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# Knowledge Networks in Scientific Productivity and International R&D Spillovers

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# INTRODUCTION

The globalization of knowledge demands that governments change their attitude towards science policy. Consensus is growing among politicians and governments that the future of countries is going to be determined by a nation's ability to convert knowledge into development and wealth, especially through international cooperation among universities, industries and research centres. At the same time, at the academic level, the number of empirical and theoretical contributions to the economics of innovation and economics of science has grown considerably, especially in the last 20 years. The importance of technology and knowledge creation is clear; however some further investigation is needed. On the one hand, it is fundamental to analyze the determinants of the scientific productivity and the linkages with different institutional scenerios. On the other hand, it is crucial to understand through which channels the technology spills over national borders.

This work, which consists of four papers, fits in with this framework and aims to investigate the economics of scientific and technological productivity both at the individual and at the country level. Given that the universities are considered the *natural* locus of fundamental research and research is a vital function of the modern universities, the current debate is placed on the efficient use of their resources. For this reason, the first two papers focus on the academic system, both of them paying a particular attention to the consequences of the institutional differences on the scientific productivity and on the academic labour market.

The first paper (*Institutional Differences in Academic System: Incentives, Productivity and Social Ties*) is an attempt to analyze theoretically the university system. In particular, the idea is that the culture of a university system depends on the way in which the higher education sector is funded. A similar idea has been developed by Beath et al. (2005) and Gautier and Wauthy (2007), even though they have analyzed the impact of a research quality based funding system on the trade-off between research and teaching.

However, despite the importance attached to it, there are few theoretical studies devoted to the analysis of the university system and most of them are mainly concerned with the academic labour market and the determination of teaching/research trade-off. On the one hand, the studies focused on the labour market have analyzed topics such as job mobility (Skeels and Fairbanks 1969), competition among universities (Carayol 2005), career concerns (Rossellò-Villalonga 2006), tenure positions (Carmichael 1988) and admission standards (De Fraja and Iossa 2001). On the other hand, the literature on the trade-off between research and teaching has emphasized the effect of different financing schemes on the levels of research and on the quality of education (Del Rey 2001), and the role of the departmental management on scholars' performance (Faria 1998). In particular, what is missing is an analysis of the linkages between different recruitment processes and scientific productivity.

Our simple dynamic model compares a centralized university system with an autonomous university system. In the former, the universities receive funds from a central government and scientists' career depends on a national concourse; in the latter, the non profit universities are able to raise money for research and are self-financed.

The model shows that institutional settings have an important role in shaping the incentive structure which in turn determines the efforts devoted by researchers. In particular, in order to increase the expected productivity of scientists, the governments should (1) raise the standard quality of the first period admission (PhD), (2) prefer a centralized university system with a national tournament when the universities find it difficult to raise funds for research (for example if a university carries out only basic research it would generate no revenue), (3) differentiate wages offered by universities at the second stage in the case of centralized university system.

The second paper (*Career Progress in Centralized Academic Systems: an Analysis of French and Italian Physicists*), jointly written with Michele Pezzoni and Francesco Lissoni, is an attempt to analyze empirically some of the previous findings (do institutional differences matter?) and investigates the determinants of academic careers through an empirical analysis of French and Italian physicists' scientific publications.

The debate concerning career advancements in academia is currently constructed along three main lines. First, studies in different fields and different countries have observed that academic career depends on the publication records not in a homogenous way (Clemente 1973, Long et al. 1993, Modena et al. 1999 among others). A second issue is the gender discrimination among scientists: the finding that women are at a disadvantage in terms of career progress is a recurrent one (Cole 1979 and Everett 1994 among others). Finally the third topic is the degree to which promotions depend on a relational and political network among scientists themselves: for example, an individual with a strong position in the network can be perceived as more influential within the scientific community (Kilduff and Krackhardt, 1994), or has more chances to influence the process of composition and the final decisions of examination committees (Perotti 2002), or finally could have an easy access to knowledge sources and funding opportunities (Gonzalez-Brambila et al. 2006).

We present new evidence regarding all the previous issues. The original idea of the paper consists of considering the scientists' network and social capital determinants of academic career alongside the traditional ones.

In the past 50 years, the process of faculty recruitment in the US has been thoroughly analyzed with a particular attention to the two kinds of recruitment used – *open*, or competitive, hiring and *closed*, or preferential, hiring – has been emphasized: "[…] *in theory, academic recruitment is mostly open. In practice, it is mostly closed* (Caplow and McGee 2001 [1958], pp.109)". In addition, while several empirical studies on academic careers have been produced for the US (most recently Long et al. 1993; Long and Fox 1995), almost none is available for European countries, whose institutional setting is both heterogeneous and altogether different from that of the US.

In this paper we aim to fill these empirical gaps. In order to do so we update the conceptual framework of the new economics of science (Dasgupta and David 1994, Stephan 1996), and examine the cases of France and Italy, where the academic advancement is heavily controlled by the central government *via* disciplines, the latter to be intended as state-sanctioned guilds of professors, over which the universities and departments exercise little control.

We develop our empirical analysis by examining the publications on national and international scientific journals because they are widely recognized to be an indicator of the scientists' research productivity, although we are aware that other measures exist such as, for example, books, book chapters or, in some fields, patents and prototypes. In order to identify those publications, we rely upon a database we compiled from the ISI-Web of Science, which contains all scientific articles published between 1975 and 2000, authored by at least one professor of physics active in an Italian or in a French university in the year 2004/2005. We consider only the publications coming from a selection of journals with high impact factor.

Social network analysis has a long tradition of application in the sociology of science, which ranges from the early identification of 'invisible colleges' (Crane, 1972) to the recent application of small-world graphs (Newman, 2001). Both works identify the structure of scientific communities on the basis of co-authorship data, and co-authorship is seen as proof of collaboration and knowledge exchange between two or more scientists.

We follow this framework and we examine the scientists' publications over a 5-year window, from 1995 to 1999. The 5-year window is meant to capture ongoing or "still fresh" research partnerships.
Our results show that rank advancements are explained both by individual characteristics (such as productivity, seniority and gender) and by relational variables (such as the position of the scientist in

the co-authorship networks and the mentoring by senior colleagues). Our analysis confirms the role of seniority and scientific productivity, as found in the literature, but at the same time it also suggests that being well connected to national colleagues has a positive impact on the probability to be promoted in Italy, but not in France. Concluding, the first two papers point out two different aspects: first, institutional differences matter; second, the scientific publications as well as the position in network enhance the academic career.

The second part of the thesis is devoted to the study of the technological productivity at country level, in particular analysing the importance of international intra-sectoral R&D spillovers in six European countries (third paper) and in five Latin American countries (fourth paper).

The main point of these papers is that international R&D sectors are not insulated, but are instead linked by knowledge flows that can be tracked via patent-citation patterns and personal links between patent co-inventors. Indeed it is widely acknowledged that scientific ideas and inventions originate, diffuse, and are improved mainly within a set of connected cliques sharing the same knowledge and jargon. We argue that the inventors' community may be close, so that it is necessary to consider network relationships in order to understand the dynamics of knowledge creation (see Breschi and Lissoni 2001).

While patent citations have already been used in the literature as a measure of knowledge flows (see for instance, Peri 2005 and Malerba et al. 2007), to our knowledge the use of patent co-inventorship has been not emphasized in the literature. If the international interpersonal links and person-to-person contacts play a prominent role in fostering the innovative domestic capacity, (1) R&D subsidies can be effective only as long as they favour the international expansion of the network relations of local inventors, (2) being close to other countries is neither a sufficient nor a necessary condition for accessing a pool of knowledge, but a significant involvement in a network of knowledge exchanges is required.

The third paper (*Flows of Ideas and Trade of Goods: Searching for International R&D Spillovers in Europe*), jointly written with Domenico Ferraro, focuses on intra-sectoral R&D spillovers in Europe over the period 1988-2003. We use patent applications at the European Patent Office (EPO) to measure innovation and extract information about intra-sectoral knowledge flows across countries. We use data for nine OECD countries (Canada, France, Finland, Germany, Italy, Japan, Netherlands, UK, US) and eleven sectors (Food, beverages and tobacco; Textiles, leather and footwear; Wood and cork; Pulp, paper, printing and publishing; Chemicals and pharmaceuticals; Rubber and plastics; Other non metallic mineral products; Basic metals and fabricated metals products; Machinery and equipment; Electrical and optical equipment; Transport equipment). The aim is to understand the nature of technological spillovers in six European countries, and the ultimate goal is to assess the role played by the *flows of ideas* as opposed to the *flows of goods* in defining the relative performance in inventive and productive activity across countries. In particular, the micro-economic literature has highlighted three channels for the international transmission of technology: imports of new capital and differentiated intermediate goods (Grossman and Helpman, 1995); learning by exporting (Clerides, Lach and Tybout, 1998), and foreign investment by multinationals (Blomstrom and Kokko, 1998). In this paper, we test the first channel.

Our results point out that on the one hand, the flows of goods (i.e. trade) have not an impact on the technological productivity, on the other hand, the flows of ideas (i.e. diffusion of codified and non-codified knowledge between people and countries) do have an impact on the technological productivity. Moreover, one additional result is that the greater is the distance from the technological frontier, the greater is the benefit which can be extracted from external knowledge. The fourth paper (*Inventing Together: Exploring the Nature of International R&D Knowledge Spillovers in Latin America*), jointly written with Fabio Montobbio, analyzes with more detail this latter finding. In particular, taking into consideration that much of the current debate about technology policy in developing countries is based on the assumption that a country's innovative performance depends significantly on its relative technological capacities, we test if knowledge transmission from developed countries may create the conditions for developing countries to catch up with the technological frontier. This issue is particularly important if we recall the different innovation policies that have been pursued in industrialized countries and in Latin American countries. "*In the more industrialized countries, the debate on technology and innovation policies had been focused on the importance of networks, linkages and interactions between agents as the main catalyst for innovation and technology transfer since 1980s. In Latin America it is only of late there has been a pressing need to take these issues into consideration in technology policy planning and implementation stages*" (Cimoli et al. 2006).

This paper is one of the first attempts to extend the economic analysis of R&D knowledge spillovers (at the country and industry level) to developing countries and investigates empirically the determinants of the international patent production in a selected number of Latin American countries (LACs). We use data for five big industrial sectors (Textile and Food, Chemicals and Pharmaceuticals, Metals, Instruments Electronic and Non-Electrical Machinery, and Transportation), five Latin American countries (Argentina, Brazil, Chile, Colombia and Mexico) and the G-5 countries (France Germany, Japan, UK and US) between 1988 and 2003. We process the information contained in the US Patent and Trademark Office (USPTO) patent documents and their citations to build the different indexes of R&D spillovers. In addition we match USPTO patent data with economic data taken from different sources at the sectoral level and control for the dynamics of domestic value added and past innovative activity.

Our preliminary evidence suggests that not only the international collaboration between inventors is growing, but also the international co-operation has a positive and significant effect on the domestic innovative activity. Developing countries seem to benefit significantly when domestic inventors collaborate with foreign inventors in developed countries through increased knowledge spillovers. Indeed, we find that international knowledge spillovers from the G-5 countries (Us, Uk, Germany, France and Japan) are a significant determinant of inventive activity in the period considered. In particular the stock of ideas produced in the US seems to have a strong impact on the international patenting activity of these countries. Moreover, controlling for these US-driven pure spillovers effects, bilateral patent citations and face-to-face relationships between inventors are both important *additional* mechanisms of knowledge transmission.

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# Institutional differences in academic systems: incentives, productivity and social ties

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**Abstract**

The relationship between institutional differences and scientist incentives is examined through a simple dynamic model. In particular, we modify the theoretical framework in Carayol (2005) combining it with the economics analysis of personnel (Lazear, 2001). Overlapping generations of researchers compete according to different institutional framework for senior positions offered by universities. *Centralized university system* (where the university receives funds from a central government and scientists' career depends on a national concourse) and *autonomous university system* cases (where non profit universities raise money for research) are considered. Moreover we assume that scientific productivity depends on two distinct types of effort: the time spent in laboratory and time spent building scientific networks. We derive equilibrium scientists' efforts under different institutional frameworks and different hypothesis on scientific production functions.

**Key words**: Academic competition, Education, Scientific productivity.

**JEL classification**: H00, I28, J62.

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# 1. Introduction

In the past 20 years or so, the number of empirical contributions to the economics of science has grown considerably (Stephan, 1996; Audretsch et al. 2004), but just a few studies have examined explicitly the issue of academic careers. In particular, what is missing is any analysis of the linkages between different recruitment processes (as to be found in different national contexts) and scientific productivity. The few existing theoretical contributions to this topic have mainly dealt with issues concerning the academic labour market and the teaching/research trade-off. On the one hand, the labour market studies analyzed topics such as job mobility (Skeels and Fairbanks, 1969), competition among universities (Carayol, 2005), career concerns (Rossellò-Villalonga, 2006), tenure positions (Carmichael, 1988) and admissions standard (De Fraja and Iossa, 2001). On the other hand, the literature on the trade-off between research and teaching has emphasized the effect of difference financing schemes on levels of research and education quality (Del Rey 2001) and the role of departmental management on scholars' performance (Faria 1998).

Focusing on an academic context, Carayol (2005) developed a dynamic model of academic competition in which researchers compete in effort in order to occupy the position (i.e. getting employed by the university) that provides the highest satisfaction. In particular Carayol has emphasized the inequality of research positions in terms of productivity, due to the positive externalities which university staff at all levels derive from top-ranked colleagues, and to the positive reputation effect of the employing university.

Rossellò-Villalonga (2006) developed a model in which three different groups of agents are involved in the university careers (public administrations, university managers, and professors). The focus here is on the principal-agent problem between professors and universities, due to the career options that professors have outside the academia.

This paper contributed to the research line concerning the academic labour market, and it focuses on the institutional framework affects scientific productivity. Different institutional frameworks are intended here as different recruitment rules and career's profiles.

A key assumption of our model is that discoveries and scientific ideas are the results of different activities, and not only the time spent in laboratory. In particular we consider here the possibility that scientists' productivity is affected by her inter-personal network, and that network building is an activity to which the scientist has to dedicate time-consuming efforts. So, two different knowledge production functions can be conceived of, each modelling a two different effort: the scientific efforts at the laboratory level and non-scientific effort devoted to build scientific networks.

Scientific networks may have in fact important implications. On one side it is plausible that scientific information is transmitted more easily in networks (free access to a pool of knowledge), and different social network patterns may be conducive to the reinforcement of moral consensus among scientists (Friedkin, 1978). On the other side social capital embedded in individual relationship may foster knowledge creation by exchange processes and social interaction; in particular social relationships may be an important factor in the development of human capital (Coleman, 1988) and an important influence on the development of intellectual capital (Nahapiet and Ghoshal, 1998).
Following the latter view, Gonzalez-Brambila et al. (2008) found that networks promote the creation of new knowledge, by granting greater access to resources and information: the individual who occupy central positions in their academic network have a propensity to create more knowledge, while the number of ties has a positive impact on the future productivity.
In the literature on academic labour market only few works emphasized the role of networks. At the theoretical level Faria (2002) analyzed how different types of networks (scientific versus business and political) affect the behaviour of scholars and underlined the risks that academic scientists can become too responsive to economic incentives linked to the second type of networks. On the other side, at the empirical level, Pezzoni et al. (2009) analyze individual data on Italian and French physicists and find evidence of a positive relationship between scientific networks - measured through co-authorship - and rank advancements for the Italian case.
The reminder of the paper is as follows. The model is presented in the next Section. Then we compare the case of a centralized university system with that of an autonomous system, on the basis of two different hypotheses on the knowledge production function. In particular, in Section 3 we analyze the case of absence of social capital in the knowledge production function; in Section 4 we assume that scientific productivity depends both on scientific effort and on time spent building scientific networks. In the last Section we conclude, present the model's policy implications, discuss some important limitations, and propose some directions for future work.

# 2. The model

We consider an academic system composed of $k = 2$ universities and two agents (scientists) from overlapping generations, whose career lasts two periods and allows for two steps: "researcher" (or "junior") and "professor" (or "senior"). Let $p \in \{1,2\}$ denote the periods at which agents are respectively (junior) researchers and professors and $r \in \{\alpha, \beta\}$ denote the two agents.

## *Agents' utility function*

Agents decide the optimal allocation of efforts aiming at maximizing their utility, which depends positively on income and research output and negatively on efforts in both the periods.
Agent's instantaneous utility is assumed to be addictively separable as follows:

$$W_r^p = U(S_k) + \vartheta_r y_r^p - \gamma_r^p v(efforts_r^p) \quad (1)$$

Where $y$ is a measure of the scientist's output (such as publications) and $\partial > 0$ represents the satisfaction derived from such output (the direct pleasure from "*puzzle solving*", as in Levin and Stephan (1991)[1]. $U(\cdot)$: $(0,\infty) \rightarrow (0,\infty)$ is the instantaneous utility function, where U' > 0, U" ≤ 0. $S_k$ represents the research budget offered to the agent by university $k$ at the beginning of the period, inclusive of the agent's wage. The instantaneous disutility of effort function $V(\cdot)$: $(0,\infty)^2 \rightarrow (0,+\infty)$ is assumed to be addictively separable in the arguments such as $v(0,0) = 0; v' > 0, v'' > 0$, where the two arguments represent the different types of effort. Both the research budget and the publications may capture the reputation effect.
The whole career net utility function is assumed to be addictively separable between the two periods of the career. Actually, we refer to expected utility both because of the randomness of the knowledge production function and because the second period utility does depend on the expected salary.
The intrinsic different ability of researchers is captured in the cost of the efforts $v(\cdot)$ by the parameter $\gamma$: the lower $\gamma$, the higher the ability.
Thus the total net utility of one agent actualized at the initial period $p$ is given by:

$$\overline{W}_r = \sum_{p=1}^{2} \delta^{p-1} E[W_r^p] \quad (2)$$

with δ the agents' actualization factor and E the expectation operator.
We model the incentive structure of the university system through two different settings. First we consider a centralized university system characterized with a recruitment process based upon merit. In such a system the universities receive from the government and distribute to each scientist a fixed research budget (whose entity depends only on the scientist's seniority), and recruit scientists on the basis of their publication records. Formally, this system can be modelled as a two-player tournament in which the rules of the game specify a fixed budget for research $\overline{S}$ to the winner and a fixed budget

[1] Carayol (2005) assumes that scholars' objective function depends on being in a distinguished and prestigious institutions.

for research $\underline{S}$ to the loser in the second period, and the winner is the scientist who has published more in the first period; in this particular setting universities' funds depend only on governmental budget.

Second, we consider an alternative setting in which universities are self-funded non profit organizations, whose aim consists of maximizing scientific output subject to the condition of zero profit and whose revenues depend crucially on scientific productivity. We call this an "autonomous" university system.

## *University objective function*

We start from the idea that universities have the goal to maximize the output of research, without taking into consideration teaching and the "third" mission of economic development. There are two main reasons for which research activities may be important for universities: (1) publications give prestige and (2) research is an income-generating activity because source of new projects and because of the "new" methods of funds allocation (Joan Rosselló-Villalonga, 2006). In particular, in the autonomous system we take into account the second issue and allow the universities to raise funds by publications' activity.

In every period each university produces two different research outputs: that of the junior scientist $y^1$ and that of the senior scientist (professor) $y^2$. Without loss of generality we assume that the research budgets for junior scientists $\left(S_\alpha^1\right)$ are fixed and paid by the government.

In the centralized system universities do not interact directly with the agent (universities are exogenous), nevertheless in the autonomous case universities have to choose the budget for research $\left(S_\alpha^2\right)$ for the senior according to the following objective function:

$$\hat{\Pi}_k^t = \xi(\hat{y}_j^{1,t} + \hat{y}_s^{2,t}) - S_\alpha^{2,t} \qquad \forall t \tag{3}$$

Due to the university non-profit status we impose the zero profit condition.

The parameter ξ>0 represents the ability of the university to convert in monetary terms the research production (public or private grants obtained for research projects). The estimate reflects the fact that all research budgets have to be defined at the beginning of each periods, when the scientists' output (publications) has not yet; materialized: $\hat{y}_j^{1,t}$ is the estimated productivity of junior scholar assigned to university $k$, while $\hat{y}_s^{2,t}$ is the estimated productivity of senior scholar whose budget for research has to be set.

The best estimator of agent α's productivity at period 2 is agent α's productivity at period 1: $\hat{y}_s^{2,t} = y_s^{1,t-1}$.

It is worthwhile to note that we do not face a principal-agent problem, because universities and scientists share the goal to maximize the same type of output (publications).

