge. 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 had become the key player and the university was very much relegated to a com-primary role with increasing emphasis on its didactic 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 has brought back the university to the center stage. The new centrality of the academic system, however, is not new. It is rather a rediscovery and a comeback. A rediscovery because the academic system never left the scene and, as a matter of fact, had kept a much more important role than it was actually recognized by the literature. A comeback because the appreciation of the central role of the academic system, as the central cornerstone of the knowledge governance and the recipient of much dedicated public support, was very much shared and practiced before the introduction and widespread adoption of the corporate model. 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 with high levels of fungibility and hence wide scope of direct application to economic activities.

This paper has contributed to confirming the central role of the academic system in the growth of the Italian economy in the first part of the XX century at a time when the corporate model had not yet diffused. The empirical evidence, based upon an original use of academic chairs as a proxy for the evolution of the Italian academic system, shows that the growth of the academic system, especially in such scientific disciplines such as engineering and chemistry played a direct and significant role in the increase of total factor productivity.

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 more sophisticated 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 firms.

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. 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 suggests that some types of knowledge are more fertile, in terms of spillovers to economic growth, than others.

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 hell substituting 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 active support to both professional and institutional interactions and transactions between the academic system and the business community is important not only to collect additional funds but also and primarily as a part of the more general goal of implementing the creation of a viable and effective information tool that help substituting for the vector of missing prices of knowledge. 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.

A comprehensive vector of information about the actual use and the economic effects of the knowledge generated by the academic system can help shrinking the room for the possible opportunistic behavior of public universities to indulge in the generation of knowledge that is not actually useful for economic growth while claiming for increased public subsidies.

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

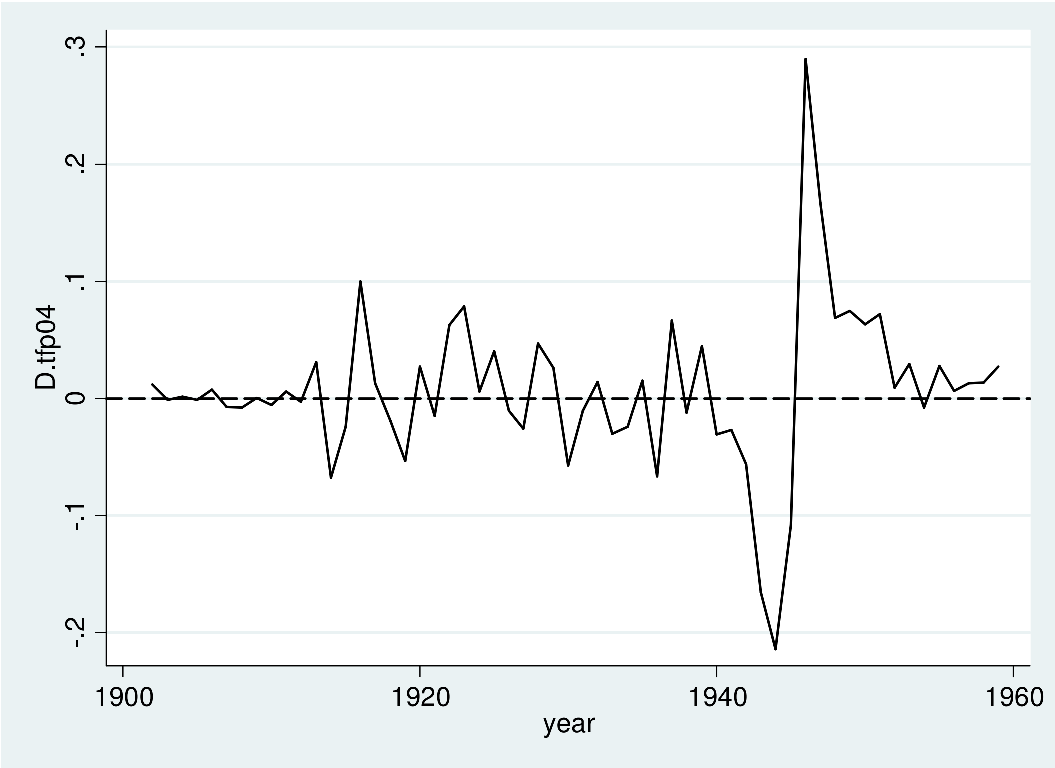

Figure 2. Total number of chairs in Italy (1900-1940 and 1900-1960)