## *Production function*

Research production is supposed to be additively separable in efforts over both the two periods of activity. In particular it does depend on two different types of effort: *scientific effort* (i.e. the time spent in laboratory) and *social networking effort* (i.e. the time spent building scientific relationship and links with other researchers, attending academic societies and conference). We start from the intuition that, although ideas are developed by individuals, the interaction between the individual and her scientific community members plays a critical role in amplifying knowledge creation (Gonzalez-Brambilla et al. 2008). Moreover it is plausible that the relationship built by the effort spent in networking does not vanish as time goes by, but follows a cumulative process.

At period p, the research output of agent *r* employed in university *k* is given by:

$$y_{r,k}^p = f_{e,r,k}^p(e_{r,k}^p) + \Phi_{r,k}^p + \varepsilon_{r,k}^p \qquad (4)$$

where network has the following generating process[2]:

$$\Phi_r^p = \Phi_r^{p-1} + f_\eta^p(\eta_r^p) \qquad (5)$$

Both the production functions are positive and increasing, with the derivative measuring the productivity of efforts at the different steps of the career. In particular $f^p(\cdot)$ is assumed to be strictly increasing, concave, and null when the researchers exert zero effort. The terms $e$ and $\eta$ represents respectively the level of efforts in scientific and networking activities[3].

The term $\varepsilon_{r,k}^p$ is a random specific shock that affects agent *r* production such as $E[\varepsilon_{r,k}^p] = 0$. Let assume that these shocks are *iid* across agents and periods. The distribution function of this random variable is denoted by $G(\cdot)$ and its density function is $g(\cdot)$. The latter is assumed to be unimodal, continuously differentiable, strictly positive over $[-\infty,+\infty]$, and symmetric around its unique

[2] For sake of simplicity we assume a deterministic process

[3] We do not impose any restriction on both the types of effort.

maximum attained at 0. Notice that this production structure specifies that a scientist's output is a random variable, but the mean of the probability distribution can be affected by the scientist's own actions.

Moreover the heterogeneity across individuals is captured by the parameter $\gamma$ in the utility function: this implies that we could consider a homogenous production function across individuals[4] and rewrite equation (4) as follows:

$$y^{p}_{r,k} = f_{e,k}(e^{p}_{r,k}) + \Phi^{p}_{r,k} + \varepsilon^{p}_{r,k} \qquad (6)$$

## *Timing*

At each period, there are two junior researchers (the best way to think of them is as PhD students) who are paid by the government to do research, and two seniors who are employed in each university. At the end of each period, the scholars' outcome is public knowledge.

At each period t of the discrete time, a fixed cohort composed of two researchers enters the academic job market.

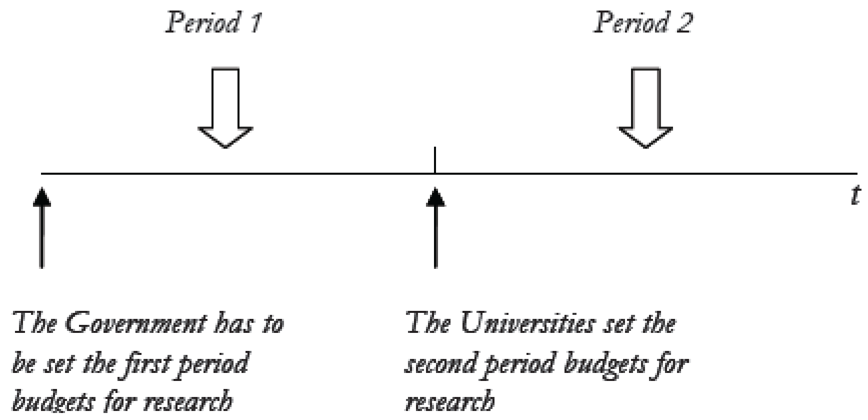
In the centralized university system the research budgets offered at the beginning of each period are exogenous (they do not depend upon the universities' strategies, but only upon the government's exogenous decisions).

In the *autonomous university* case, universities set the budgets of research for the senior positions according to their budget constraint.

After the first period, the government and/or the universities obtain an estimate of how productive the scientists are (how much effort has been devoted), namely $y^1_r$. But since $\varepsilon^1_r$ is the period one transitory component (transitory ability or random shock), is $f_e(e^1_r)$ and not $y^1_r$ on which a hiring decision (either by the government or by universities) should be made. Nevertheless $f_e(e^1_r)$ is not observed, so the employer (the university) is forced to base its decision only upon $y^1_r$.

[4] We also assume that the productivity of the effort is the same for both periods, i.e. the production function is the same at the first and at the second stage of the career.

**Figure 1. Timing**




## 3. Absence of social capital in knowledge production

In this section we assume that scientific production at each period depends only on scientific effort. Thus at period p, the research output of agent *r* employed in university *k* is given by:

$$y_{r,k}^{p} = f_{e,k}(e_{r,k}^{p}) + \varepsilon_{r,k}^{p} \tag{7}$$

In order to simplify the model we also assume that the expected production conditional to the effort is the same in all universities (i.e. we are not considering the work of context effect). We can rewrite equation (7) as follows:

$$y_{r}^{p} = f_{e}\,(e_{r}^{p}) + \varepsilon_{r}^{p} \tag{8}$$

In Section 3.1 we derive second stage optimal scientists' effort. Then we concentrate on the first stage, discussing two alternative institutional frameworks. In Section 3.2 we consider a centralized university system whose career profile depends crucially on a two-player tournament in which the probability of winning is either endogenously determined (linked to the scientific production) or exogenously determined. In Section 3.3 we analyze an autonomous university system characterized by two non profit universities.

### 3.1 Second stage optimal effort

We now concentrate on the computation of the optimal choice in case of homogeneity[5] across individuals (whose behaviour will turn out to be identical). In particular, we assume that the cost associated to the effort is the same for both agents. Thus we are able to rewrite the instantaneous utility function as follows[6]:

$$W_r^p = U(S_k) + \vartheta_r^p y_r^p - \gamma v(e_r^p) \tag{9}$$

At each stage, agents maximize the expected utility over their remaining career cycle. For this reason we use standard backward induction reasoning.

Because the budget for research has been determined at the beginning of the second period, the optimal second period effort is not influenced by it.

Moreover, it is important to note that as long as the scientific output gives some direct utility to researchers, in the last period the optimal effort will be not zero even in absence of competition between scholars.

At second stage agent *a* chooses her effort level $\hat{e}_\alpha^2$, in order to maximize her net utility function:

$$\hat{e}_\alpha^2 \equiv \arg\max\left\{W_\alpha^2 = U(S_k^2) + \vartheta_\alpha^2 y_\alpha^2 - \gamma v(e_\alpha^2)\right\} \tag{10}$$

where the F.O.C. is simply the follows:

$$\vartheta f'(e_\alpha^2) = \gamma v'(e_\alpha^2) \tag{11}$$

The optimal choice for the first period does depend on the institutional setting of the university system.

### *3.2* First stage optimal effort: *centralized universities* with *two-player tournament*

In this section we shall focus on agents' behaviour in the case of centralized university system in which, at each stage, the agent who wins the competition occupies the position that provides the

[5] See Appendix B for the heterogeneity case

[6] For sake of simplicity we also assume the same cost for both the periods.

highest satisfaction. The research budgets that each university can offer are imposed by the government.

For sake of simplicity suppose that $U\left(S_x^2\right)=S_x^2$.

At the first stage of the game (*p*=1), because of competition, *a* chooses her effort level $\hat{e}_\alpha^1$, given *β*'s $\hat{e}_\beta^1$ in order to maximize her expected net utility function:

$$\begin{aligned}\hat{e}_\alpha^1 &\equiv \arg\max\left\{E\left[W_\alpha^1\right]+\delta E\left[W_\alpha^2\right]\right\}= \\ &=\left\{U\left(S_k^1\right)+\vartheta_\alpha^1 E\left[y_\alpha^1\right]-\gamma v\left(e_\alpha^1\right)+\delta\left[\overline{S}^2 prob(\cdot)+\underline{S}^2\left(1-prob(\cdot)\right)+\vartheta_\alpha^2 E\left[y_\alpha^2\right]-\gamma v\left(\hat{e}_\alpha^2\right)\right]\right\}\end{aligned} \tag{12}$$

where *prob(.)* represents the probability of winning the competition.

The F.O.C. is:

$$\vartheta f'\left(e_\alpha^1\right)-\gamma v'\left(e_\alpha^1\right)+\frac{\partial prob_\alpha(\cdot)}{\partial e_\alpha^1}\delta\overline{S}^2-\frac{\partial prob_\alpha(\cdot)}{\partial e_\alpha^1}\delta\underline{S}^2=0 \tag{13}$$

where the optimal effort chosen clearly depends on the probability of winning the competition.

Let's suppose to be in a meritocratic system. In this case the probability of winning depends on the scientific production at the end of the first period and hence on the effort chosen at that time. Therefore the probability of winning can written as the probability of having a greater scientific production with respect the competitor.

The simultaneously resolution of the two programs detailed in the Appendix A leads to a unique Nash equilibrium which is symmetric and given by:

$$\hat{e}^1=\left(\Psi^p\right)^{-1}\left[\frac{\vartheta+\delta g(0)\Delta S^2}{\gamma}\right] \tag{14}$$

with function $\Psi(\cdot)$ defined by $\Psi(x)=V'(e)/f'(e)$. This function is null at zero and strictly increasing from then.

Therefore the first period effort is increasing with agents' actualization factor, with differences in second stage expected research budgets - so each agent's investment depends on the spread between winning or loosing prizes - and increasing with the pleasure scientists derive directly from doing research; of course is decreasing with the cost of effort.

Thus first stage equilibrium efforts are crucially increasing with the differences in research budgets that the government grants to the universities; and when government provides identical funds to each university the optimal level of effort is simply the following:

$$\hat{e}^{1} = \left(\Psi^{p}\right)^{-1}\left[\frac{\vartheta}{\gamma}\right] \qquad (15).$$

The rationale for differentiating research budgets could be found in the *a priori* government's decision to maintain two different types of universities in relation to their orientation to research rather than teaching or vocational training (I'm referring for example to the Germany's dual system of both*Universitäten* and *Fachhochschulen*, where the latter on average get per student about of the resources of universities[7])

It is interesting to see that the solution in case of identical research budgets is the same of the case where the probability of winning the competition does not depend on the effort and so is not stochastic (for example it is one). Clearly, in this case the effort chosen by an agent is independent from the other one.

The simultaneously resolution of the two programs leads to a unique Nash equilibrium which is symmetric and is again (15).

**Proposition 1.**

*In the case of homogeneity across individuals and absence of social capital effect, agents' equilibrium efforts are unique and symmetric at each stage of the career. In particular, the greater the differences in terms of research budgets offered by universities, the greater the equilibrium efforts in the first stage. Moreover, individuals perform worse after having received their promotion (Lazear, 2001). Finally, when there are not differences in funds provided by the government to the universities* $\left(\Delta S^{2} = 0\right)$ *the two-player tournament in a meritocratic system has the same consequences of a system in which the probability of winning the competition does not depend on the effort.*

### *3.3* First stage optimal effort: *autonomous university system case*

As explained in Section 2, we now shall refer to a different setting, in which there are two autonomous universities raise public (or private ) funds in relation to their scientific productivity.

[7] For further details see Lepori B. (2007)

In particular, for every period there are *2* universities which are endowed by a junior scientist, whose research budget (PhD grant) is fixed (and offered by the State), and have to recruit and pay a senior researcher. Universities are non profit organizations. Therefore the budget for research will be as higher as the expected productivity.

Recall the university objective function: at the beginning of each period universities have to choose the budget for research $\left(S_\alpha^2\right)$ for the senior according to the following objective function:

$$\Pi_k^t = \xi(\hat{y}_j^{1,t} + \hat{y}_s^{2,t}) - S_s^{2,t} \tag{3}$$

Due to the non profit status, the budget for research offered to senior scientists is uniquely determined as follows:

$$S_s^{2,t} = \xi(\hat{y}_j^{1,t} + \hat{y}_s^{2,t}) \tag{16}$$

where $\hat{y}_j^{1,t}$ represents the estimated productivity of the new junior scientist, while $\hat{y}_s^{2,t}$ the estimated productivity of the senior scientist whose budget for research has to be fixed by the university. Obviously a consistent estimator for $\hat{y}_s^{2,t}$ is $y_s^{1,t-1}$, that is the scientific production of the same agent in the previous period (junior stage).

Therefore the budget for research offered by the university can be re-written as:

$$S_s^{2,t} = \xi(\hat{y}_j^{1,t} + y_s^{1,t-1}) \tag{17}$$

At the first stage of the game ($p$=1) $a$ chooses her effort level $\hat{e}_\alpha^1$, in order to maximize her expected net utility function:

$$\hat{e}_\alpha^1 \equiv \arg\max\left\{E\left[W_\alpha^1\right] + \delta E\left[W_\alpha^2\right] = S_\alpha^1 + \vartheta_\alpha E\left[y_\alpha^1\right] - \gamma v\left(e_\alpha^1\right) + \delta\left[S_\alpha^2 + \vartheta_\alpha E\left[y_\alpha^2\right] - \gamma v\left(\hat{e}_\alpha^2\right)\right]\right\} \tag{18}$$

It straightforward to see that in equilibrium the optimal effort is:

$$\hat{e}^1 = \left(\Psi^p\right)^{-1}\left[\frac{\vartheta + \delta\xi}{\gamma}\right] \tag{19}$$

with function $\Psi(\cdot)$defined by $\Psi(x) = V'(e)/\,f'(e)$.

**Proposition 1.**

*In the autonomous university system case and in the case of homogeneity across individuals and absence of social capital effect, agents' equilibrium efforts are unique and symmetric at each stage of the career. In particular, the greater the ability of the university to convert in monetary terms the research production, the greater the equilibrium efforts in the first stage.*

### *3.4 Summing-up*

**Table 1.**

| INSTITUTIONAL CONTEXT | OPTIMAL EFFORT IN THE FIRST PERIOD |
|---|---|
| *A: centralized and meritocratic university system* with *two-player tournament* | $\hat{e}^1 = \left(\Psi^p\right)^{-1}\left[\dfrac{\vartheta + \delta g(0)\Delta S^2}{\gamma}\right]$ |
| *B: autonomous university system case* (non profit and self-funded universities) | $\hat{e}^1 = \left(\Psi^p\right)^{-1}\left[\dfrac{\vartheta + \delta\xi}{\gamma}\right]$ |

**Proposition 3.**

*A centralized (i.e. research funds are set by the government) and meritocratic (i.e. the probability of winning the competition depends on the scientific production) university system obtains a higher level of effort than the autonomous university system case when the differences in research budgets are such that* $\Delta S^2 > \dfrac{\xi}{g(0)}$.

# 4. Social capital in own knowledge production

In this section we assume that scientific production at each period depends on two distinct types of effort. The effort spent in laboratory (hereby after scientific effort) and time spent building scientific networks that provide a forum for discussion, co-authorship and critical analysis of a scholar's output (Faria 2002, Beckmann 1994), which increases the probabilities of academic success (in terms of scientific publication and hence of career advancements).

Thus at period p, the research output of agent *r* employed in university *k* is given by:

$$y_{r,k}^{p} = f_{e,k}(e_{r,k}^{p}) + \Phi_{r,k}^{p}\left(\eta^{p}, \Phi^{p-1}\right) + \varepsilon_{r,k}^{p} \tag{20}$$

In order to simplify the model we also assume that the expected production conditional to the effort is the same in both the universities (i.e. we are not considering the work of context effect). In particular we are assuming that the context of work does not affect individual scientific productivity: only individual scientific network (for example measured through scientific co-authorship) has a positive impact on knowledge productivity.

We can rewrite equation (20) as follows:

$$y_{r}^{p} = f_{e}\,(e_{r}^{p}) + \Phi_{r}^{p}\left(\eta^{p}, \Phi^{p-1}\right) + \varepsilon_{r}^{p} \tag{21}$$

### 4.1 Second stage optimal effort

We now concentrate on the computation of the second stage optimal choice in case of homogeneity across individuals. In particular we assume that the cost of the effort is the same for both the agents. Thus we are able to rewrite the instantaneous utility function as follows:

$$W_{r}^{p} = U\left(S_{k}\right) + \vartheta y_{r}^{p} - \gamma v\left(e_{r}^{p}, \eta_{r}^{p}\right) \tag{22}$$

At second stage agent $a$ chooses her effort level $\hat{e}_{\alpha}^{2}$ and $\hat{\eta}_{\alpha}^{2}$, in order to maximize her net utility function:

$$\hat{e}_{\alpha}^{2}, \hat{\eta}_{\alpha}^{2} \equiv \arg\max\left\{W_{\alpha}^{2} = U\left(S_{k}\right) + \vartheta y_{\alpha}^{2} - \gamma v(e_{\alpha}^{2}, \eta_{\alpha}^{2})\right\}$$

(23)

Where the first order conditions are simply the follows:

$$\begin{aligned} \vartheta f_{e}'\left(e_{\alpha}^{2}\right) &= \gamma \frac{dv\left(e_{\alpha}^{2}, \eta_{\alpha}^{2}\right)}{de_{\alpha}^{2}} \\ \vartheta f_{\eta}'\left(\eta_{\alpha}^{2}\right) &= \gamma \frac{dv\left(e_{\alpha}^{2}, \eta_{\alpha}^{2}\right)}{d\eta_{\alpha}^{2}} \end{aligned} . \tag{24}$$

This is equivalent to the requirement that for the efforts we have

$$\frac{\frac{dv\left(e_\alpha^2,\eta_\alpha^2\right)}{de_\alpha^2}}{\frac{dv\left(e_\alpha^2,\eta_\alpha^2\right)}{d\eta_\alpha^2}}=\frac{f_e'\left(e_\alpha^2\right)}{f_\eta'\left(\eta_\alpha^2\right)}. \tag{25}$$

The expression on the left of (25) is the marginal rate of substitution of effort $e$ for effort $\eta$ in optimum. In particular in optimum the ratio of marginal costs is equal to the ratio of marginal revenues (marginal productivities). Actually, because of symmetry, the above expression holds for the agent β too.

### *4.2* First stage optimal effort: *centralized universities* with *two-player tournament*

At the first stage of the game (*p*=1), because of competition, *a* chooses her effort level $\hat{e}_\alpha^1$, given *β*'s $\hat{e}_\beta^1$ in order to maximize her expected net utility function:

$$\begin{aligned}&\hat{e}_\alpha^1,\hat{\eta}_\alpha^1 \equiv \arg\max\left\{E\left[W_\alpha^1\right]+\delta E\left[W_\alpha^2\right]\right\}=\\&=U\left(S_k^1\right)+\vartheta_\alpha y_\alpha^1-\gamma v\left(e_\alpha^1,\eta_\alpha^1\right)+\delta\left[\overline{S}^2 prob(\cdot)+\underline{S}^2\left(1-prob(\cdot)\right)+\vartheta_\alpha y_\alpha^2-\gamma v\left(\hat{e}_\alpha^2,\hat{\eta}_\alpha^2\right)\right]\end{aligned} \tag{26}$$

where *prob(.)* represents the probability of winning the competition.

The first order conditions are:

$$\begin{aligned}&\vartheta f'\left(e_\alpha^1\right)-\gamma\frac{dv}{de_\alpha^1}\left(e_\alpha^1,\eta_\alpha^1\right)+\frac{\partial prob_\alpha(\cdot)}{\partial e_\alpha^1}\delta\overline{U}^2-\frac{\partial prob_\alpha(\cdot)}{\partial e_\alpha^1}\delta\underline{U}^2=0\\&\vartheta f'\left(\eta_\alpha^1\right)-\gamma\frac{dv}{d\eta_\alpha^1}\left(e_\alpha^1,\eta_\alpha^1\right)+\frac{\partial prob_\alpha(\cdot)}{\partial\eta_\alpha^1}\delta\overline{U}^2-\frac{\partial prob_\alpha(\cdot)}{\partial\eta_\alpha^1}\delta\underline{U}^2=0\end{aligned} \tag{27}$$

Clearly the optimal efforts chosen depend on the probability of winning the competition.

The simultaneously resolution of the maximization problem for the scientific effort leads to a unique Nash equilibrium which is symmetric and given by:

$$\hat{e}^1=\left(X^p\right)^{-1}\left[\frac{\vartheta+\delta g(0)\Delta S^2}{\gamma}\right] \tag{28}$$

with function $\mathrm{X}(\cdot)$defined by $\mathrm{X}(x)=V_e^{'}(e,\eta)/\ f_e^{'}(e)=V_e^{'}(e)/\ f_e^{'}(e)$. This function is null at zero and strictly increasing from then. Clearly because of non substitution effect between the two types of efforts, the optimum scientific effort in equilibrium is the same of Section 3.2.

For the optimal effort spent in networking we have:

$$\hat{\eta}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta(1+\delta)+\delta g(0)\Delta S^2}{\gamma}\right] \tag{29}$$

with function $\mathrm{X}(\cdot)$defined by $\mathrm{X}(x)=V_\eta^{'}(e,\eta)/\ f_\eta^{'}(\eta)$.

Clearly, as long as the individual cares for the future ($\delta \geq 0$) and as long as the cost of the scientific effort is the same of networking effort, the effort spent in networking is greater or equal to the effort spent in laboratory because of the cumulativeness of the former.

### *4.3* First stage optimal effort: *autonomous university system case*

As in the previous section, at the beginning of each period universities have to choose the wage $\left(S_\alpha^2\right)$ for the senior according to the following objective function:

$\Pi_k^t = \xi(\hat{y}_j^{1,t} + \hat{y}_s^{2,t}) - S_s^{2,t}$.

Again, due to the no profit status, the budget for research offered to senior scientists is uniquely determined as follows:

$S_s^{2,t} = \xi(\hat{y}_j^{1,t} + \hat{y}_s^{2,t})$.

At the first stage of the game (*p*=1) *a* chooses her effort level $\hat{e}_\alpha^1$ in order to maximize her expected net utility function:

$$\hat{e}_\alpha^1 \equiv \arg\max\left\{E\left[W_\alpha^1\right]+\delta E\left[W_\alpha^2\right]=S_\alpha^1+\vartheta_\alpha E\left[y_\alpha^1\right]-\gamma v\left(e_\alpha^1\right)+\delta\left[S_\alpha^2+\vartheta_\alpha E\left[y_\alpha^2\right]-\gamma v\left(\hat{e}_\alpha^2\right)\right]\right\} \tag{30}$$

It straightforward to see that in equilibrium the optimal scientific effort in the first period is:

$$\hat{e}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta+\delta\xi}{\gamma}\right] \tag{19}$$

with function $\mathrm{X}(\cdot)$defined by $\mathrm{X}(x)=V_e^{'}(e,\eta)/\ f_e^{'}(e)=V_e^{'}(e)/\ f_e^{'}(e)$.

Clearly also in this case because of non substitution effect between the two types of efforts, the optimum scientific effort in equilibrium is the same of Section 3.3.

At the same time, the optimal networking effort in the first period is the following:

$$\hat{\eta}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta(1+\delta)+2\delta\xi}{\gamma}\right] \tag{31}$$

with function $\mathrm{X}(\cdot)$ defined by $\mathrm{X}(x) = V_e'(e,\eta)/ f_e'(e)$.

**Proposition 4.**

*A centralized (i.e. research funds are set by the government) and meritocratic (i.e. the probability of winning the competition depends on the scientific production) university system determines a higher level of networking effort than the autonomous university system case when the differences in research budgets are such that* $\Delta S^2 > \frac{2\xi}{g(0)}$.

### *4.4 Summing-up*

**Table 2.**

| INSTITUTIONAL CONTEXT | OPTIMAL SCIENTIFIC EFFORT IN THE FIRST PERIOD | OPTIMAL NETWORKING EFFORT IN THE FIRST PERIOD |
|---|---|---|
| *A: centralized and meritocratic university system* with *two-player tournament* | $\hat{e}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta+\delta g(0)\Delta S^2}{\gamma}\right]$ | $\hat{\eta}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta(1+\delta)+\delta g(0)\Delta S^2}{\gamma}\right]$, |
| *B: autonomous university system case* (non profit and self-funded universities) | $\hat{e}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta+\delta\xi}{\gamma}\right]$ | $\hat{\eta}^1 = \left(\mathrm{X}^p\right)^{-1}\left[\frac{\vartheta(1+\delta)+2\delta\xi}{\gamma}\right]$ |

# 5. Concluding remarks and future extension

In this paper we have discussed a model of academic competition which aims to capture the life-cycle effect and the incentive structure ruled out by the government. Moreover we have analyzed some hypotheses on the scientific production function and on the institutional structures.

The key result we derived from the model is that institutional settings have an important role in shaping the incentive structure that determines the efforts devoted by researchers. Without taking into account issues on social welfare analysis, if the target is simply to produce more knowledge as possible, the set of available policies to achieve this target is vast, and among them the government may (1) develop a competitive academic labour market, (2) differentiate wages offered by universities at the second stage in the case of centralized university system, (3) adopt a tournament (national concourse) instead preferring a decentralized university system when universities find difficulties to raise funds for research (for example for those disciplines far away from industrial needs) , (4) raise the standard quality of first period admission (PhD) to diminish the heterogeneity of candidates.

Further extensions of the paper are needed. In particular the substitution effect between different types of efforts has to be considered, by imposing a maximum time to be allocated among scientific and networking effort.

Moreover a natural extension of the model consists in developing the social welfare analysis. It is interesting to study under which conditions (in particular, the maximum amount of budgets of research that the government may allocate) a centralized university system may be preferred and *vice versa*.

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# Appendix

## *Appendix A. Computation of the first stage Nash equilibrium in the case of centralized and meritocratic university system* with *two-player tournament*

The first order condition of program (11) is

$$\vartheta f'\left(e_\alpha^1\right)-\gamma v'\left(e_\alpha^1\right)+\frac{\partial prob_\alpha(\cdot)}{\partial e_\alpha^1}\delta\overline{U}^2-\frac{\partial prob_\alpha(\cdot)}{\partial e_\alpha^1}\delta\underline{U}^2=0$$

Notice that the probability that agent *a* wins the tournament is given by

$$prob\left(y_\alpha^1>y_\beta^1\right)=P\left(f\left(e_\alpha^1\right)+\varepsilon_\alpha^1>f\left(e_\beta^1\right)+\varepsilon_\beta^1\right)=p\left(\Delta\varepsilon^1>f\left(e_\beta^1\right)-f\left(e_\alpha^1\right)\right)=1-G\left[f\left(e_\beta^1\right)-f\left(e_\alpha^1\right)\right].$$

Therefore, differentiating that expression with respect to *a*'s efforts, we obtain:

$$\frac{\partial prob\left(y_\alpha^1>y_\beta^1\right)}{\partial e_\alpha^1}=g\left(f\left(e_\beta^1\right)-f\left(e_\alpha^1\right)\right)\left[\frac{\partial f\left(e_\alpha^1\right)}{\partial e_\alpha^1}\right].$$

Introducing this expression in the first order condition (A1), we get:

$$\gamma v'\left(e_\alpha^1\right)=g\left(f\left(e_\beta^1\right)-f\left(e_\alpha^1\right)\right)f'\left(e_\alpha^1\right)\delta\Delta U^2+\vartheta f'\left(e_\alpha^1\right)=f'\left(e_\alpha^1\right)\left[g\left(f\left(e_\beta^1\right)-f\left(e_\alpha^1\right)\right)\delta\Delta U^2+\vartheta\right]$$

Now, let us define the function $\Psi(\cdot)$ defined by $\Psi(x)=v'(x)/f'(x)$. This function is defined over $\Re^+$. Since $v'(0)=0$, this function is null at zero. Moreover having $v'>0, v''>0, f'>0, f''<0$, it can easily be shown this function is strictly increasing, that is $\Psi'>0$. Thus, its inverse function is also increasing.

Now we can rewrite the first order condition using this new notation:

$$\Psi\left(e_\alpha^1\right)=\frac{\left[g\left(f\left(e_\beta^1\right)-f\left(e_\alpha^1\right)\right)\delta\Delta U^2+\vartheta\right]}{\gamma}.$$

Similarly, the first order condition for the agent $\beta$ is:

$$\Psi\left(e_{\beta}^{1}\right)=\frac{\left[g\left(f\left(e_{\alpha}^{1}\right)-f\left(e_{\beta}^{1}\right)\right)\delta\Delta U^{2}+\vartheta\right]}{\gamma}.$$

These two equations are of the form $e_{\beta}^{1}=h\left(e_{\alpha}^{1}\right)$ and $e_{\alpha}^{1}=h\left(e_{\beta}^{1}\right)$, with $h(\cdot)$ a continuous function over $\Re^{+}$. If an equilibrium exists it is necessarily symmetric, satisfying the following expression:

$$\Psi\left(e^{1}\right)=\frac{\left[g(0)\delta\Delta U^{2}+\vartheta\right]}{\gamma}.$$

The equation admits a unique solution, because $\Psi(\cdot)$ is strictly positive, is null at zero, is strictly increasing and $\lim_{e\to\infty}\Psi(e)=\infty$. Moreover since $g(\cdot)>0, \Delta U>0, f'>0,$ this solution is strictly positive. The unique symmetric Nash equilibrium is thus given by:

$$\hat{e}^{1}=(\Psi)^{-1}\left[\frac{g(0)\delta\Delta U^{2}+\vartheta}{\gamma}\right].$$

## *Appendix B. Heterogeneity across individuals in the case of centralized and meritocratic university system* with *two-player tournament*

In this section we assume that individuals differ in the cost of the effort, that is $\gamma_{\alpha}\neq\gamma_{\beta}$.

Suppose for example that agent *a* is more capable than agent *β*. It is straightforward to see that in the last period the optimal effort chosen by the former is greater than the one chosen by the less capable agent.

It is more interesting to analyze the optimal choices in the first period, because the strategic behaviour of agents reflects the different probability of winning the competition or the expected monetary returns. Again, if there is no reason for winning the competition (that is, the expected wages are the same in the two universities) or if the probabilities are exogenous with respect to the efforts, then the optimal efforts are the same in both the periods.

*Case 1bis:* $prob_\alpha(\cdot) = prob_\alpha\left(y_\alpha^1 > y_\beta^1\right)$

The two agents will maximize (2) with respect their optimal effort. The two first order conditions will be:

$$\begin{cases} \vartheta f'\left(e_\alpha^1\right) - \gamma_\alpha v'\left(e_\alpha^1\right) = + \dfrac{\partial prob_\alpha\left(e_\alpha^1, e_\beta^1\right)}{\partial e_\alpha^1}\delta \overline{U}^2 - \dfrac{\partial prob_\alpha\left(e_\alpha^1, e_\beta^1\right)}{\partial e_\alpha^1}\delta \underline{U}^2 = 0 \\ \vartheta f'\left(e_\beta^1\right) - \gamma_\beta v'\left(e_\beta^1\right) = + \dfrac{\partial prob_\beta\left(e_\alpha^1, e_\beta^1\right)}{\partial e_\beta^1}\delta \overline{U}^2 - \dfrac{\partial prob_\beta\left(e_\alpha^1, e_\beta^1\right)}{\partial e_\beta^1}\delta \underline{U}^2 = 0 \end{cases}$$

Solving for the probability of winning the competition we have:

$$\begin{cases} \gamma_\alpha v'\left(e_\alpha^1\right) = f'\left(e_\alpha^1\right)\left[\vartheta + g\left(f\left(e_\beta^1\right) - f\left(e_\alpha^1\right)\right)\delta \Delta U^2\right] \\ \gamma_\beta v'\left(e_\beta^1\right) = f'\left(e_\beta^1\right)\left[\vartheta + g\left(f\left(e_\alpha^1\right) - f\left(e_\beta^1\right)\right)\delta \Delta U^2\right] \end{cases}$$

In this case obviously we cannot impose the symmetry of the efforts. Anyway we are able to reach an interesting result. Let suppose that for some unknown reason agent β becomes more stupid with respect the initial situation of symmetry (I'm introducing heterogeneity), let assume $\gamma = \gamma_\alpha < \gamma_\beta$ and simplify the two FOCs:

$$\begin{cases} \hat{e}_\alpha^1 = \left(\Psi^p\right)^{-1}\left[\dfrac{\vartheta + \delta g\left(f\left(e_\beta^1\left(e_\alpha^1\right)\right) - f\left(e_\alpha^1\left(e_\beta^1\right)\right)\right)\Delta\left(U^2\right)}{\gamma_\alpha}\right] \\ \hat{e}_\beta^1 = \left(\Psi^p\right)^{-1}\left[\dfrac{\vartheta + \delta g\left(f\left(e_\alpha^1\left(e_\beta^1\right)\right) - f\left(e_\beta^1\left(e_\alpha^1\right)\right)\right)\Delta\left(U^2\right)}{\gamma_\beta}\right] \end{cases}$$

Because of the symmetry of the density function then numerator of the parenthesis is the same for both the solutions. Therefore we can conclude that high skilled the agent the more the effort chosen in the equilibrium.

Moreover if we compare the last solution with the case of homogeneity across agents we observe that now both the agents will devote a lower level of effort in equilibrium (the density function reaches the maximum value at zero). A possible solution is to rely on more tighten admission in the first rank (PhD position) of academic life: in this case the expected variance among researchers is low.

*Case 2bis:* $prob_{\alpha}(\cdot) = \sigma$

The optimal efforts are the same in both periods.

**Proposition A1.**

*In the case of heterogeneity across individuals agents' equilibrium efforts in the first period are such that the more skilful the individual, the higher is the effort. Moreover both agents devote a lower level of effort with respect the case of homogeneity.*

# Career progress in centralized academic systems : an analysis of French and Italian physicists.

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## Abstract

We examine the career profiles of French and Italian academic physicists of the matter in between 2000 and 2005. In particular, we show that rank advancements (from assistant to associate or full professor equivalent positions) are explained both by individual variables (such as productivity, seniority and gender) and relational ones (such as the position of the scientist in co-authorship networks and mentoring by senior colleagues). We find significant differences between the two countries, some of which can be explained by institutional differences. In both France and Italy seniority has a non-linear impact on the probability of career advancement. However, scientific productivity and gender are better predictors of advancements in France than in Italy, while social connections play a role only in the latter.

# 1. Introduction

In the past 20 years or so, the number of empirical contributions to the economics of science has grown considerably (Audretsch et al., 2004). This literature has focussed especially on the rate and direction of universities' research and on how the latter may be affected by changes in university funding patterns (Geuna, 1999) as well as by the spreading of commercialization practices (surveys by: Geuna and Nesta, 2006; Siegel *et al.,* 2007). Several essays have dealt also with the issue of scientific productivity and its determinants at the individual level (Stephan and Levin, 1992; Hall *et al.*., 2007; Azoulay *et al.*., 2007; Breschi *et al.*, 2007).

None of these studies, however, has examined explicitly the issue of academic careers; nor they have paid much attention to the role of wages and tenure, as analysed by the economics of higher education (Ehrenberg, 2003). In general, recent studies on scientific productivity have taken on board, without much discussion, the classical sociological analysis proposed by Merton (1957), as reformulated by Dasgupta and David (1994). Indeed, the coupling of classical sociological assumptions and economic analysis is a distinctive mark of what many now identify as the "new economics of science" (Stephan, 1996).

According to such a view, scientists progress in their career to the extent that they are given credit for their contribution to knowledge advancement. Credit for such contribution has to be obtained by one's own academic peers, who rely, for their judgement, on each individual scientist's publication record (so that an incentive system comes into place, that forces the disclosure and diffusion of data, methods and discoveries).

Although still valid its general lines, this theory is not without limitations, some of which were pointed out early on by Merton himself or his immediate followers. Issues related to gender, mentoring, and social networking may have a part in explaining scientific careers, alongside with increasing returns to reputation. These factors may combine with increasing returns to reputation (famously described by Merton, 1968, as the 'Matthew effect') to create career trajectories that reward scientists who meet early success well beyond their initial merits. In addition, while several empirical studies on academic careers in have been produced for the US (most recently: Long 1993; Long and Fox, 1995), almost none is available for European countries, whose institutional setting is both heterogeneous and altogether different from that of the US.

In this paper we aim to fill these empirical gaps. In order to do so we update the conceptual framework of the new economics of science, and examine the cases of France and Italy, where academic advancement is heavily controlled by the central government *via* disciplines, the latter to be intended as state-sanctioned guilds of professors, over which universities and departments exercise little control.

In section 2 we provide a brief summary of the relevant literature, and of the key determinants of academic careers it proposes; we also discuss briefly the specificities of the Italian and French academic career paths and the consequences they bear for our analysis. In section 3 we describe our data and methodology. In section 4 we illustrate the results of our empirical analysis. Section 5 concludes.

# 2. Determinants of academic careers: background literature, and the of cases of France and Italy

In this section we discuss the key determinants of rank advancement in science, as they emerge from the existing literature (section 2.1) and from our own remarks on the specificities of the recruitment process in France and Italy (2.2). From the discussion, we derive some a priori for regression analysis that follows.

## 2.1 Background literature

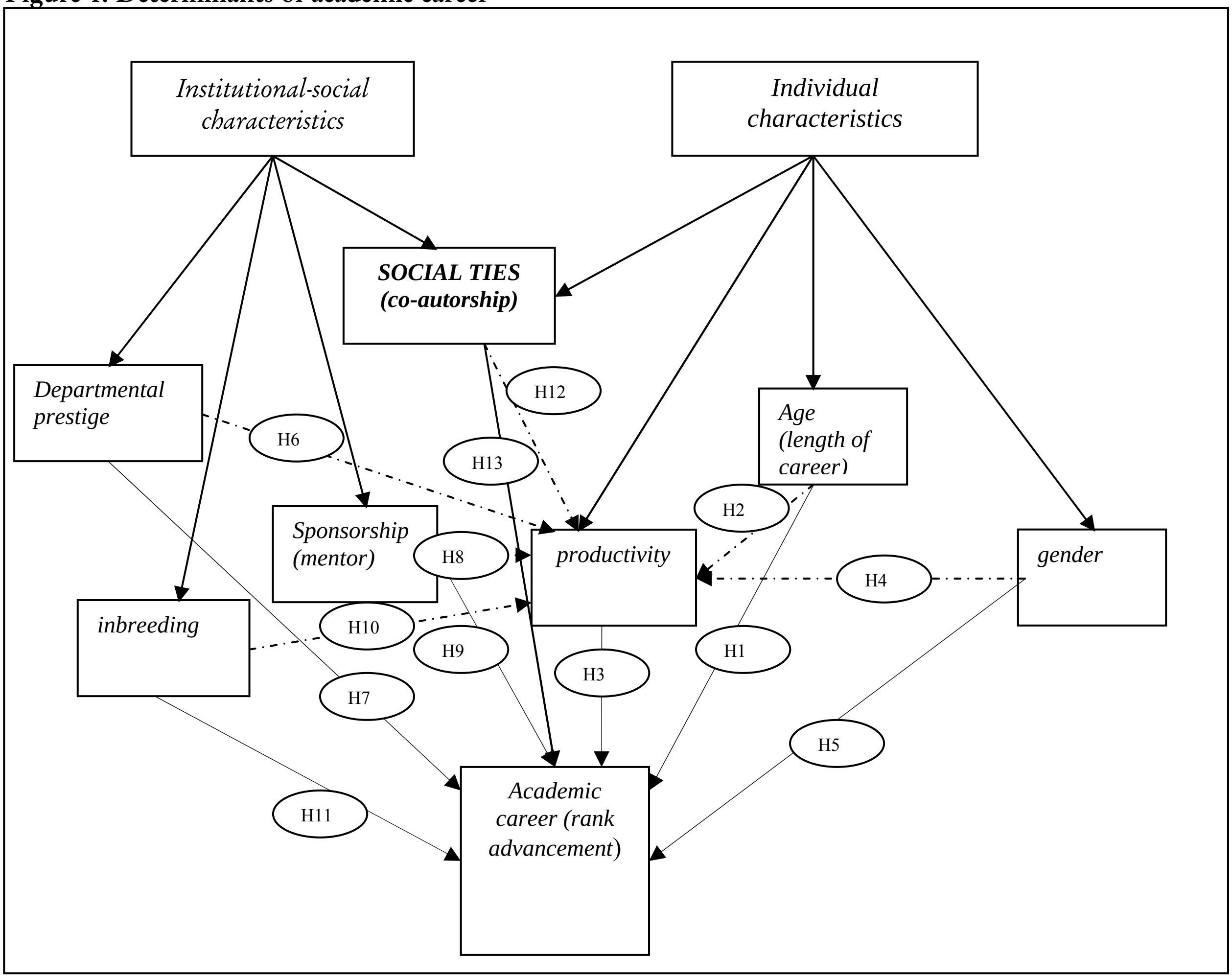
Both the classical sociology of science and the new economics of science have devoted considerable efforts to examine how individual *scientific productivity* is affected by biographical variables, such as scientists' age and gender, and "institutional" or "social" ones, such as departmental prestige and the role of 'invisible colleges', (Crane 1965, Hargens and Hagstrom 1967, Clemente 1973, Allison and Stewart 1974, Reskin 1977, 1978, Long 1978, Cole 1979, Allison and Long 1990, Levin and Stephan 1991, Xie and Shaumann 1998, Hall *et al.,* 2007),. However, much less attention has been given to the effects of productivity on academic careers, possibly because of data constraints or because of the common presumption that scientific productivity, by itself, can be a useful predictor of a scientist's career.