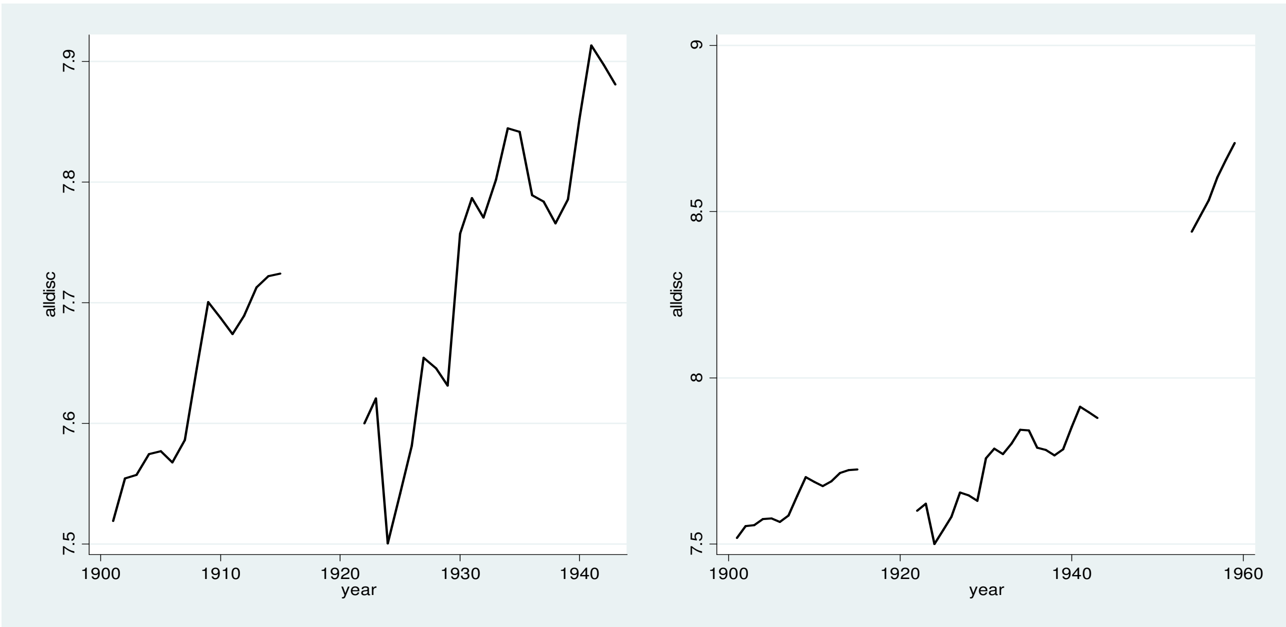

Figure 3. The number of chairs in Italy, divided by disciplinary field

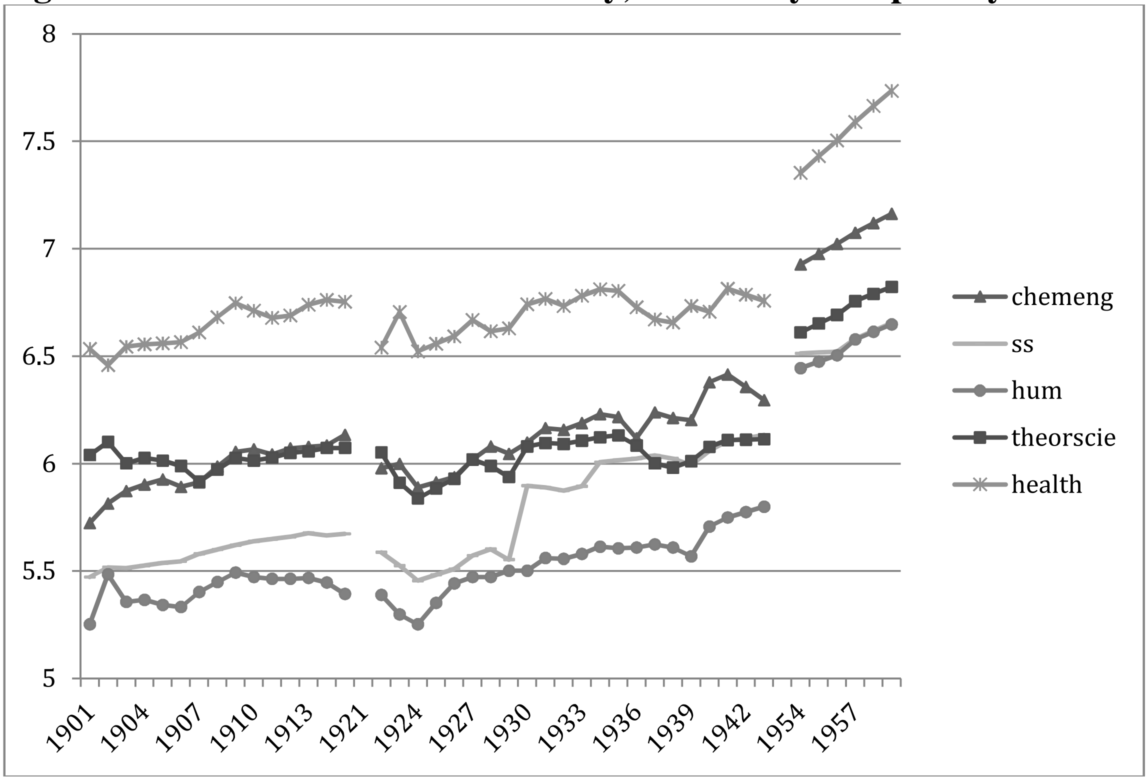

Table (1) Dickey-Fuller test on the levels of the variables

Variables	D-F	CV	
Applied Sciences	0.421	-2.61*	I(1)
Social Sciences	0.681	-2.61*	I(1)
Humanities	1.022	-2.61*	I(1)
Other Natural Sciences	0.412	-2.61*	I(1)
Medicine	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	
Applied Sciences	-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)
Other Natural Sciences	-5.675	-3.66***	I(0)	0.080	0.119*	6	I(0)
Medical 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(ONS_t)	-0.209	-0.211	-0.163	-0.165	-0.160
	(0.171)	(0.174)	(0.203)	(0.206)	(0.207)