In fact, starting with Hollingshead (1940), the determinants of academic careers have been examined jointly with those of productivity. Only a few studies have analyzed separately the two concepts, and highlighted explicitly the mechanisms that drive the recruitment process. A notable exception is represented by Caplow and McGee (1958)

> "A distinction must be made between the two kinds of recruitment in general use - "open", or competitive, hiring and "closed", or preferential hiring. In theory, academic recruitment is mostly open. In practice it is mostly closed" (Caplow and McGee, 1958; p. 109).

Four dimensions of career success could be considered: participation, position, productivity, and recognition (Long and Fox, 1995). In this paper, we focus mainly on position, expressed by the rank advancement within or across organizations. In this respect, most of the empirical work has focused on either biographical and individual determinants (age, productivity, gender) or institutional and social ones (departmental reputation, sponsorship and inbreeding). In what follows we highlight those determinants by attaching them a short label (H plus a progressive number), and then report all of them combined in figure 1.

**Figure 1. Determinants of academic career**




*Time (length of career)*

In many jobs, career progress is a matter of time: seniority is rewarded (either formally or informally) with promotion. Academic jobs are no exception: the time spent by a scientist on a given academic rank is one of the most important factors determining her chances of promotion (Long *et al.*, 1993, Modena *et al.,* 1999). As time goes by, individuals see their seniority grow (H1) and have also a chance to increase their publication record (H2).

*Scientific productivity*

Classical sociologists of science have studied scientific productivity for a long time, and confirmed invariably Lotka's (1928) original results: whenever a large or random sample of scientists is considered, the distribution of scientific productivity is found to be highly skewed to the right. This means that a small minority of highly productive scientists is responsible for the majority of scientific publications, especially of those with large or at least meaningful impact (as measured by citations).

Productivity therefore has been also analyzed in relation to rank advancement in academic careers (H3), in particular trying to distinguish the effect of quality versus quantity.

While the impact of quantity is beyond doubt (see, for example, Clemente 1973) more controversial is the role of quality, usually measured by citations to the paper or the journal (impact factor)). Hargens and Farr (1973) find that the number of citations received is positively associated with promotion, but their result is not confirmed by other works (Long et al. 1993).

*Gender*

The finding that women are at a disadvantage in terms of career progress is a recurrent one (Everett 1994, Modena *et al.,.* 1999). Gender affects the probability of promotion both indirectly, through the channel of scientific productivity (H4)[8], and directly. Long *et al.* (1993) find that even after controlling for productivity, women scientists have a lower promotion probability. Similar results have been found by Modena et al. (1999), Everett (1994), and Cole (1979) (H5).

*Departmental prestige*

Many empirical studies show the importance of departmental prestige for a successful career. On the one hand, graduating and working in a prestigious institution gives visibility and access both to information and to knowledge embedded in other productive scientists (H6); on the other hand "because a department's reputation depends in part on the reputation of its faculty, prestigious departments are expected to apply more stringent criteria for promotion" (Long *et al.*, 1993) (H7). Longitudinal studies find evidence that departmental reputation affects productivity and that changes

[8] Gender differences in productivity have attracted both the sociologists' and the economists' attention (Reskin 1978, Cole 1979, Stephan and Levin 1992, Prpic 2002; see also Modena et al. 1999). Several reasons have been put forward to explain why woman appear to be less productive than their male equals (Xie and Shaumann 1998, Zainab 1999): more limited access to relevant social networks (woman are more isolated and excluded from "old boys" social circle; Cole and Zuckerman 1984); less interested in pure research; lower graduation rate from prestigious universities; more severe family-career trade-offs .

in departmental location are associated to changes in productivity (Allison and Long, 1990). Studies of stratification in science find that the ranking of Ph.D. education is one of the most useful predictor of success in academia, where success means getting a job in a highly-ranked academic institution. Hargens and Hagstrom (1967) analyzed the career data of a number of U.S. natural scientists and found that the prestige of the institution from which the latter received their PhD diploma is associated to the prestige of the same scientists' current affiliation, even after controlling for productivity

Early access to substantial resources gives scientists advantages both in terms of visibility and knowledge. This initial advantage may be then enhanced by the so-called Matthew effect, according to which scientific credit is more easily recognized to those scientists who already enjoy it, than to non-tested or less-tested ones (Merton 1968). Long *et al.* (1979) found evidence that entry in academic career does not depend on scientific productivity once he controlled for the effects of doctoral origins and the prestige of the junior scientist's mentor.

*Mentoring*

The 'mentor' is typically a senior member of an organization who commits to facilitating his (or less often her) protégés' careers (Kirchmeyer, 2005). There are two different channels through which mentors may influence the career success of the protégé (Kram, 1985): mentoring affects rank advancement indirectly, by improving the protégé's performance (performance perspective, H8), and directly, by developing the protégés' social network and providing signal of reputation and ability within it (political perspective, H9) (Ferris and Judge, 1991).

Reskin (1979) used data from a random sample of chemists and stressed the importance of sponsorship in career over the first ten years of their scientific productivity. The role of the political perspective has been emphasized by Kirchmeyer (2005) analyzing a sample of American accounting academics.

*Inbreeding*

Academic 'inbreeding' occurs whenever an academic institution tends to recruit its scientists chiefly among those who took their degrees there, either at the undergraduate level and/or at the graduate level. Inbreeding has been viewed as an expression of academic particularism. However McGee (1960), through an investigation of the junior faculty of the University of Texas, found that 29% of the full-time professors had some University of Texas degree and justified the use of inbreeding for financial reasons and geographical isolation. In this view, inbreeding can be seen as an efficient way for selecting people, under proper circumstances.

The relationship between academic inbreeding and scientific performance has been examined by Hargens and Farr (1973). For scientists on their first academic job, no relationship appeared to exist between their academic origins and scientific performance (either at the quantity or quality level). For scientists at their second and or successive career step, it was found that "who have been inbred throughout their careers [..] tend to be less productive" (Hargens and Farr 1973, p1392; H10). Hargens and Farr (1973) also examined how many years it takes to an assistant professor to be promoted to an associate position, and found that inbred scientists wait for longer than the others, even after controlling for differences in terms of productivity (H11).

*Social ties and network*

The existing literature suggests that social connections affect promotion chances indirectly through productivity: Gonzalez-Brambila *et al.* (2006) found that networks promote the creation of new knowledge, by granting greater access to resources and information: the individual who occupy central positions in their academic network have a propensity to create more knowledge, while the number of ties has a positive impact on the future productivity (H12).

Still, it is possible to hypothesize a direct relationship (H13), in particular through two different channels:

1. Following again Gonzalez-Brambila *et al.* (2006), it is reasonable to assume that universities, after deciding to fill a vacancy, give positive consideration to the candidates' academic network, to the extent that the latter may add to the university's visibility and access to resources; however, no author has apparently investigated this possibility, either theoretically or empirically.
2. In addition, the individual with a strong network position can be perceived as more influential within the scientific community (Kilduff and Krackhardt, 1994). As individual performances are often hard to evaluate just on the basis of past scientific production and citations (especially when recent publications are considered), perspective recruiters may look for other signals of quality, such as the position of the scientist in his or her community, and the influence she is expected to exert on her peers. Following this view, a direct effect has been found by Seibert *et al.* (2001) for employees with various occupations and organizations (outside academics): the questionnaire data they collected revealed the role of social capital in the career advancement, because of career sponsorship and a greater access to resource information.

One should notice, however, that when it comes to empirical analysis of junior scientists' careers it may be hard to tell these network effects apart from mentoring. Junior scientists working in association with influentional mentors will tend to occupy a more central position in the network than other same-age colleagues. As a result, it will be hard to say whether their higher promotion chances are explained, ceteris paribus, by the recruiters' consideration of their social capital, or by the influence exercised by their mentors on the recruiters.

## 2.2. Academic careers in France and Italy

As one can easily gather from checking the references in the previous section, most of the existing literature on academic careers (especially if quantitative) derives from US scholars, whether economists or sociologists. As stressed by many authoritative studies (Ben-David, 1977; Clark, 1993), however, the US system has unique features in terms on universities' autonomy and academic labour market mobility. Universities select candidates for professorial jobs in total autonomy, with no control whatsoever from the central (federal) or state governments. Once selected, professors become university employees and can bargain for their wages and working conditions on an individual basis (as opposed to many of their colleagues in Europe, who are civil servants in the public administration, and see their wages set or limited in range by law). Besides, the sheer number of US academic institutions, and a competitive funding system, give US-based scientists with a strong publication record the opportunity to move from one university to another in search of better paid, or better funded research positions (Ehrenberg *et al.*, 1991). Finally, the system is openly stratified according to the research *vs.* teaching intensity of institutions, and the latter's wealth: two- and four-year colleges follow different recruitment criteria than the 200 or so "research universities"[9], and the latter differ widely in terms of financial resources one from another, with private institutions most often being in a better-off position than the state ones.

On the contrary, both the Italian and French academic recruitment processes derive from a mix of state control and professional corporatism. As such they represent, at an extreme, a common situation in Europe. All French and Italian professors are civil servants, whose recruitment rules, duties, and wages are fixed by national laws, and cannot be bargained at the local level, let alone the individual one. The French academic system has two main positions called "*Maitre de conference*" (MCF) and "*Professor*" (PR). In Italy there are three positions called "*Ricercatore universitario*" (RU), "*Professore associato*" (PA) and "*Professore ordinario*" (PO). Here we are concerned mainly with career advancements, from MCF to PR in France, and from RU to PA or PO in Italy.

[9] Research universities are commonly identified as those granting PhDs, and are ranked according to a number of criteria. The original classification was proposed in 1970 by the Carnegie Commission of Higher Education, which has updated it since then (http://www.carnegiefoundation.org/classifications/)

All positions are tenured, and for all of them wages are defined by national laws. All academic personnel are classified by the government according to their discipline. Disciplines fulfil a role similar to professional guilds: their members, and not individual universities or department, control the recruitment process.

In Italy, disciplinary classification is very detailed, and it is negotiated periodically between the Ministry and the leading senior professors of the country. Over the past 20 years, the classification system has grown longer and more fragmented, and now it includes more than 170 disciplines just for science, medicine and engineering[10]. Any university willing to fill a vacancy or simply to offer a new position has first to specify for what discipline the position is offered; then it has to launch a call for applications (*concorso*) and set up an examination committee. All the committee members must belong to the same discipline for which the position is offered; one of them is chosen by the university, most often among the internal faculty, and two to four others are elected with a national secret ballot by all professors ranked as high or higher than the position on offer, also from the selected discipline. Nominally, the commission has not the task to pick the most suitable candidate for the university that launched the call (on the basis, for example, of the coincidence of the candidate's and the university's research interests), but the best possible candidate in absolute terms, who should be the one with the best publication record (called "idoneo", which means *fit-for-the-job*). In principle, if the university does not like this candidate, it can always refuse to nominate him/her and launch a new job call. In practice, most commissions try to steer the selection process towards candidates who they know will be palatable to the university.[11] In some job competitions, the commissions are also let free to declare two winners (two *idonei*), only one of which will be selected by the university.[12]

The French recruitment system follows different producers for different disciplines, the most notable differences being between the natural sciences and the social sciences, including humanities and law. Differences also exist between the procedures for the recruitme of "*Maitres de conference*" (MCFs)

[10] Overall there are no less than 300 disciplines; some of them, such as "Ship Architecture" and "Ship and Marine Plants" – notice they are considered different - counted less than 30 affiliates in 2005.

[11] This requires a lot of political background work to do by the university, in order to steer the secret ballot in the direction of selecting at least a majority of external commissioners in good terms with the university. Once that result has been achieved, those commissioners will take care of letting some perspective candidates to know their presence would be of embarrassment to the commission (these are typically those candidates who have a strong publication record, so that they are at risk to win, but are not liked by the university issuing the *concorso*). On the long-standing importance of such practices in the Italian academic systems, see Clark (1977)

[12] In this way, the examining commission are free to let both the strongest candidate and a local insider win (then the latter will be chosen for the job, and the former will be possibly called by some other university) A controversial rule, in fact, allows candidates who have been judged fir-for-the-job (idonei) but not recruited, to be offered a job position by other universities, which in this case will be exempted from the duty of setting a national call for applications. Needless to say that this possibility is often exploited for more political bargaining among the professoriate: external commissioners may agree to trade the nomination of a local candidate liked by the university issuing the job call in exchange for a 'fit-for-the-job' certificate for another candidate, who they wish to recruit in their own university (Moscati, 2001).

and "*Professors*" (PRs). As for MCFs seeking promotion to PRs in physics (who are investigated in this paper), the so-called *concours* runs over two phases. The first phase, called "*qualification*" is centrally managed by National Council of Universities (*Conseil National des Universités*, CNU), an oversight body under governmental control. The second phase, on the contrary, is up to the individual universities that have to fill the vacant positions.

The CNU is divided in sections and each section has to evaluate the candidates in each single discipline. Each CNU section is composed both of members elected by the professors in the discipline, and of members appointed by the minister. All members serve for more than one year. As in the Italian system professors are classified according to their disciplines, although the latter are not as much finally specified (there are 73 of them overall). Every year, the CNU release the list of "qualified" candidates, on the basis of the latter's publication and teaching record.

The second phase of the recruitment process see the qualified candidates applying for professor jobs at the local institutions (after four years, candidates who have not got a job lose their qualification). Each university has recruitments committees (*commissions de specialistes*) devoted to the evaluation of applicants, one for each disciplines or at least for each group of related disciplines in small universities. The committee, elected every four years, is composed of members of the faculty and invited members from other institutions or disciplines.

Notice that the main difference between Italian *concorsi* and French *concours* lies at the qualification stage. While French candidates get it from a committee which is both national and under some degree of ministerial control, in Italy the qualification can be obtained through strategic agreements among members of the many commissions scattered across the individual universities (see footnote5).

Both the Italian and the French recruitment systems have undergone severe criticism over the years, which resulted in a succession of reforms that shifted the balance of decision power in recruitment matters back and forth between the national and local level (Musselin, 2005; Moscati, 2001). None of these reforms, however, has gone as far as to grant universities total freedom in recruitment matters, nor to re-establish total control by government. As for the role of disciplines, this has possibly increased in Italy, due to progressive fragmentation, which makes it easier to control elections.

This brief examination of the recruitment process in the two countries suggests a few observations on the factors affecting academic careers, as derived from the US-centric literature we examined in section 2.1.

Length of career, in principle, should not affect rank advancement chances, since seniority does not enter the examination criteria either of *concorsi*. On the contrary, productivity should be a key determinant of career advancement in both countries, more so in Italy than in France.

The egalitarian norms typical of the French and Italian legislation forbid considering departmental prestige as a factor to be evaluated by the examining commissions: all PhD titles have to be considered the same, since no official ranking of universities or department exists, and no unofficial information can be deemed as relevant by examiners. Similarly, mentoring should have no role, since no reference letters are admitted in the process. However, in the Italian system, mentors may either lobby in order to be elected in the examination committee, or to ensure that some close colleagues of theirs will be elected in their place, so they can exert a direct influence on the recruitment process. In France, this result is also possible but harder to achieve, the national examination committee not being entirely elective, and the disciplines being too large for their members' voting intentions to be easily steered.

Inbreeding is a major force behind recruitment in both countries. Again, in principle it should not be so, but in practice all peripheral universities face the problem of fending off candidates who, although qualified, would not be dedicated to the institution. This situation is due to the civil servant status of professors in both countries: professors' wage profile over time does not depend upon the universities' decision, but is fixed by law and linked exclusively to seniority; nor universities have any power to fire absentee professors, or to module the balance between their research and teaching duties, according to the university's needs (teaching loads are also determined by law). So, brilliant scientists from top universities (or foreign ones) are seen by peripheral, teaching-oriented universities as a threat: once recruited, they would try to spend locally as little time as possible, in order to maintain informal research ties with their *alma mater* (Musselin, 2005). These universities will try to play the system in order to push forward their internal candidates, rather than recruiting external ones (see footnote 9).

As for gender, no apparent reason exists to think of peculiarities for France and Italy with respect to the US-based evidence at hand.

Finally, as social ties are concerned, one should notice that in the French and Italian system they do not only serve the purpose of information sharing and knowledge creation. Prospective candidates to professorial positions have an incentive to nurture ties with senior members of their disciplines, the latter being very likely to sit in their examination boards; this ought to be especially true of Italy, where both stages of the recruitment process are in the hands of local committees. When trying to measure the importance of junior scientists' social capital, an effort should be made to distinguish between contacts that have the potential to increase the scientists' productivity (because they allow him/her to tap in the resources of a flourishing "invisible college"), and those that are more instrumental, and serve the purpose of linking up with decision-makers at the disciplinary level, irrespective of the latter's scientific reputation.

# 3 Data and methodology

This section provides a description of the data and a formal specification of the statistical models. Paragraph 3.1 outlines the covariates and some statistics about their distributions. Paragraph 3.2 shows the statistical models estimated.

## 3.1 Data

The data collected for this paper draw from the complete list of Italian and French academic scientists active in a.y. 2004/2005, in the field of physics of the matter, which we obtained from the Ministries of Education of the two countries. We concentrate on rank advancements between 2000 and 2005 (that is, our dependent variable is the promotion event that a scientist may incur into).

We recall from section 2.2. that steps in academic career are country-specific. The French academic system has two main positions called "*Maitre de conference*" (MCF) and "*Professor*" (PR). In Italy there are three positions called "*Ricercatore universitario*" (RU), "*Professore associato*" (PA) and "*Professore ordinario*" (PO). Since a direct comparison between careers of academic scientists in the two countries cannot be done without an aggregation of two of the three Italian positions, we decided to compare the promotions from MCF (in France) and RU (in Italy) to higher ranks; and to examine separately the promotion from PA to PO (which apply only to Italy).

The main reason for this choice is that academic careers (acquisition of the MCF or RU rank) start roughly at the same age (33, on average) in both countries (see Appendix 1); this allow us to consider a uniform starting point for the admission to higher ranks. However, the age structure of MCFs and RUs is not the same, the former being quite younger than the latter. Therefore, in order to increase comparability, we excluded from both the MCF and RU samples those scientists that were either too young or too old to be considered for promotion, namely those younger than 30 or older than 50. This leaves us with a total amount of scientists in our sample of 1285, of which 816 French and 469 Italian. Of these, less than 14% got promoted to a professorial position in France, as opposed to 45%

to Italy (table 1). Most of the promoted scientists did not change affiliation after the promotion: only 20% changed university in France, less than 6% in Italy. Some gender gap also appears to be significant, and it is more visible for France.

**Table 1. Promotion and mobility**

| | FRANCE | | | ITALY | | |
|---|---|---|---|---|---|---|
| | **All** | **Men** | **Women** | **All** | **Men** | **Women** |
| *Nr of scientists [MCFs-France; RUs-Italy]* | 816 | 601 | 215 | 469 | 365 | 104 |
| *Promoted, nr. and % over nr. of scientists* | 110 *(13,5%)* | 95 *(15,8%)* | 15 *(7%)* | 211 *(45,0%)* | 172 *(47%)* | 39 *(39%)* |
| *Mobile*, nr. and % over promoted* | 22 *(20%)* | 19 *(20%)* | 3 *(20%)* | 12 *(5,7%)* | 11 *(6,4%)* | 1 *(2,5%)* |

* MCFs and RUs promoted to professor positions
** MCFs and RUs who have changed university affiliation when promoted

We then went on to build two classes of explanatory variables: a selection of the most important career determinants as discussed in the classical sociology of science (and the new economics of science), and a few measures of social capital derived from social network analysis.

### 3.1.1 *Classical covariates*

As discussed in section 2, scientific productivity is nominally the main determinant of rank advancement in both Italy and in France. The publications on national and international scientific journals are widely recognized to be an indicator of the scientist's research productivity although exist other measures as, for example, books, book chapter or, in some fields, patents and prototypes. In order to identify those publications we rely upon a database we compiled from the ISI-Web of Science, which contains all scientific articles published in between 1975 and 2000, authored by at least one professor of physics active in an Italian or French universities in the year 2004/2005. We consider only the publications coming from a selection of journals with high impact factor [13].