Δ_1 ln(AS_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(ONS$_t$)	-0.147	-0.201	-0.147
	(0.272)	(0.263)	(0.202)
Δ_3 ln(AS$_t$)	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(ONS$_{t-1}$)	0.084	0.049	0.066
	(0.158)	(0.149)	(0.144)
Δ_2 ln(AS$_{t-1}$)	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_0.4t)
Δ_1 ln(TOT_t)	0.015	0.025	0.046	0.022	-	-
	(0.164)	(0.222)	(0.226)	(0.227)		
Δ_1 ln(TOT_{t-1})	-	-0.061	-0.043	-0.058	-	-
		(0.180)	(0.182)	(0.185)		
Δ_1 ln(TOT_{t-2})	-	-0.029	-0.008	-0.025	-	-
		(0.188)	(0.191)	(0.194)		
Δ_3 ln(TOT_t)	-	-	-	-	-0.022	-
					(0.174)	
Δ_2 ln(TOT_{t-1})	-	-	-	-	-	0.071
						(0.070)
Δ_1 ln($TFP\_0.4_{t-1}$)	-	-	-	0.029	-	-
				(0.262)		
Δ_1 ln($TFP\_0.4_{t-3}$)	-	-	-	-	0.043	-
					(0.371)	
Δ_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<0.1