We do not distinguish between quality and quantity of the publications, but we use a summary index that accounts for both these features. First, we weigh each publication for the impact factor of the journal. Second, we take into account multiple authorship by giving to each individual author a fraction of publication, which we calculate as $1/(1-\alpha)^{aut-1}$, where $\alpha$ is a parameter greater or equal to zero, and $aut$ is the number of co-authors of the publication considered. Equation 1 shows the productivity measure of scientist $i$ between the time interval ($t_0$ ,$T$):

[13] The impact factor of a scientific journals is defined as the number of citations received in a given year, divided by a the number of articles in that journal over the past 2 years (Garfield 1972). The list of selected journals is reported in the Appendix

$$\Pr oductivity_{i,t}(\alpha) = \sum_{t=t_{0i}}^{T} \sum_{a=0}^{n_t} \frac{imp_{a,i}}{(1+\alpha)^{aut_{a,i}-1}} \tag{1}$$

where $n_t$ is the number of articles signed in the year $t$ by scientist $i$, $imp_{a,i}$ is the impact factor of the journal where article $a$ is published and $aut_{a,i}$ is the number of co-authors of $a$. The overall value is given by the cumulate sum of scientist's productivity index along all her career until 2000, $t_{0i}$ is the year when *i's* career begins and T is 2000.

We experiment with different values for $\alpha$, such as $\alpha$=0 (each publication is assigned to the scientist in its entirety, no matter the number of co-authors) and $\alpha$=1 (which is such that publications with two co-authors count exactly half a publication, while publications with $n$>2 co-authors count for a fraction smaller than $1/n$, and declining faster than $1/n$ as n→0).

We also experiment with the simple count of publications (*Articles*) over the time interval ($t_0$ ,$T$), a measure that does not take into account the number of co-authors nor the impact factor of journals. Appendix 2 shows the correlation values of the three measures of productivity.

We measure the Matthew effect (*Matthew*), as described in section 2.1, with the maximum impact factor scored by a scientist's publications over her first 5 years of career[14]. We speculate that scientists who manage to place a paper in a high-impact factor journal early on in their careers stand more chances to enhance their reputation than colleagues with similar productivity, but a less noticeable profile.

[14] More precisely, we record the impact factor of all the journals the scientists published in over his/her first 5 years of career, and pick the highest one.

**Table 2. Career determinants (explanatory variables for the promotion event)**

| | |
|---|---|
| ***2a. Productivity and individual characteristics*** | |
| Gender | Gender dummy (=1 for woman scientists) |
| Age | Scientist's age in year 2000 |
| Productivity (α) | Cumulative sum of impact factors of the journals where articles are published, weighted by the number of co-authors (see equation 1) |
| Articles | Gross number of publications |
| Matthew effect | Maximum impact factor of the articles-journal in the first 5 years of careers for each individual |
| Inbreeding | Nr of co-authors from same university / Nr of co-authors |
| ***2b. Network variables*** | |
| PrincipalComponent | Connection dummy (=1 if scientist belong to principal component of co-authorship network, 1995-1999) |
| Closeness | Inverse of avg shortest path between the scientist and other scientists in the principal component (co-authorship network, 1995-1999; =0 for scientists outside the principal component) |

In order to capture the inbreeding effect we consider how well positioned is the scientist in the university he/she is affiliated to (and where he/she stands the best chances to be promoted, as discussed in section 3.1); in particular, we measure the ratio between the number of the scientist's past co-authors still active in the same scientist's university, over the total number of co-authors.

Other variables of interest at the individual scientist's level are age (which we treat as a proxy for the scientist's career length[15]) and gender all listed in table 2a.

As shown in table 3a, Italian scientists' productivity appears to be more than three times higher than that of their French colleagues, with a higher standard deviation. Table 3a also shows that French MCFs are on average younger than Italian RUs, even if they reach that position (on average) at the same age of 33.

### *3.1.2 Social network covariates*

Social network analysis has a long tradition of application in the sociology of science, which ranges from the early identification of 'invisible colleges' (Crane, 1972) to the recent application of small-world graphs (Newman, 2001). Both works identify the structure of scientific communities on the basis of co-authorship data. Co-authorship is seen as proof of collaboration and knowledge exchange between two or more scientists[16]. Each scientist is seen as a node on a graph, with ties with other

[15] In the absence of information on their actual date of completion of PhD studies, we assume all scientists to start their academic career at 25 (which is the lowest possible age of completion of a PhD, for students who followed standard lower and higher education curricula). As a consequence of assuming the same starting year of careers for all scientists, we have perfect correlation between a scientist career's length (measured in years) and age.

[16] For a different approach to social network analysis of science, see Mullins et al. (1977), who base their graphs on co-citations patterns. For a different use of co-authorship data see Gonzalez-Brambila et al. (2006)

representing co-authorship instances. This allows both to measure the cohesiveness of a scientific community, and the role of individual scientists therein, whether central or peripheral[17].

In order to do so, we examine our scientists' publications both over a 5-year window, from 1995 to 1999. The 5-year window is meant to capture ongoing or "still fresh" research partnerships. Admittedly, the 5-year window is a rather arbitrary one; however, it has been used also by Newman (2001) and related work on small worlds in science, so it makes our work comparable with that.

**Table 3. Descriptive statistics**

| | Obs. | Mean | Standard deviation | Min | Max | Median | Skewness |
|---|---|---|---|---|---|---|---|
| | | | | **France** | | | |
| *3a. Productivity and individual characteristics* | | | | | | | |
| Gender | 816 | 0.26 | 0.44 | 0 | 1 | 0 | 1.07 |
| Age | 816 | 36.37 | 4.77 | 30 | 50 | 35 | 0.83 |
| Productivity($\alpha$=1) | 816 | 19.55 | 44.54 | 0 | 560.28 | 10.26 | 8.40 |
| Productivity($\alpha$=0.25) | 816 | 35.21 | 76.49 | 0 | 987.97 | 19.54 | 8.12 |
| Productivity($\alpha$=0.10) | 816 | 53.96 | 110.10 | 0 | 1416.39 | 30.30 | 7.79 |
| Articles | 816 | 12.30 | 22.23 | 0 | 308 | 8 | 7.49 |
| Matthew | 816 | 8.81 | 6.31 | 0 | 21.39 | 8.16 | 0.71 |
| Inbreeding | 570 | 0.56 | 0.40 | 0 | 1 | 0.59 | -0.24 |
| *3b. Network variables* | | | | | | | |
| Principal Component | 816 | 0.39 | 0.49 | 0 | 1 | 0.47 | 0.47 |
| Closeness | 816 | 0.04 | 0.05 | 0 | 0 | 0.65 | 11 |
| | | | | **Italy** | | | |
| *3a. Productivity and individual characteristics* | | | | | | | |
| Gender | 469 | 0.22 | 0.42 | 0 | 1 | 0 | 1.34 |
| Age | 469 | 40.00 | 4.75 | 30 | 50 | 39 | 0.39 |
| Productivity($\alpha$ =1) | 469 | 49.33 | 51.88 | 0 | 326.67 | 33.25 | 1.74 |
| Productivity($\alpha$=0.25) | 469 | 82.98 | 86.02 | 0 | 573.53 | 57.09 | 1.72 |
| Productivity($\alpha$=0.10) | 469 | 118.20 | 111.79 | 0 | 745.27 | 90.78 | 1.66 |
| Articles | 469 | 24.44 | 18.27 | 0 | 117 | 21 | 1.22 |
| Matthew | 469 | 10.74 | 6.34 | 0 | 60.68 | 10.84 | 1.41 |
| Inbreeding | 424 | 0.56 | 0.32 | 0 | 1 | 0.57 | -0.31 |
| *3b. Network variables* | | | | | | | |
| Principal Component | 469 | 0.66 | 0.48 | 0 | 1 | 1 | -0.66 |
| Closeness | 469 | 0.10 | 0.07 | 0 | 0.21 | 0.13 | -0.44 |

[17] The incessant growth in the number of authors per paper, however, suggests some caution in the use of this kind of data. The higher the number of co-authors, the more likely the presence, among the latter, of scientists who have not really participated to the research effort and may not know all the other scientists listed on the paper, as it may happen with 'guest' and 'gift' authors (see Lissoni and Montobbio, 2008, and references therein). More importantly, papers authored by very large numbers of scientists are little more than reports on the activity of multi-institute collaborative efforts, essentially a collection of results obtained by sharing funds or facilities, rather than the specific outcome of joint research effort by a group of individuals (Brambila-Gonzalez et al., 2006). In this spirit, we do not consider articles in our analysis any paper with more than 30 authors..

It is also important to stress a number of restrictions we applied to our network measurement. The latter is based exclusively on the publication records of the Italian or French academic physicists still active in 2004/2005, from the selected journals. Thus it excludes all the articles appeared on those journals who did non include the scientists of our interest.

From this limitation it follows that our co-authorship network excludes all the co-authors of the selected paper who do not fall in our sample of Italian and French scientists (that is, the only nodes in our network are the Italian or French academic physicists still active in 2004/2005; none of their co-authors, who could be students, retired or foreign colleagues, or technicians, has been included). This choice has both practical and a theoretical explanation. On the practical ground, the inclusion of the co-authors of the scientists in our sample would have required collecting also all the publications of such co-authors, that is also those not written in collaboration with any of the scientists in our sample. On the theoretical ground, including such co-authors in our network without including also the co-authorship ties between them would have meant introducing a severe distortion in our measurement effort.

Summing up, we have built two distinct networks, one for Italy and one for France, each of them having as nodes only the academic physicists still active in 2004/2005 in each country, and as ties the co-authorship ties between them, to the exclusion of any other node or tie that one could derive from co-authorship with other scientists. We consider the position of each scientist within such network to be a useful measure of the influence such scientist can exert on the national scientific community when it comes to raising funds (especially through collective proposals) or to supporting her own or some other colleague's candidacy to a more senior position in the academic ladder. At the same time, there is no reason why se should presume that a scientist's position in such a network has any or strong relationship with her international reputation or influence, since we do not measure her co-authorship ties, either direct or indirect, with her international peers. For example, isolates in our network could be scientists with limited connection to their national communities, but many co-authorship ties with foreign colleagues (as it may happen for young scholars with a PhD from a foreign institution).

**Table 4. Co-authorship networks, 1975-1999 (only national scientists); selected statistics**

| | *ITALY* | *FRANCE* |
|---|---|---|
| % of scientists in the principal component (over non-isolates*) | *83.2%* | *64.2%* |
| Size ratio second largest / principal component | *1.5%* | *1.8%* |
| % of isolated scientists over total scientists * | *26.7%* | *65.9%* |
| Network density ° | *0.0090* | *0.0057* |

** isolates=scientists with no publications or no-co-authors from the same country*
*° nr. ties /nr. of potential ties*

Table 4 shows that our networks show both low density and a "giant" component, that is a principal component (the largest in the network) which collects the vast majority of connected scientists (in between 64% and 83%), many more than any other cluster of scientists (see the very low size ratio between the second largest and the principal component). These are common features to all co-authorship networks in science, as measured in the literature. Notice also that the relative size of the principal component for Italy is quite larger than its counterpart for France. This is explained by the much higher rate of co-authorship in Italy, when measured considering only national co-authors as we did. We also remark that we do not expect such networks to be channel of scientific knowledge exchange (or at least not to be the primary channel in that respect, for the scientists include), but primarily channels for the exertion of political influence in the selection of candidates to senior position in the university.

In our regressions, we will consider two alternative synthetic measures of such influence: *Principal Component* and *Closeness* (see also table 2b above). The former is a dummy that takes value 1 if the scientist belong to the principal component in her national network; the latter is the reciprocal of the mean geodesic distance between the node and all the other nodes in the principal component (it is set to zero fro all nodes that do not belong to the principal component; it has maximum value equal to one, which can be achieved only by a central node in a star network)[18]. While *Principal Component* indicates merely whether the scientist is somehow connected to her national scientific community, *Closeness* indicates more precisely how well the scientists is connected to her colleagues, either directly (through a co-authorship tie) or a indirectly (through ties to other well-connected scientists).

**Table 4bis. Co-authorship networks, mean by rank**

| | FRANCE | | |
|---|---|---|---|
| | MCFU | PR | |
| Comp | *.3071325* | *.4076517* | |
| Closeness | *.0332204* | *.0453887* | |
| | ITALY | | |
| | RU | PA | PO |
| Comp | .630394 | .5519031 | .6419753 |
| Closeness | .0925064 | .0805823 | .0942427 |

[18] For a complete description of closeness, and its relationship to other centrality measures, see Wasserman and Faust (1994). The complete equation for our implementation of the measure for a node (scientist) *i* is as follows:

$$C_i = \begin{cases} 0 & \text{if } i \text{ does not belong to the principal component} \\ \dfrac{1}{1/V \sum_{v=1}^{V} g(i,v)} & \text{if } i \text{ belongs to the principal component} \end{cases}$$

where $v=1...V$ are the nodes (scientists) in the principal component and g(i,v) is the geodesic distance (shortest path) between nodes *i* and *v*.

### 3.2 Models

In order to explore the determinants of the academic rank advancement we proceed in steps. First we run a Logit regression of promotion on the classical determinants of academic career advancements (*Model1*). A second model takes also the social network measures introduced in section 3.1.2 (*Model2*). Finally, we also test for the overall influence of classical and social network co-variates on rank advancements PO positions in Italy (*Model3*).

Promotion is a binary realization of the dependent variable $y_i$ , where $i$ is the individual. The reported estimations refer to logistic regressions, although we also applied Probit models, with no appreciable differences in results. Results for *Models 1* and *2* are presented jointly for French and Italian data, which gives us the opportunity to compare the effect of the variables looking at the odds ratio estimates. Appendix 2 shows the correlation tables of all the covariates to avoid problems of multi-collinearity, no variables show problems of high correlation, except the various, alternative measures of productivity.

# 4 Results

### 4.1 Classical determinants

Regression results in table 5 confirms many of the results available for US academic careers, but also some interesting discrepancies between Italy and France physicists. Coefficients cannot be interpreted as partial derivates, so we examine what they suggest in terms of marginal effect with the help of several graphs.

We estimate three different models for each country, using different measures of productivity.

We use the first column [(1) and (2)] in order to explain the results.

**Table 5. Logistic model for promotion, 2000-05 (Italy) and 2000-03 (France): classical determinants (model 1)**

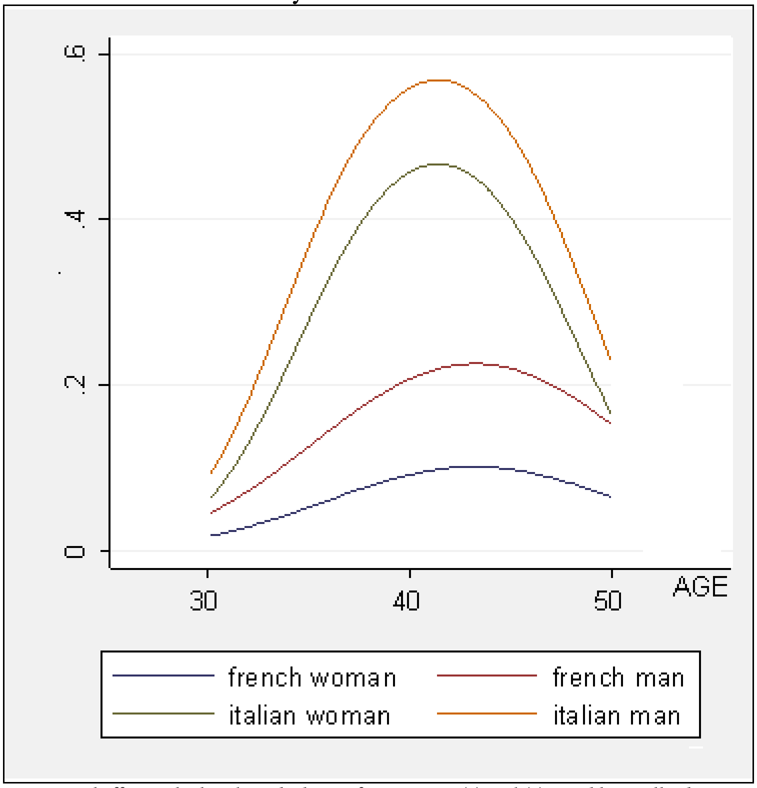
| | (1) France | (2) Italy | (3) France | (4) Italy | (5) France | (6) Italy | (7) France | (8) Italy |
|---|---|---|---|---|---|---|---|---|
| *Gender* | -0.80*** | -0.17 | -0.78** | -0.16 | -0.76** | -0.15 | -0.74** | -0.21 |
| | (0.30) | (0.25) | (0.31) | (0.25) | (0.31) | (0.25) | (0.31) | (0.25) |
| *Age* | 1.09*** | 1.83*** | 1.04*** | 1.80*** | 1.00*** | 1.76*** | 0.96*** | 1.73*** |
| | (0.35) | (0.37) | (0.35) | (0.37) | (0.35) | (0.37) | (0.35) | (0.37) |
| *Age²* | -0.013*** | -0.022*** | -0.012*** | -0.022*** | -0.012*** | -0.021*** | -0.011** | -0.021*** |
| | (0.0045) | (0.0045) | (0.0045) | (0.0045) | (0.0045) | (0.0045) | (0.0045) | (0.0045) |
| *Matthew* | 0.047** | -0.00012 | 0.038* | -0.0028 | 0.030 | -0.010 | 0.035* | 0.0023 |
| | (0.019) | (0.018) | (0.020) | (0.018) | (0.021) | (0.019) | (0.020) | (0.017) |
| *Inbreeding* | -0.091 | 0.29 | -0.12 | 0.26 | -0.15 | 0.28 | -0.21 | 0.34 |
| | (0.29) | (0.30) | (0.29) | (0.30) | (0.29) | (0.30) | (0.30) | (0.31) |
| *Productivity (α=1)* | 0.016*** | 0.015*** | | | | | | |
| | (0.0053) | (0.0050) | | | | | | |
| *Productivity² (α=1)* | -0.000028** | -0.000040* | | | | | | |
| | (0.000011) | (0.000022) | | | | | | |
| *Productivity (α=0,25)* | | | 0.012*** | 0.0094*** | | | | |
| | | | (0.0033) | (0.0028) | | | | |
| *Productivity² (α=0,25)* | | | -0.000014*** | -0.000014* | | | | |
| | | | (0.0000045) | (0.0000075) | | | | |
| *Productivity (α=0,1)* | | | | | 0.0099*** | 0.0082*** | | |
| | | | | | (0.0024) | (0.0022) | | |
| *Productivity² (α=0,1)* | | | | | -0.0000082*** | -0.0000088** | | |
| | | | | | (0.0000024) | (0.0000044) | | |
| *Articles* | | | | | | | 0.056*** | 0.038** |
| | | | | | | | (0.012) | (0.016) |
| *Articles²* | | | | | | | -0.00026*** | -0.00012 |
| | | | | | | | (0.000070) | (0.00022) |
| *Constant* | -24.9*** | -37.9*** | -24.0*** | -37.4*** | -23.2*** | -36.7*** | -22.6*** | -36.3*** |
| | (6.79) | (7.50) | (6.80) | (7.51) | (6.79) | (7.54) | (6.76) | (7.59) |
| *Observations* | 816 | 469 | 816 | 469 | 816 | 469 | 816 | 469 |

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

### *Age*

The age variable (considered here a proxy of career length,) has a significant and non-monotonic impact on the scientists' promotion chances, in both countries. The effect of age on the odds of promotion has a concave shape, with an initial increment and a gradual decline as scientists seniority increases. Figure 2 is a conditional effects plot, which represents the probability of promotion conditional to age of an average French and Italian professor in our two national samples.

**Figure 2. Promotion probability as a function of age and gender*, France and Italy**




** Marginal effects calculated on the basis of regressions (1) and (2) in table 5. All other regressors besides gender and age are set at avg values*

This result is really close to Long, Allison and McGinnis (1991). Instead of age, those authors consider the years spent in a given rank, but the inverted U shape of the odds of promotion are quite the same as ours. In both cases, the estimated indicate a trend of increasing, then decreasing chances of being promoted as time goes by. Considering only the linear component of age, an additional year of career in the same position generates for Italy an odds ratio double than in France, that is an Italian physicist's chances of promotion (relative to non promotion) on the mere basis of seniority are double than those of a French colleague. Figure 4 shows the expected probability of promotions for a representative individual (i.e. a male scientist with average productivity) in France and in Italy: notice that advancement probabilities are constantly higher for the Italian physicists. This is due both to the longer time interval over which promotion may occur (5 years in Italy vs. 3 in France) and to the existence of an intermediate step (such as that of associate professor) in the Italian academic ladder, which may facilitate progress out of the bottom step of the ladder.

*Gender*

Gender has a strong negative impact on promotion chances in France, but not in Italy. Being a woman physicist in France means having half the chances of promotion than a man, other things being equal. In Italy, the sign of the estimated coefficient is the same as the French one, but it is not significant. This result is confirmed also for the promotion to full professor for the Italian case (see Appendix 3).

A note of caution is due here. Our data cannot tell whether a scientist does not get promoted because he or she fails a *concorso* or *concours*, or because he/she does not even try it. So it may either be that French examination committees discriminate somehow against women, but also that women self-select them out of the competition for professor jobs. It remains to be seen whether the two explanations are complementary (as when women do not even try to enter competition they are bound to lose) or alternative (as when women decide that, for many possible reason, they do not want to get a professor's job).

*Productivity*

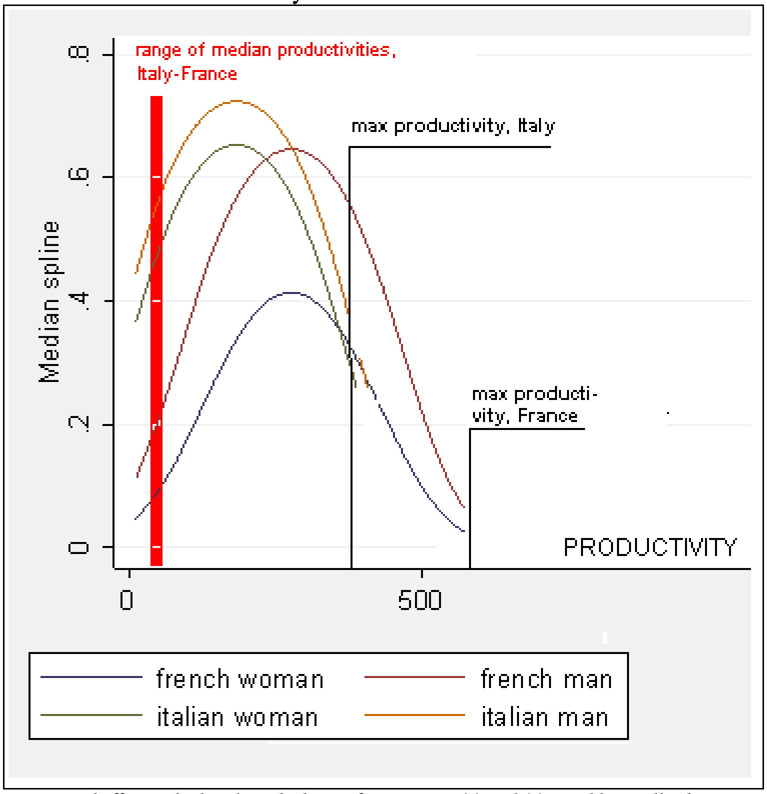
The impact of scientific productivity on promotion chances has a concave shape, although the quadratic component is less significant than that of age. All the measures of productivity have a positive impact on the probability of promotion. It is worthwhile noting that the productivity effect in the rank advancement between PA and PO disappears (see Appendix 3)

Figure 3 shows the promotion probability for men and women scientists in Italy and France. The inverted U-shape of the curves is determined by the existence of a few outliers with max productivity value. As a matter of fact, most scientists have productivity value well below the mean. This suggests that for almost all scientists the probability to get promoted are always increasing (never decreasing) with productivity, although with diminishing returns[19].

Taking into account only for the linear component of productivity, in France each unitary increment of productivity grows the probability promotion of male scientists by 2.6%. In Italy the increment is limited to 1.4%. In Italy, in addition, diminishing returns to productivity seem to kick in much sooner that in France. In France, the gender bias appears so heavy that women cannot compensate for it with productivity, no matter how high. As shown in table 5, changing the productivity proxy does not alter much our results.

[19] If we do not consider the outliers the second derivative effect disappears.

**Figure 3. Promotion probability as a function of age and gender*, France and Italy**




** Marginal effects calculated on the basis of regressions (1) and (2) in table 5. All other regressors besides gender and productivity are set at avg values*

*Matthew and Inbreeding effects*

Our *Inbreeding* variable is never significant, possibly due to the high number of scientists for which it takes value zero, due to the absence of co-authors. The Matthew effect appears to have some limited impact on careers in France, although it appears to be sensitive to the change of productivity measure.

## 4.2 Classical determinants *cum* social capital

This model accounts for classical determinants and two network indexes: principal component and closeness. As shown in table 5, the effect of the classical covariates remains unchanged.

We use the first column [(1) and (2)] in order to explain the results.

Age and the productivity remain significant and with a concave shape even if the quadratic component of productivity now becomes somehow less significant. Considering only the linear component of productivity, each additional (weighted) article now gives an extra 2.8% or promotion probabilities in France and only 1.3% in Italy. Also the probability to be promoted is more than six time higher for each year of age in Italy and only three times in France.

**Table 6 Logit model for promotion, 2000-05 (Italy) and 2000-03 (France), classical and social capital determinants (Model 2)**

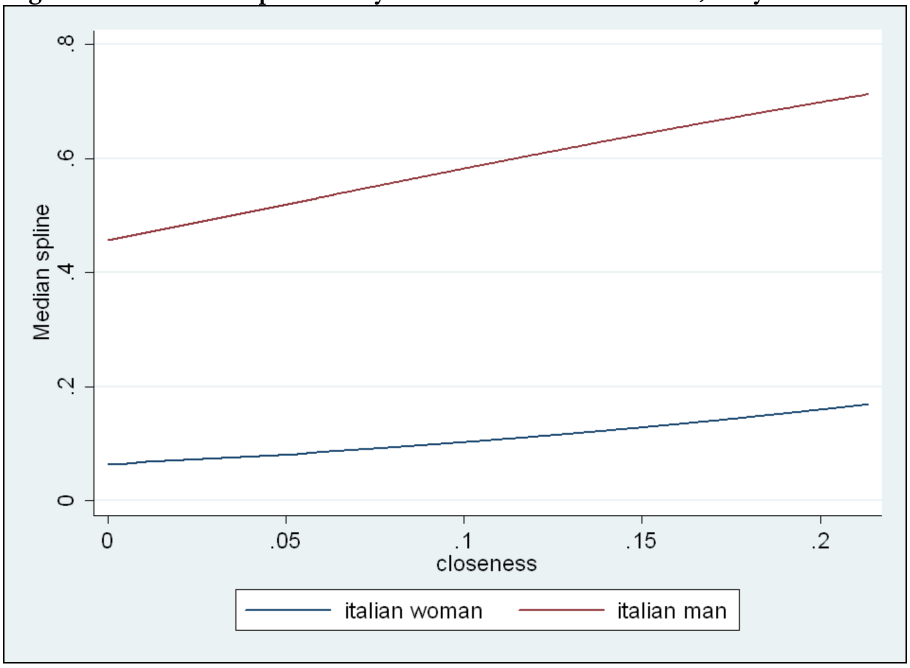
| | (1) France | (2) Italy | (3) France | (4) Italy |
|---|---|---|---|---|
| *Gender* | -0.78*** | -0.13 | -0.78** | -0.14 |
| | (0.30) | (0.25) | (0.30) | (0.25) |
| *Age* | 1.09*** | 1.83*** | 1.09*** | 1.83*** |
| | (0.35) | (0.37) | (0.35) | (0.37) |
| *Age*$^2$ | -0.013*** | -0.022*** | -0.013*** | -0.022*** |
| | (0.0045) | (0.0045) | (0.0045) | (0.0045) |
| *Matthew* | 0.047** | -0.0044 | 0.046** | -0.0053 |
| | (0.019) | (0.018) | (0.019) | (0.019) |
| *Productivity* ($\alpha=1$) | 0.016*** | 0.014*** | 0.015*** | 0.014*** |
| | (0.0054) | (0.0050) | (0.0054) | (0.0050) |
| *Productivity*$^2$ ($\alpha=1$) | -0.00003** | -0.00004* | -0.00003** | -0.00004* |
| | (0.000011) | (0.000022) | (0.000011) | (0.000022) |
| *PrincipalComponent* | 0.051 | 0.68*** | | |
| | (0.23) | (0.22) | | |
| *Closeness* | | | 1.03 | 5.08*** |
| | | | (2.00) | (1.44) |
| *Constant* | -25.0*** | -38.6*** | -25.0*** | -38.7*** |
| | (6.79) | (7.56) | (6.78) | (7.59) |
| *Observations* | 816 | 469 | 816 | 469 |

*Standard errors in parentheses - *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$*

Network measures exhibit a strikingly different impact in the two countries: null in France and highly significant in Italy. Being part of the principal component of the national scientific network does not affect the promotion chances of French scientists, while it increases considerably those of Italian ones. More strikingly, as shown in figure 4, non connected scientists in Italy stand almost half a chance to get promoted than those with maximum observed closeness (which is equal to 0.2).

We interpret this result as evidence of the importance of a specific type of social capital for Italian scientists, namely links with the national scientific community. The peculiar institutional arrangements of the Italian academic recruitment system are such that senior colleagues of those seeking promotion have considerable (and largely unchecked) power on the latter's careers, and are at the same time involved in a web of job commissions, local in nature but elected by peers on a national basis. As a consequence, proximity to influential decision-makers, as measured by closeness, may be decisive for a scientist's career. In France, where job commissions are not entirely elective and stand for several years, and not just the celebration of one competition for one academic post, this effect does not appear. We are aware that the network effect for Italy could be explained by the recruitment norms as much as by the social norms of the community, with their emphasis on inbreeding and mentoring (which could also be responsible for the existence of such a baroque and easily rigged recruitment system). However, at this stage of our research, we cannot tell social vs. institutional norms apart.

**Figure 4. Promotion probability as a function of closeness*, Italy**




** Marginal effects calculated on the basis of regression (4) in table 6. All other regressors besides gender and productivity are set at avg values*

The role of social capital in Italy is confirmed also by the analysis of promotion to the top rank of PO. As shown in table 7 (regression 1), productivity has lower and less significant impact on the promotion chances from PA to PO, than it has from RU to PA. More strikingly, productivity enters the regression merely as a proxy for social capital: when we control for the latter, as in regressions (2) and (3), we cannot reject any more the null hypothesis for productivity (the same applies to the Matthew effect).

**Table 6. Logistic model for promotion from PA to PO: classical and social capital determinants (model 3)**

| | (1) | (2) | (3) |
|---|---|---|---|
| Female | -0.35 | -0.39 | -0.40 |
| | (0.30) | (0.31) | (0.31) |
| Age | 1.83*** | 1.90*** | 1.92*** |
| | (0.27) | (0.27) | (0.27) |
| $Age^2$ | -0.019*** | -0.020*** | -0.020*** |
| | (0.0027) | (0.0027) | (0.0028) |
| Matthew | 0.037* | 0.030 | 0.031 |
| | (0.020) | (0.020) | (0.020) |
| Productivity | 0.0052** | 0.0041 | 0.0039 |
| | (0.0025) | (0.0025) | (0.0025) |
| $Productivity^2$ | -0.0000054 | -0.0000031 | -0.0000028 |
| | (0.0000055) | (0.0000052) | (0.0000052) |
| Comp | | 0.78*** | |
| | | (0.22) | |
| Closeness | | | 5.45*** |
| | | | (1.45) |
| Constant | -44.4*** | -46.7*** | -47.2*** |
| | (6.56) | (6.72) | (6.76) |
| Observations | 578 | 578 | 578 |

*Standard errors in parentheses - *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$*

## 5. Discussion and conclusions

In this paper we have studied the effects of classical (such as age, gender, productivity and Matthew effect) and social determinants (taken from the network analysis literature) on academic career using comparable data for French and Italian academic physicists. In particular, we compared the probability of promotion from the bottom rank of the academic ladder either to the top – as in France – or to an intermediate position – as in Italy. For Italy, we also investigate promotion from the intermediate to the top academic rank.

Our analysis confirm the role of seniority and scientific productivity, as found in the literature. The older the scientist the higher her chances of promotion, but only a to an age comprised in between 40 and 45 (for promotion from the bottom to the top/intermediate ranks in France and Italy) or well over 50 (for promotion to the top rank in Italy), after which promotion chances decline. As for productivity, our estimates suggest the existence of positive but diminishing returns, which are considerably higher for French scientists as opposed to Italian ones. Overall, the balance between seniority and productivity appears as promotion determinants seems to be relatively more shifted in the favour of the former in Italy, and of the latter in France.

Our results also suggest that being well connected to national colleagues has a positive impact on the probability to be promoted in Italy, but not in France. It is tempting to explain these findings with differences in the recruitment system in the two countries: while the Italian system is based on highly political and local-specific *concorsi*, the French academic system is based on two-faces competition, where the first is nationwide competition that leaves less room for manoeuvring. At this stage of our research, however, it would be premature to jump to conclusions. As discussed by the literature on both the economics and sociology of science, and more generally by the literature on social networks, our network measures may be indicative not only of the existence of a 'political' capital (to be spent for influencing the process of composition and the final decisions of examination committees), but also of genuine access to knowledge sources and funding opportunities. However, our results certainly suggest that the link between recruitment procedures and the importance of social ties is worth exploring.

A puzzling result of our paper is that the differential impact of *gender* on career in the two countries, negative in France and non-significant in Italy. At this stage of our research we can only observe that the French system host more women than the Italian one overall, and that it is more selective (fewer French *maitres a conference* become professors, as opposed to Italian *ricercatori*). It may well be that while Italy exhibits its gender effect at the entry level (number of women who manage to enter the academic system, at its lowest rank) France has its own at the promotion level.

Going back to the literature on the new economics of science, our results confirm the role of scientific productivity as a determinant of academic career, but also suggest that such a role is tempered by other determinants, such as seniority, gender, and social connections. While evidence exists on the importance of seniority and age also in the US academic career system, we are not aware of studies that have highlighted the role of social connections for that country.

In the near future, we plan to develop both a more sophisticated theory of the recruitment process in the two countries and a more accurate analysis of network effects on promotion. On a longer time horizon, we expect that a better understanding of the career process will be instrumental in framing the ongoing debate on the changing economics of universities in a more general model of individual scientists' incentives and constraints.

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**Appendix 1. Rank and age distribution of physicists of the matter on active duty in 2005 (all Italian and French universities)**

| | Number (and % of tot physicists) - (1) | Age in 2005 | Age of nomination (avg) | Promoted to present rank after 2000 [% of (1)] |
|---|---|---|---|---|
| *France* | | | | |
| MCFU | 1397 | 43.95702 | 33 | .2091691 |
| PR | 758 | 54.2876 | 42 | .2242744 |
| *Italy* | | | | |
| PA | 640 | 53.28594 | 41 | .384375 |
| PO | 606 | 60.57426 | 47 | .3316832 |
| RU | 524 | 43.55344 | 34 | .4045802 |

**Appendix 2a. Correlation France**

| | Gender | Age | Productivity | Productivity (α=0.25) | Productivity (α=0.1) | Articles | Matthew | Princial Component | Closeness | Inbreeding |
|---|---|---|---|---|---|---|---|---|---|---|
| Gender | 1 | | | | | | | | | |
| Age | -0.0335 | 1 | | | | | | | | |
| Productivity | -0.0623 | 0.0999* | 1 | | | | | | | |
| Productivity (α=0.25) | -0.0664 | 0.0957* | 0.9951* | 1 | | | | | | |
| Productivity (α=0.25) | -0.0730 | 0.0859 | 0.9848* | 0.9949* | 1 | | | | | |
| Articlea | -0.0784 | 0.0920* | 0.9504* | 0.9639* | 0.9774* | 1 | | | | |
| Matthew | -0.111* | -0.235* | 0.3068* | 0.3185* | 0.3388* | 0.2992* | 1 | | | |
| Principal Component | -0.120* | -0.138* | 0.1628* | 0.1767* | 0.2035* | 0.2450* | 0.2860* | 1 | | |
| Closeness | -0.120* | -0.130* | 0.1726* | 0.1877* | 0.2191* | 0.2631* | 0.2973* | 0.9687* | 1 | |
| Inbreeding | - 0.0600 | -0.0267 | 0.0689 | 0.0659 | 0.0715 | 0.0708 | 0.1625* | 0.0085 | 0.5362* | 1 |

**Appendix 2b. Correlation Italy**

| | Gender | Age | Productivity | Productivity (α=0.25) | Productivity (α=0.1) | Articles | Matthew | Principal Component | Closeness | Inbreeding |
|---|---|---|---|---|---|---|---|---|---|---|
| Gender | 1 | | | | | | | | | |
| Age | 0.0994 | 1 | | | | | | | | |
| Productivity | -0.192* | -0.0298 | 1 | | | | | | | |
| Productivity (α=0.25) | --0.181* | -0.0311 | 0.9845* | 1 | | | | | | |
| Productivity (α=0.25) | -0.172* | -0.0469 | 0.9521* | 0.9832* | 1 | | | | | |
| Articlea | -0.1180 | 0.0093 | 0.7183* | 0.7502* | 0.8328* | 1 | | | | |
| Matthew | -0.0955 | -0.231* | 0.4403* | 0.4405* | 0.4499* | 0.3183* | 1 | | | |
| Principal Component | -0.0789 | -0.201* | 0.1345* | 0.1603* | 0.2189* | 0.2998* | 0.1890* | 1 | | |
| Closeness | -0.0552 | -0.213* | 0.1030 | 0.1320* | 0.2069* | 0.3339* | 0.1810* | 0.9618* | 1 | |
| Inbreeding | -0.0846 | -0.0444 | 0.0616 | 0.0533 | 0.0749 | 0.1127 | 0.0715 | 0.1406* | 0.1492* | 1 |

**Appendix 3. List of Journal Titles**

| *Journal Title* |
|---|
| ACOUSTICAL PHYSICS |
| ACTA PHYSICA POLONICA A |
| ACTA PHYSICA POLONICA B |
| ACTA PHYSICA AUSTRIACA |
| ACTA PHYSICA ET CHEMICA |
| ACTA PHYSICA ACADEMIAE SCIENTIARUM HUNGARICAE |
| ACTA POLYTECHNICA SCANDINAVICA-PHYSICS INCLUDING NUCLEONICS SERIES |
| ACUSTICA |
| ADVANCES IN ATOMIC AND MOLECULAR PHYSICS |
| ADVANCES IN ATOMIC MOLECULAR AND OPTICAL PHYSICS |
| ADVANCES IN CHEMICAL PHYSICS |
| ADVANCES IN CHEMICAL PHYSICS |
| ADVANCES IN CLINICAL CHEMISTRY |
| ADVANCES IN ELECTRONINCS AND ELECTRON PHYSICS |
| ADVANCES IN IMAGING AND ELECTRON PHYSICS |
| ADVANCES IN MOLECULAR RELAXATION AND INTERACTION PROCESSES |
| ADVANCES IN MOLECULAR RELAXATION PROCESSES |
| ADVANCES IN NUCLEAR PHYSICS |
| ADVANCES IN PHYSICS |
| AIP CONFERENCE PROCEEDINGS |
| AMERICAN JOURNAL OF PHYSICS |
| AMERICAN LABORATORY |
| ANALES DE FISICA |
| ANALES DE LA REAL SOCIEDAD ESPANOLA DE FISICA Y QUIMICA SERIA A-FISICA |
| ANALYTICAL INSTRUMENTATION |
| ANNALES DE LA SOCIETE SCIENTIFIQUE DE BRUXELLES SERIES 1-SCIENCES MATHEMATIQUES ASTRONOMIQUES ET PHY |
| ANNALES DE L INSTITUT HENRI POINCARE SECTION A PHYSIQUE THEORIQUE |
| ANNALES DE L INSTITUT HENRI POINCARE-PHYSIQUE THEORIQUE |
| ANNALES D OCULISTIQUE |
| ANNALS OF PHYSICS |
| ANNALEN DER PHYSIK |
| ANNALES DE PHYSIQUE |
| ANNUAL REVIEW OF FLUID MECHANICS |
| ANNUAL REPORTS ON NMR SPECTROSCOPY |
| ANNUAL REVIEW OF NUCLEAR SCIENCE |
| ANNUAL REVIEW OF NUCLEAR AND PARTICLE SCIENCE |
| APPLIED AND COMPUTATIONAL HARMONIC ANALYSIS |
| APPLIED PHYSICS B-LASERS AND OPTICS |
| APPLIED MAGNETIC RESONANCE |
| APPLIED OPTICS |
| APPLIED PHYSICS |
| APPLIED PHYSICS A-MATERIALS SCIENCE & PROCESSING |
| APPLIED PHYSICS B-PHOTOPHYSICS AND LASER CHEMISTRY |
| APPLIED PHYSICS LETTERS |
| APPLIED SCIENTIFIC RESEARCH SECTION A-MECHANICS HEAT CHEMICAL ENGINEERING MATHEMATICAL METHODS |
| APPLIED SCIENTIFIC RESEARCH SECTION B-ELECTROPHYSICS ACOUSTICS OPTICS MATHEMATICAL METHODS |
| APPLIED SPECTROSCOPY REVIEWS |
| APPLIED SPECTROSCOPY |
| APPLIED SUPERCONDUCTIVITY |
| APPLIED SURFACE SCIENCE |
| ARKIV FOR FYSIK |
| ATOMIZATION AND SPRAYS |