APPENDIX A

The Italian National Statistical Office (ISTAT) and the Ministry of Education, University and Research (MIUR) do not provide a coherent database containing historical data on the number of chairs in the Italian University: the only accessible sources are the published yearbooks of the Ministry of Education. The database used in this paper is the result of the first attempt to harmonize such data and it has been created through a careful collection of all the data concerning the number and type of chairs in each Italian university and in each faculty during the years 1901-1959. The sources of the data were the Yearbooks of the Ministry of Public Education (Annuario del Ministero della Pubblica Istruzione, Roma, Tipografia Elzeveriana) for the years 1894-1929 and 1953-1959, and the Yearbooks of the Ministry of National Education (Annuario del Ministero dell'Educazione Nazionale, Roma, Provveditorato generale dello Stato) for the years 1930-1943.

Together with the chairs of full professors, it was also possible to identify the type and number of positions for assistant professors in the same time period, in order to have a complete measure of the total supply of academic expertise present in the Italian university system. Considering jointly the chairs and the positions for assistant professors, with our database we were able to identify a total of 72,959 chairs/positions in the time period considered. After this first mapping we aggregated the number of chairs in 5 big disciplinary fields: Table (A.1) shows the distribution of the total number of chairs (including the positions for assistant professors) in the period considered.

The database displays some missing observations: we do not have any data for the years that correspond to the two World Wars and for the subsequent years, hence we have 16 missing observations for the periods 1916-1921 and 1944-1953, which reduces our data to 43 observations.

In Table (A.2) are reported the total number of chairs and positions for assistant professors in the years 1901-1959 used in our analysis.

Table A.1. Distribution of the total number of chairs (professors and assistant professors): years 1901-1959

	num.	share		num.
Applied Sciences	15,353	21.04	Chemicals	6,425
			Engineering	8,928
Social Sciences	10,766	14.76	Law	6,740
			Economics Statistics Sociology	4,026
Other Natural Sciences	12,302	16.86	Mathematics Physics	5,625
			Natural Sciences	6,677
Humanities	8,829	12.10	Humanities and Arts	8,829
Medical Sciences	25,710	35.24	Medicine and Veterinary Medicine	25,710
Grand Total				72,959

Table A2. The number of chairs (professors and assistant professors) in each academic field in Italy in the years 1901-1959

YEAR	APPLIED SCIENCES		SOCIAL SCIENCES		OTHER NATURAL SCIENCES		HUMAN SCIENCES		MEDICAL SCIENCES		TOTAL
	num.	*share*	*num.*	*share*	*num.*	*share*	*num.*	*share*	*num.*	*share*	*num.*
1901	306	16,6	238	12,9	420	22,8	191	10,4	688	37,3	1843
1902	335	17,5	249	13,0	446	23,4	241	12,6	638	33,4	1909
1903	355	18,5	248	13,0	404	21,1	212	11,1	695	36,3	1914
1904	366	18,8	251	12,9	414	21,3	214	11,0	703	36,1	1948
1905	375	19,2	254	13,0	409	20,9	209	10,7	706	36,1	1953
1906	362	18,7	256	13,2	399	20,6	207	10,7	710	36,7	1934
1907	370	18,8	265	13,4	371	18,8	222	11,3	743	37,7	1971
1908	398	19,0	271	13,0	393	18,8	233	11,1	797	38,1	2091
1909	426	19,3	276	12,5	414	18,7	243	11,0	851	38,5	2210
1910	431	19,8	281	12,9	409	18,8	238	10,9	822	37,7	2181
1911	421	19,6	284	13,2	415	19,3	236	11,0	795	37,0	2151
1912	433	19,8	287	13,1	424	19,4	236	10,8	804	36,8	2184
1913	436	19,5	292	13,1	427	19,1	237	10,6	845	37,8	2237
1914	439	19,4	289	12,8	434	19,2	232	10,3	864	38,3	2258
1915	461	20,4	291	12,9	434	19,2	220	9,7	857	37,9	2263
1921	.	.	.	.	.	.	.	.	.	.	.
1922	395	19,8	267	13,4	425	21,3	219	11,0	692	34,6	1998
1923	403	19,8	251	12,3	369	18,1	200	9,8	817	40,0	2040
1924	361	20,0	234	12,9	343	19,0	191	10,6	680	37,6	1809
1925	371	19,7	241	12,8	360	19,1	211	11,2	705	37,4	1886
1926	379	19,3	247	12,6	376	19,2	231	11,8	729	37,2	1962
1927	411	19,5	263	12,5	411	19,5	238	11,3	787	37,3	2110
1928	437	20,9	271	13,0	399	19,1	238	11,4	747	35,7	2092
1929	422	20,5	258	12,5	379	18,4	245	11,9	757	36,7	2061
1930	445	19,0	364	15,6	437	18,7	245	10,5	847	36,2	2338
1931	476	19,8	361	15,0	444	18,4	260	10,8	868	36,0	2409
1932	472	19,9	356	15,0	442	18,7	259	10,9	840	35,5	2369
1933	487	19,9	363	14,8	449	18,4	265	10,8	881	36,0	2445
1934	508	19,9	406	15,9	456	17,9	274	10,7	908	35,6	2552
1935	501	19,7	410	16,1	460	18,1	272	10,7	901	35,4	2544
1936	454	18,8	413	17,1	439	18,2	273	11,3	835	34,6	2414
1937	512	21,3	419	17,5	404	16,8	277	11,5	789	32,9	2401
1938	499	21,2	413	17,5	396	16,8	273	11,6	778	33,0	2359
1939	494	20,5	401	16,7	408	17,0	262	10,9	840	34,9	2405
1940	589	22,9	428	16,6	436	17,0	301	11,7	818	31,8	2572
1941	611	22,4	448	16,4	450	16,5	314	11,5	910	33,3	2733
1942	577	21,4	455	16,9	451	16,8	322	12,0	886	32,9	2690
1943	542	20,5	461	17,4	452	17,1	330	12,5	861	32,5	2646