ATM MESSTECHNISCHE PRAXIS
ATOMIC DATA AND NUCLEAR DATA TABLES
ATOMIC SPECTROSCOPY
ATTI DELLA ACCADEMIA NAZIONALE DEI LINCEI RENDICONTI-CLASSE DI SCIENZE FISICHE-MATEMATICHE & NATURAL
ATTI DELLA ACCADEMIA NAZIONALE DEI LINCEI RENDICONTI-CLASSE DI SCIENZE FISICHE-MATEMATICHE & NATURAL
AUDIOLOGY
AUSTRALIAN JOURNAL OF PHYSICS
AUSTRALIAN JOURNAL OF SCIENTIFIC RESEARCH SERIES A-PHYSICAL SCIENCES
AUTOMATION AND REMOTE CONTROL
BULLETIN OF THE AMERICAN PHYSICAL SOCIETY
BULLETIN DE L ACADEMIE POLONAISE DES SCIENCES-SERIE DES SCIENCES MATHEMATIQUES ASTRONOMIQUES ET PHYS
BEITRAGE AUS DER PLASMAPHYSIK-CONTRIBUTIONS TO PLASMA PHYSICS
BIOLOGICAL MASS SPECTROMETRY
BIOMEDICAL AND ENVIRONMENTAL MASS SPECTROMETRY
BIOMEDICAL MASS SPECTROMETRY
BRITISH JOURNAL OF APPLIED PHYSICS
BRITISH JOURNAL OF PHYSIOLOGICAL OPTICS
CANADIAN JOURNAL OF ANALYTICAL SCIENCES AND SPECTROSCOPY
CANADIAN JOURNAL OF APPLIED SPECTROSCOPY
CANADIAN JOURNAL OF PHYSICS
CANADIAN JOURNAL OF RESEARCH SECTION A-PHYSICAL SCIENCES
CANADIAN JOURNAL OF SPECTROSCOPY
CESKOSLOVENSKY CASOPIS PRO FYSIKU SEKCE A
CHAOS
CHAOS SOLITONS & FRACTALS
CHEMICAL BIOMEDICAL AND ENVIRONMENTAL INSTRUMENTATION
CHEMICAL INSTRUMENTATION
CHEMOMETRICS AND INTELLIGENT LABORATORY SYSTEMS
CHEMICAL PHYSICS LETTERS
CHEMICAL PHYSICS
CHEMICAL PHYSICS REPORTS
CHEMICAL VAPOR DEPOSITION
CHINESE JOURNAL OF PHYSICS
CHINESE PHYSICS
CHINESE PHYSICS LETTERS
CLASSICAL AND QUANTUM GRAVITY
COMMUNICATIONS IN MATHEMATICAL PHYSICS
COMMUNICATIONS ON PHYSICS
COMMUNICATIONS IN THEORETICAL PHYSICS
COMPUTER PHYSICS COMMUNICATIONS
COMPUTER PHYSICS REPORTS
COMPUTERS IN PHYSICS
COMPUTER PHYSICS COMMUNICATIONS
COMPUTER PHYSICS COMMUNICATIONS
CONTEMPORARY PHYSICS
CONTRIBUTIONS TO PLASMA PHYSICS
CRITICAL REVIEWS IN SOLID STATE AND MATERIALS SCIENCES
CRC CRITICAL REVIEWS IN SOLID STATE AND MATERIALS SCIENCES
CRC CRITICAL REVIEWS IN SOLID STATE AND MATERIALS SCIENCES
CRYOGENICS
CRYSTAL LATTICE DEFECTS AND AMORPHOUS MATERIALS
CZECHOSLOVAK JOURNAL OF PHYSICS
DISCUSSIONS OF THE FARADAY SOCIETY
ELECTRON SPIN RESONANCE-A SPECIALIST PERIODICAL REPORT

ELECTRO-OPTICS
EUROPEAN PHYSICAL JOURNAL-APPLIED PHYSICS
ERGEBNISSE DER EXAKTEN NATURWISSENSCHAFTEN
EUROPEAN PHYSICAL JOURNAL A
EUROPEAN PHYSICAL JOURNAL B
EUROPEAN PHYSICAL JOURNAL C
EUROPEAN PHYSICAL JOURNAL D
EUROPHYSICS LETTERS
EXCITED STATES
EXPERIMENTS IN FLUIDS
FERROELECTRICS LETTERS SECTION
FERROELECTRICS
FESTKORPERPROBLEME-ADVANCES IN SOLID STATE PHYSICS
FESTKORPERPROBLEME-ADVANCES IN SOLID STATE PHYICS
FESTKORPERPROBLEME-ADVANCES IN SOLID STATE PHYICS
FEW-BODY SYSTEMS
FIELD ANALYTICAL CHEMISTRY AND TECHNOLOGY
FIZIKA NIZKIKH TEMPERATUR
FIZIKA TVERDOGO TELA
FORTSCHRITTE DER PHYSIK-PROGRESS OF PHYSICS
FOUNDATIONS OF PHYSICS LETTERS
FOUNDATIONS OF PHYSICS
FULLERENE SCIENCE AND TECHNOLOGY
GENERAL RELATIVITY AND GRAVITATION
HADRONIC JOURNAL
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HELVETICA PHYSICA ACTA
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IEE PROCEEDINGS-MICROWAVES ANTENNAS AND PROPAGATION
IEE PROCEEDINGS-OPTOELECTRONICS
IEE PROCEEDINGS-D CONTROL THEORY AND APPLICATIONS
IEE PROCEEDINGS-H MICROWAVES ANTENNAS AND PROPAGATION
IEE PROCEEDINGS-J OPTOELECTRONICS
IEE PROCEEDINGS-OPTOELECTRONICS
IEEE TRANSACTIONS ON ACOUSTICS SPEECH AND SIGNAL PROCESSING
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY
IEEE CIRCUITS & DEVICES
IEEE TRANSACTIONS ON ELECTRON DEVICES
IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS
IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS AND CONTROL INSTRUMENTATION
IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT
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IEEE TRANSACTIONS ON MAGNETICS
IEEE PHOTONICS TECHNOLOGY LETTERS
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IEEE TRANSACTIONS ON POWER DELIVERY
IEEE TRANSACTIONS ON POWER APPARATUS AND SYSTEMS
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IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING
IEEE TRANSACTIONS ON SIGNAL PROCESSING
IEEE TRANSACTIONS ON SONICS AND ULTRASONICS
IEEE TRANSACTIONS ON ULTRASONICS FERROELECTRICS AND FREQUENCY CONTROL
IMAGE AND VISION COMPUTING
INFRARED PHYSICS & TECHNOLOGY
INFRARED PHYSICS
INSTITUTE OF PHYSICS CONFERENCE SERIES
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INSTRUMENTS AND EXPERIMENTAL TECHNIQUES
INSTRUMENTATION SCIENCE & TECHNOLOGY
INTERNATIONAL AUDIOLOGY
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY
INTERNATIONAL JOURNAL OF INFRARED AND MILLIMETER WAVES
INTERNATIONAL JOURNAL OF MASS SPECTROMETRY
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INTERNATIONAL JOURNAL OF MODERN PHYSICS A
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INVERSE PROBLEMS
IRE TRANSACTIONS ON AUDIO
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# Flows of Ideas and Trade of Goods: Searching for International R&D Spillovers in Europe

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Abstract

The paper analyses the importance of international intra-sectoral R&D spillovers in six European countries (France, Finland, Germany, Italy, Netherlands and UK) over the period 1988-2003 on international patenting at the European Patent Office (EPO).
In order to calculate measures of foreign R&D capital stock, we use four different weighting schemes: simply total foreign R&D, bilateral patent co-inventor shares, bilateral patent citation shares and bilateral import shares. Moreover we use data also for industrialized and non European countries such as Canada, Japan and US.
We implement different econometric techniques (OLS, Count Data Models, GMM) and our results provide evidence of positive spillovers from foreign R&D capital stock: in particular, bilateral patent citations and face-to-face relationship between inventors are both important mechanism of knowledge transmission. Interestingly, foreign R&D stock weighted by bilateral import shares has no impact on innovative activity.

**Jel Codes:** O30, O10, O11

**Keywords:** Innovation, R&D Spillover, Knowledge flows, Patents, Citations, Inventors, TFP

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# 1. Introduction

The purpose of the paper is to investigate the effects of international R&D spillovers on innovative activity in six European countries. The analysis will focus on intra-sectoral R&D spillovers within eleven industries and over the period 1988-2003. The paper belongs to a large body of literature that essentially took two different research avenues. On one hand there is the Knowledge Production Function approach (KPF hereafter) pioneered by Zvi Griliches (1991), on the other hand is the trade-growth literature. While the KPF literature heavily relies on a broad notion of knowledge flows, the trade-growth literature focused on more specific channels of knowledge diffusion such as trade and foreign direct investment. Interestingly, the theoretical side of the trade-growth literature makes an emphatic distinction between trade flows and knowledge flows, arguing that the second, rather than the first, are responsible for development and growth (see for instance, Grossman and Helpman 1991 (chapter 9), Rivera-Batiz and Romer ,1991 and Feenstra, 1996).

On the other hand, the effect of international trade on the pure innovative activity is at least questionable. For this reason we will compare the relative importance of flows of goods and flows of ideas (i.e. patent citations and co-inventor relations) in explaining domestic innovative activity. The literature on KPF has largely addressed knowledge flows as possible mechanism through which foreign R&D affects domestic innovative ability (patent counts).

The main point of this paper is that international R&D sectors are not insulated but instead are linked by knowledge flows that can be tracked via patent-citation patterns and personal links between patent co-inventors. While patent citations have already been used in the literature as measure of knowledge flows (see for instance, Peri, 2005 and Malerba *et al.*, 2007), to our knowledge the use of patent co-inventorship has not been emphasized in the literature.

Moreover geography proximity is considered the key element in order to access externalities from foreign R&D (see for instance Jaffe *et al.*, 1993, Keller, 2002, and Bottazzi and Peri, 2003), and therefore knowledge spillovers are considered localized.

However being close to other countries is neither sufficient nor necessary condition for accessing a pool of knowledge, but a significant involvement in a network of knowledge exchanges is required.

It is widely acknowledged that scientific ideas and innovations originate, diffuse, and are improved mainly within a set of connected cliques sharing same knowledge and jargon: therefore we argue that inventors' community may be close so that it is necessary consider network relationships in order to understand the dynamic of knowledge creation (see Breschi and Lissoni, 2001).

This work could also be seen as an attempt to provide new measures of appropriable foreign R&D capital stock in the same vein of Keller (1998), Lichtenberg and van Pottelsberghe de la Potterie (1996) and many others.[20]

We use patent applications at the European Patent Office (EPO) to measure innovation and extract information about intra-sectoral knowledge flows across countries. We focus on bilateral citations and co-inventor relationships as potential mechanisms of knowledge flows.

We use data for nine OECD countries (Canada, France, Finland, Germany, Italy, Japan, Netherlands, UK, US) and eleven sectors (Food, beverages and tobacco; Textiles, leather and footwear; Wood and cork; Pulp, paper, printing and publishing; Chemicals and pharmaceuticals; Rubber and plastics; Other non metallic mineral products; Basic metals and fabricated metals products; Machinery and equipment; Electrical and optical equipment; Transport equipment), in the years between 1988 and 2003. The aim is to understand the nature of technological spillovers in six European countries, and the ultimate goal is to assess the role played by *flows of ideas* as opposed to *flows of goods* in defining the relative performance in inventive and productive activity across countries.

The rest of the paper is organized as follows: Section 2 provides the review of the related literature. Section 3 introduces a theoretical framework to understand the setting in which we implement the empirical analysis. Section 4 presents data. Section 5 estimates a patents production function and shows results on the relative performance of several measures of foreign R&D capital stock. Section 6 concludes the paper.

## 2. Related Literature

From an historical perspective it may be argued that not only inventiveness but also receptivity to new technologies and the capacity to assimilate them from abroad have played a major role in defining the economic performance of most developed countries (Rosenberg, 1982).

Once historically stated the importance of technology transfers it is crucial to understand through which channel technology spills over national borders. Technology is linked to knowledge, and knowledge is a (quasi) public good characterized by non-appropriability and non-rivalry (Callon, 1994). The flows of knowledge are favoured by different channels, such as trade and foreign

[20] The main difference between these studies is the weights applied to the foreigh R&D capital stocks. Weights based on the fraction of trading partners'output exported to the recipient countries (Lichtenberg and van Pottelsberghe de la Potterie, 1998), weights based on inward and outward FDI (van Pottelsberghe de la Potterie and Lichtenberg, 2001), and stocks (Zhu and Jeon, 2007), weights based on the bilateral technoligical proximity between countries (Park, 1995; Guellec and van Pottelsberghe de la Potterie, 2004), weights based on indirect trade (Lumenga-Neso et al., 2005), and weights based on information technology (Zhu and Jeon, 2007).

investments; but due to its immaterial and tacitness nature, knowledge spills over besides the channel considered: it is possible track "learning" of ideas across countries with the use of patent citations and patent co-inventors.

## 2.1 Citations

Patent citations are included in a patent document to restrict the scope of the property right and refer to the relevant prior art. In particular if a patent Y cites a patent X, it reasonable to assume that knowledge embedded in X has been developed by Y and therefore it plausible that knowledge flowed from X to Y.

It is worthwhile to note that there are institutional differences between citation practices in the USPTO and EPO (Bachiocchi and Montobbio, 2004; Breschi and Lissoni, 2004; EPO, 2005) . In the US there is the 'duty of candor' rule that impose all applicants to disclose all the prior art they use; at the European Patent Office there is not such a rule: patent examiners draft their report and include all relevant prior art within a minimum number of citations. Therefore citations are mainly added by patent office examiners and this reduces the probability to have citations that are included to deceive patent examiners (Malerba *et al*., 2007).

The influential paper of Jaffe *et al.* (1993) uses patent-citation patterns to infer the degree of geographic localization of knowledge spillovers. In a sample of U.S patent data, they find strong evidence of geographic localization of citations: citations to domestic patents are more likely to come from the same country, state and even the same metropolitan areas.

In addition there is a consolidate stream of literature that uses patent citations to track knowledge flows and spillovers (among others see Maurseth and Verspagen, 2002, Malerba and Montobbio, 2003, Peri 2005, Malerba *et al*,.2007, Mancusi, 2004).

## 2.2 Co-inventors

Scholars emphasize that scientific ideas and innovations originate, diffuse, and are improved mainly within a set of connected cliques sharing same knowledge and jargon: therefore we argue that inventors' community may be close so that it is necessary consider network relationship in order to understand the dynamic of knowledge creation (Breschi and Lissoni, 2001). Moreover research collaboration creates social networks: inventors may continue to rely on free information in subsequent research projects after the collaboration itself has finished.

Social proximity may be identified by citations and co-inventor relations; even though it is worth clarifying that citation patterns and co-inventor relations measure different kind of disembodied knowledge flows. Citations are able to measure flows of codified knowledge, that is, knowledge acquired by direct reading and comprehension of the closest output of innovative activity such as publications and patents (see for instance, Jaffe *et al.* 1993, Maruseth and Verspagen 2002, Peri 2005 and Malerba *et al.* 2007). On the other side, if we assume that inventors listed on the same patent know each other, co-inventor relationships, instead, can be seen as diffusion mechanism of non-codified knowledge (e.g. technical know-how, non-standardized production procedures, etc.). Diffusion of non-codified knowledge requires, at least periodically, face-to-face interactions and it is likely to have a great impact on the inventive activity.

Singh (2005) examine whether social networks of inventors are a significant mechanism for diffusion of knowledge and found that the probability of knowledge flows between inventions is a decreasing function of the social distance: patterns of citations and patterns of co-inventorhip are linked. At a micro level, Gonzalez-Brambilla *et al.* (2008) emphasize the relationship between social capital and the creation of knowledge: they found that scientists embedded in networks have superior success due to better communication skills.

Finally, analyzing international patenting in Latin America, Montobbio and Sterzi (2008) find that patent citations and face-to-face relationship between inventors are both significant mechanism of knowledge transmission.

### 2.3 Trade

Part of the empirical literature addressed the trade channel as the crucial mechanism of cross-country knowledge diffusion. Coe and Helpman (1995) find that foreign R&D expenditures weighted by bilateral imports shares have a positive and significant effect on total factor productivity (TFP hereafter) of the importing countries. By importing goods, countries directly import the technology embedded in those goods such that greater the stock of knowledge of trade partners larger are the gains from trade. Moreover, international trade offers channels of communication that favour learning of production methods, development of new technology and imitation of foreign technology.

However as pointed out by Keller (1998) the relationship between trade-related technology transfers and TFP is weakly identified at cross-country level. Keller (1998) carries out two robustness checks: he run the same regressions as Coe and Helpman (1995) but instead of using data on actual bilateral imports he uses both randomly created bilateral imports and no imports shares as weights for foreign R&D expenditures. Since these variables produce similar or even stronger results than in Coe and Helpman (1995), Keller (1998) infers that observed import patterns cannot explain the estimated effects and so identify the trade-related technology transfer effect on TFP.

Furthermore, Keller (2000) and Xu and Wang (1999) argued that as a matter of theory, international technology spillovers are the result of capital goods trade, and not aggregate trade, which Coe and

Helpman (1995) use to construct their bilateral imports shares. Xu and Wang (1999) show that if foreign R&D expenditures are weighted by bilateral capital goods imports then these variables perform better than the original ones used by Coe and Helpman (1995) and Keller (1998).

Another study closely related to the empirical approach discussed above is that of Keller (2002). It assesses the strength of spillovers from foreign R&D expenditures on a geographic basis. As in the previous literature, Keller (2002) finds that domestic productivity benefits from both domestic and foreign R&D expenditures but the international spillover effect is sharply declining with distance between countries. These results suggest that geographic localization of technology diffusion can be an important source of differences between productivity levels across countries. Even though there are several reasons why international technology transfer might be related to geographic distance, one possible explanation is that geographic distance is capturing the standard effect of international trade which itself is geographically localized.

Finally, Hafner (2008) finds there is no significant influence on labour productivity from bilateral trade.

Beside the empirical findings discussed above, from a theoretical perspective imports of goods may have a positive effect on TFP in two different ways.

The first one is related to the direct usage of imported goods (new and /or more quality ones) into the production process. This latter is the standard effect occurring in the expanding variety and quality ladders models with trade (Grossman and Helpman, 1991). However in this case spillovers occur whether the prices of imported goods do not embody completely the product innovation or the quality improvement that result from foreign innovative activities.

The second effect is related to the fact that by using imported goods countries at least partially understand their technological content such that they can exploit it to produce new varieties or improve the existing ones (*innovation effect*) with the resulting positive effect on domestic TFP.

Furthermore, through the exposure to imported goods and contractual relationships with (knowledge-intensive) trade partners, countries can acquire the basics to imitate their products and production procedures – *imitation effect*.

The magnitude of these two effects crucially depends on the absorptive capacity of the importing countries. Put in different words, even though there are technological opportunities from abroad, countries need a minimum level of knowledge to exploit them. From this latter argument comes the rationale for the research on technology-skill mismatch and adoption capacity.

The weakness of the strand of literature identifying trade as conduit of international knowledge diffusion is that flows of ideas cannot be separated from flows of goods. This approach neglects knowledge can diffuse beyond national borders through flows of ideas independently from trade flows. Interestingly, the theoretical trade-growth literature has emphasized the importance of analyzing international knowledge flows as channels of productivity diffusion, differentiating them from flows of goods. Rivera-Batiz and Romer (1991) argue that « flows of ideas deserve attention comparable to that devoted to flows of goods, for public policy can influence international communications and information flows to the same extent that it influences goods flows ». Furthermore they show that trade in goods has no effect on the long-run growth rate while flows of ideas (i.e. knowledge flows) result in permanently higher growth rate.

Grossman and Helpman (1991) point out that the effect of knowledge spillovers and those of trade in goods are conceptually distinct. Also Feenstra (1996) argues that most of the benefits from international openness come from the access to the international pool of knowledge.