1953	.	.	.	.	.	.	.	.	.	.	.
1954	1019	22,0	674	14,6	743	16,1	629	13,6	1561	33,7	4626
1955	1070	22,0	677	13,9	775	16,0	649	13,4	1688	34,7	4858
1956	1121	22,0	679	13,3	806	15,8	668	13,1	1815	35,7	5089
1957	1181	21,6	722	13,2	859	15,7	719	13,2	1977	36,2	5458
1958	1236	21,5	749	13,0	889	15,5	745	13,0	2131	37,1	5749
1959	1290	21,4	776	12,8	918	15,2	771	12,8	2285	37,8	6040

Table A3. Akaike and Bayesian Information Criteria on the correct number of lags to include in the specification of equation (5).

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_1 ln(HUM$_t$)	-0.068	-0.083	-0.131
	(0.163)	(0.183)	(0.251)
Δ_1 ln(ONS$_t$)	-0.163	-0.217	-0.350
	(0.203)	(0.234)	(0.301)
Δ_1 ln(AS$_t$)	0.340**	0.375**	0.609***
	(0.144)	(0.154)	(0.210)
Δ_1 ln(SS$_t$)	-0.198	-0.167	-0.150
	(0.134)	(0.148)	(0.170)
Δ_1 ln(MS$_t$)	0.069	0.153	0.242
	(0.140)	(0.185)	(0.246)
Δ_1 ln(HUM$_{t-1}$)	-	-0.217	-0.098
		(0.174)	(0.247)
Δ_1 ln(ONS$_{t-1}$)	-	-0.050	0.063
		(0.202)	(0.272)
Δ_1 ln(AS$_{t-1}$)	-	0.139	0.186
		(0.174)	(0.218)
Δ_1 ln(SS$_{t-1}$)	-	-0.004	0.098
		(0.152)	(0.185)
Δ_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)*
Δ_1 ln(HUM$_{t-2}$)	-	-	-0.020
			(0.222)
Δ_1 ln(ONS$_{t-2}$)	-	-	-0.088
			(0.237)
Δ_1 ln(AS$_{t-2}$)	-	-	0.257
			(0.235)
Δ_1 ln(SS$_{t-2}$)	-	-	0.139
			(0.171)
Δ_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)*
Δ_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