## 2.4 Foreign direct investments

In respect to the late criticism, the literature has addressed foreign direct investment (FDI hereafter) as another potential channel of technology transfer. Recently, authors focus on panel data analysis with micro data, since this reduces problems resulting from unobserved heterogeneity across firms and sectors. It is worth noting that FDI may have two different effects, one on the affiliate-firms and the other one on firms in the same industry of the affiliates – *spillover effect*. While the empirical evidence about the positive productivity effect on affiliate-firms is quite robust, the literature on FDI spillover, though large, has not reached conclusive results as reflected in a number of surveys [see Lipsey and Sjohölm (2005) and Hanson (2001)].

Aitken and Harrison (1999) even find evidence of negative spillover effect from foreign to domestically owned firms. In a sample of Venezuelan plant-level data, they find that individual plants benefit from foreign investments but this positive effect is robust only for smaller plants (less than fifty employees). More interesting, productivity in domestically owned plants in the same industry declines when foreign investments increase. Since technology spillovers can unrealistically be negative, the authors interpret this negative spillover from foreign to domestic firms as a market-stealing effect – increased competition for local plants through foreign entry. The negative effect could also be due to endogeneity if FDI flows to sectors in which firms have relatively low productivity. However the authors strongly argue that previous works fail in finding that negative spillover effect because they do not account for (unobserved) heterogeneity across firms. The paucity of evidence about intra-industry positive FDI spillovers led some researchers assess whether technology spillovers exist for domestic suppliers of foreign-owned affiliates. Smarzinska Javorcik (2004) finds evidence of spillovers between firms in different industries in Lithuania but not within-industry spillovers.

However, most recent micro productivity studies tend to estimate positive spillover even in the same industry of the foreign-owned affiliates. In a sample of U.K. plant-level data, Haskel *et al.* (2007) find evidence consistent with positive, though relatively small, technology spillovers. Keller and Yeaple (2003), instead, in a sample of U.S firm-level data, find that FDI leads to substantial productivity gains for domestic firms.

Finally, at macro level Hafner (2008) finds a positive relationship between FDI inflows and labour productivity with an estimated elasticity of 6.2%.

# 3. Theoretical framework and empirical model

## 3.1 Theoretical framework

This section derives the empirical model we use to estimate international knowledge spillovers, starting from a knowledge production function describing the production of technological output from R&D investments (Griliches, 1984; Malerba *et al.*, 2007; Montobbio and Sterzi, 2008)):

$$Q_{h,j,t} = f(\bar{R}_{h,j,t}, \alpha, v_{h,j}) = \bar{R}^{\alpha}_{h,j,t} v_{h,j} \tag{1}$$

where $Q_{h,j,t}$ is some latent measure of technological output in field $j$ (j=1,..11), country $h$ and period $t$. In addition $\alpha$ represents the unknown technological parameter, and $\nu_{h,i}$ captures the country and technological field specific effects. We assume that R&D is composed of domestic R&D efforts and international R&D efforts that produce usable knowledge at the international level. As emphasised in the previous section we compare four different modes of knowledge flows. The first mode is the "pure" spillover simply measured as total foreign R&D ($IS_1$); the second is the knowledge spillover measured through patent citations ($IS_s$), then the third is knowledge spillover that is related to collaboration activities and face-to-face contacts (i.e. co-inventorship) ($IS_3$), and finally the fourth one refers to knowledge incorporated in goods, that is knowledge spillover through bilateral trade ($IS_4$).

$$\bar{R}^{\alpha}_{h,j,t} = R^{\alpha 1}_{h,j,t} IS^{\beta 1}_{1h,j,t} IS^{\beta 2}_{2h,j,t} IS^{\beta 3}_{3h,j,t} IS^{\beta 4}_{4h,j,t} \tag{2}$$

Moreover we use patents as a noisy indicator of technological output:

$$P_{h,j,t} = Q_{h,j,t} e^{\theta_t} u_{h,i} \quad (3).$$

Clearly the number of patents applied for (*P*) in a given year is only a share of the new relevant knowledge created; in fact some inventions are not patentable (1), patenting is a strategic choice and firms can decide to keep secret inventions (2), and finally knowledge acquired through the R&D process is persistent and so it exerts his utility for long time affecting future patent applications (3).

We focus on intra-sectoral R&D spillovers neglecting inter-industry knowledge flows. The idea behind this choice, also supported by some previous works[21], is that most of the spillover effect of knowledge flows occurs between firms within the same "technological group". Since the industries in the data sample are broadly aggregate, we are consistent with the argument exposed above and with the focus of the paper.

We take into consideration possible common time effects in patenting ($\theta_t$) and differences in country specific propensity to patent in each technological field ($u_{h,j}$). Combining equation (3) with (2) and (1) results in the following patent equation:

$$P_{h,j,t} = R^{\alpha 1}_{h,j,t} IS^{\beta 1}_{1h,j,t} IS^{\beta 2}_{2h,j,t} IS^{\beta 3}_{3h,j,t} IS^{\beta 4}_{4h,j,t} e^{\theta_t} \xi_{h,j} \quad (4)$$

In its general formulation international knowledge spillover are typically expressed as follows:

$$IS_{h,j,t} = \prod_f R_{f,j,t}^{\lambda_{h,f,j,t}} \quad (5)$$

where $\lambda_{h,f,j,t}$ weights the impact of R&D expenditures from foreign countries. R is the knowledge source and λ is the vehicle of knowledge spillovers.

### 3.2 Empirical model

Taking logs of (4) we propose to estimate the following logarithmic specification:

$$\ln P_{h,i,t} = a_1 \ln R_{h,i,t} + \beta_1 \ln IS_{1,h,i,t} + \beta_2 \ln IS_{2,h,i,t} + \beta_3 \ln IS_{3,h,i,t} + \beta_4 \ln IS_{4,h,i,t} + \theta_t + \varsigma_{h,i,t} \quad (6)$$

[21] A widely used approach assumes that knowledge flows exist only between firms within the same "technoligical group". This approach was used by Bernstein and Nadiri (1989a, 1989b) for the U.S high-tech industries, by Bernstein and Mohnen (1998) for U.S and Japanese firms, and by Bernstein and Yan (1997) for Canadian and Japanese firms.

where the dependent variable is the log of the number of EPO patent applications in county *h* (*h*=1,..6), sector *j*(*j*=1,..11), and time *t* (t=1,..16 for the period 1988-2003). Note that our observational unit refers to industries (sectors) in different countries for gives a total of 66 different groups. Moreover we use data also for industrialized and non European countries such as Canada, Japan and US.

The core of this paper is the calculation of the international spillover variables: we measure four different channels of international knowledge spillovers.

The first international spillover variables measures knowledge spillovers when knowledge is a "pure" public good: following this characteristic 1$ in R&D will have a direct impact on the knowledge production in other countries. We call this variable:

$$\ln IS_1 = foreignR\&D\_tot_{h,j,t} = \sum_{f \neq h} \ln R\&D_{f,j,t} \tag{7}$$

where total foreign R&D is equal to the sum of the logarithm of R&D stocks performed in all the countries but the country *h* (i.e. domestic country).

The second variable measures knowledge spillover captured by patent citations. Knowledge is a public good but travels embedded in codified documents (patents). We use EPO citations to build a set of matrices that map citations between countries we considered. Each cell of the matrix is the number of citations in patents with at least an inventor resident in country *h* to patents with at least an inventor resident in a foreign country *f*. We build these matrices for each sector and for each year. Then we construct the weight $\lambda_{h,f,j,t}=cit_{h,f,j,t}$, which is the ratio of the number of citations flowing from country *h* to country *f* in sector *j* at time *t* over the total number of citations flowing from country *h* to all the 5 industrialized countries in sector *j* at time *t:*

$$\ln IS_2 = foreignR\&D\_cit_{h,j,t} = \sum_{f} cit_{h,f,j,t} \ln R\&D_{f,j,t} \tag{8.}$$

The third spillover effect we considered is related to interpersonal links and possibly face-to-face contacts (see Montobbio and Sterzi, 2008). In this case each cell *(h,f)* of the matrix is the number of patents with at least an inventor resident in country *h* and an inventor resident in country *f*. Again we build these matrices for each sector *i* and for each year *t* in the sample. Then we construct the weight $\lambda_{h,f,j,t}=coinv_{h,f,j,t}$, as the ratio of the number of patents with co-inventors in country *h* and country *f* in sector *j* at time *t* over the total number of patents with inventors in country *h* and all the 9-*h* industrialized countries in sector *j* at time *t*. As a result our index of international knowledge spillover (*foreignR&D_coinv*) based on co-inventorship behaviours is calculated as follows:

$$\ln IS_3 = foreignR\&D\_coinv_{h,j,t} = \sum_f coinv_{h,f,j,t} \ln R\&D_{f,j,t} \quad (9).$$

Finally, the last spillover reflects *trade in good*: in this case each cell (*h,f*) of the matrix is the bilateral import of country *h* from country *f*. Then we construct the weight $\lambda_{h,f,j,t}=import_{h,f,j,t}$, as the ratio of bilateral import (thousand of US dollars at current prices) of country *h* from country *f* over the total imports from all the eight industrialized countries in sector *j* at time *t*. As a result our index of international knowledge spillover (*foreignR&D_coinv*) based on co-inventorship behaviours is calculated as follows:

$$\ln IS_4 = foreignR\&D\_import_{h,j,t} = \sum_f import_{h,f,j,t} \ln R\&D_{f,j,t} \quad (10).$$

# 4. Data

Our study uses data for nine OECD countries (Canada, France, Finland, Germany, Japan, Italy, Netherlands, UK, US) and eleven sectors (Food, beverages and tobacco; Textiles, leather and footwear; Wood and cork; Pulp, paper, printing and publishing; Chemicals and pharmaceuticals; Rubber and plastics; Other non metallic mineral products; Basic metals and fabricated metals products; Machinery and equipment; Electrical and optical equipment; Transport equipment), in the years between 1988 and 2003. We consider and match data from different sources: patent data are collected from EPO-CESPRI database, R&D expenditure in the private business sector from OECD-ANBERD and OECD STAN (2005), and bilateral trade data from STAN-OECD (2006) database.

## 4.1 Patent data

The EPO-CESPRI dataset contains all patent applications to the European Patent Office (EPO) from 1978 to 2006 by firms and individuals of all countries looking for legal protection in any countries adhering to the Munich Convention which established the EPO. Although the EPO database starts in 1978, our analysis will cover only the period from 1988 to 2003. In fact, the sample of patent applications in the first years could be biased by the fact that only the largest firms (and especially those located in Germany and US) were likely to know it well enough to apply for patent protection and therefore patent counts strongly underestimate innovative activity.

There are two different ways to assign a patent to a country: it is possible to consider the country of the inventors or the country of the applicants. In this work we use the country of inventors as assignment rule. In fact we assume that patent counts based on inventors' address may reflect more directly the innovative activity of researchers in a given country (see Montobbio, 2006). Moreover, a patent can be dated in three different ways: the priority date (i.e. the date of filing the first application), application date and the year when the patent is (eventually) granted. The choice of the patent date depends on the aim of the investigation. We consider patent applications and therefore use the priority date when there exists or the application date as the year of the patent. We prefer priority date to application date because it is the closest to the inventive effort.

Our analysis is at industry level and we consider 11 technological fields [see Appendix 1 for details on conversion from IPC to ISIC classification].

In Figure 1 and 2 are shown the trends in international patenting activity by countries and sectors: among European countries Germany, and Chemicals (including Pharmaceuticals) and Machinery have the greater propensity to patent since 1988. Furthermore, US and Germany, and Machinery show a marked upward trend in patenting.

**Figure 1. Trends in patenting activity by countries**

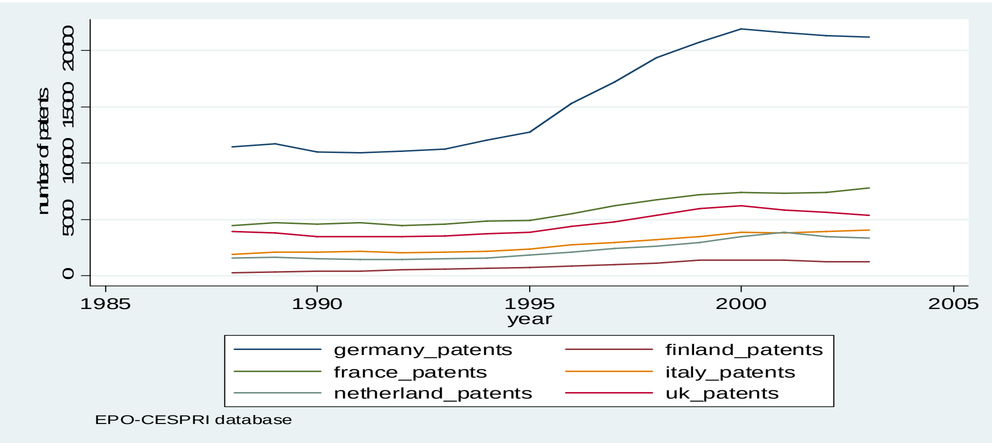


**Figure 2. Trends in patenting activity by sectors (main sectors)**

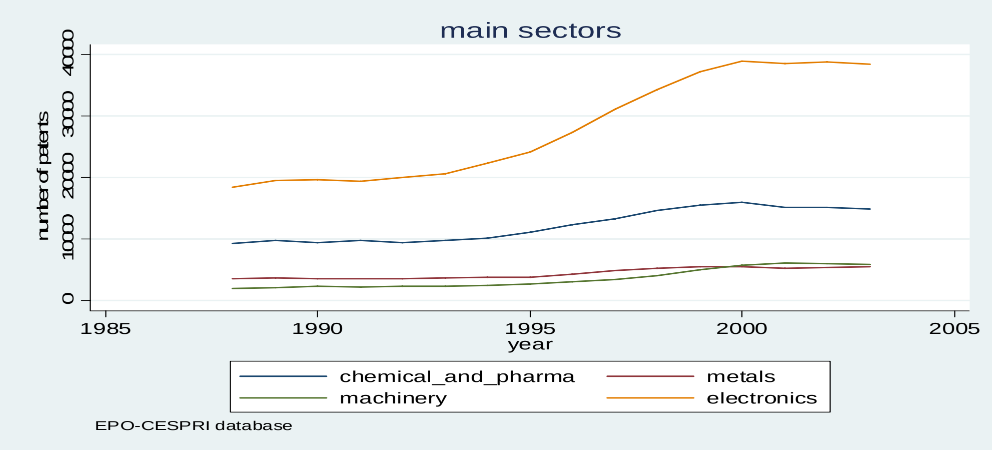



Table 1 shows the frequency of patents by sectors. This table provides evidence of important sectoral differences in patenting activity. Two industries, Chemicals and Electrical and Optical Equipment, account for the 72 percent of patents in our sample.

**Table 1. Break-down of patents by sectors**

| Aggregated sectors | Number of patent applications | % share |
|---|---|---|
| Food, beverages and tobacco | *17426,8* | *1,9%* |
| Textiles, leather and footwear | *7388,3* | *0,8%* |
| Wood and Cork | *3384,55* | *0,4%* |
| Pulp, paper, printing and publishing | *16687,8* | *1,9%* |
| Chemicals and Pharmaceuticals | *196495* | *21,9%* |
| Rubber and Plastics | *3289,4* | *0,4%* |
| Other non metallic mineral products | *15989,05* | *1,8%* |
| Basic metals and fabricated metals products | *71362,9* | *7,9%* |
| Machinery and Equipment | *58151* | *6,5%* |
| Electrical and Optical Equipment | *449461,5* | *50,1%* |
| Transport Equipment | *58254,6* | *6,5%* |

From patent data we extract citations and co-inventorship to measure knowledge flows and analyze different channels of intra-sectoral knowledge spillovers.

In the patent document, citations are needed to identify the degree of novelty of the claims and provide the boundary of the property rights. As also pointed out by Jaffe *et al.* (1993), citations have legal value in the granting procedure such that they can be used as reliable measure of knowledge flows. Because of the legal value of citations and the presence of patent examiners, we are confident that patent applicants have the right incentives to cite the relevant knowledge. Over-citing is ruled out by the fact that citations to other patents decrease the scope of the patent. Under-citing is compensated by the work of patent examiners. At the EPO citations are, with few exceptions, added by the patent examiners (see Breschi and Lissoni 2004).

We use citations to build a matrix CIT, where each element of the matrix $\{CIT_{h,i,j,t}\}$ represents the number of patent citations flowing from country *h* to country *i* in sector *j* at time t. As example, Table 3 shows the CIT matrix for Germany and UK without the time-series dimension. The same procedure is used to build the matrix COINV, in which instead of citations are reported the number of co-inventors between the country *h* and country *i* in sector *j* at time t. As example, Appendix 1 shows the COINV matrix for Germany and UK without the time-series dimension.

**Table 2. CIT matrix for Germany and UK: share by countries and sectors (years 1988-2003)**

| Country | Sector | TOTAL_cit | CA_share | DE_share | FI_share | FR_share | GB_share | IT_share | JP_share | NL_share | US_share |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DE | Food, beverages and tobacco | *2891* | 1% | ***32%*** | 1% | 6% | 8% | 2% | 10% | 7% | 32% |
| DE | Textiles, leather and footwear | *4221,3* | 1% | ***37%*** | 1% | 7% | 8% | 3% | 12% | 5% | 27% |
| DE | Wood and Cork | *618,5* | 2% | ***63%*** | 0% | 8% | 6% | 8% | 2% | 4% | 7% |
| DE | Pulp, paper, printing and publishing | *3308,55* | 1% | ***42%*** | 2% | 5% | 8% | 3% | 13% | 3% | 23% |
| DE | Chemicals and Pharmaceuticals | *71838,9* | 1% | ***45%*** | 0% | 5% | 7% | 2% | 13% | 2% | 26% |
| DE | Rubber and Plastics | *72381,9* | 1% | ***45%*** | 0% | 5% | 7% | 2% | 13% | 2% | 25% |
| DE | Other non metallic mineral products | *75571,6* | 1% | ***45%*** | 0% | 5% | 7% | 2% | 13% | 2% | 25% |
| DE | Basic metals and fabricated metals products | *90278* | 1% | ***46%*** | 0% | 6% | 7% | 3% | 12% | 2% | 23% |
| DE | Machinery and Equipment | *95527* | 1% | ***44%*** | 0% | 6% | 7% | 3% | 13% | 2% | 24% |
| DE | Electrical and Optical Equipment | *102156* | 1% | ***38%*** | 2% | 7% | 6% | 4% | 16% | 3% | 24% |
| DE | Transport Equipment | *18877,4* | 0% | ***48%*** | 0% | 10% | 7% | 5% | 14% | 2% | 13% |
| UK | Food, beverages and tobacco | *2176,5* | 2% | 8% | 0% | 4% | ***30%*** | 1% | 7% | 6% | 41% |
| UK | Textiles, leather and footwear | *386* | 1% | 14% | 1% | 7% | ***37%*** | 5% | 11% | 0% | 24% |
| UK | Wood and Cork | *89,2* | 2% | 26% | 0% | 9% | ***32%*** | 6% | 3% | 4% | 18% |
| UK | Pulp, paper, printing and publishing | *1222,65* | 1% | 13% | 1% | 6% | ***36%*** | 3% | 14% | 3% | 24% |
| UK | Chemicals and Pharmaceuticals | *31509,1* | 1% | 10% | 0% | 5% | ***36%*** | 2% | 9% | 3% | 33% |
| UK | Rubber and Plastics | *172* | 1% | 11% | 0% | 7% | ***33%*** | 6% | 17% | 2% | 24% |
| UK | Other non metallic mineral products | *1054,65* | 1% | 18% | 1% | 10% | ***30%*** | 3% | 10% | 2% | 24% |
| UK | Basic metals and fabricated metals products | *3427,45* | 1% | 19% | 0% | 8% | ***37%*** | 4% | 7% | 4% | 20% |
| UK | Machinery and Equipment | *3476,5* | 1% | 5% | 0% | 3% | ***18%*** | 1% | 25% | 2% | 46% |
| UK | Electrical and Optical Equipment | *33799,6* | 1% | 11% | 2% | 6% | ***27%*** | 2% | 14% | 3% | 32% |
| UK | Transport Equipment | *36616,9* | 1% | 12% | 2% | 6% | ***28%*** | 3% | 14% | 3% | 31% |

## 4.2 R&D Capital Stock

Total business enterprise expenditure on R&D at industry level comes from OECD-ANBERD (2005) dataset. We convert the R&D flows, valued in US purchasing power parity,
into constant 1995 prices. The deflators used for that are output deflators. The output deflators are derived from figures on value-added both in current as well as constant 1995 prices, both included in the OECD STAN-Industry database. The R&D capital stocks are then estimated using the perpetual inventory method:

$$R\&D\_S_t = (1-\delta)\ R\&D\_S_{t-1} + R\&DV_t\ , \quad t = 2,\ldots\ldots,16 \qquad (11).$$

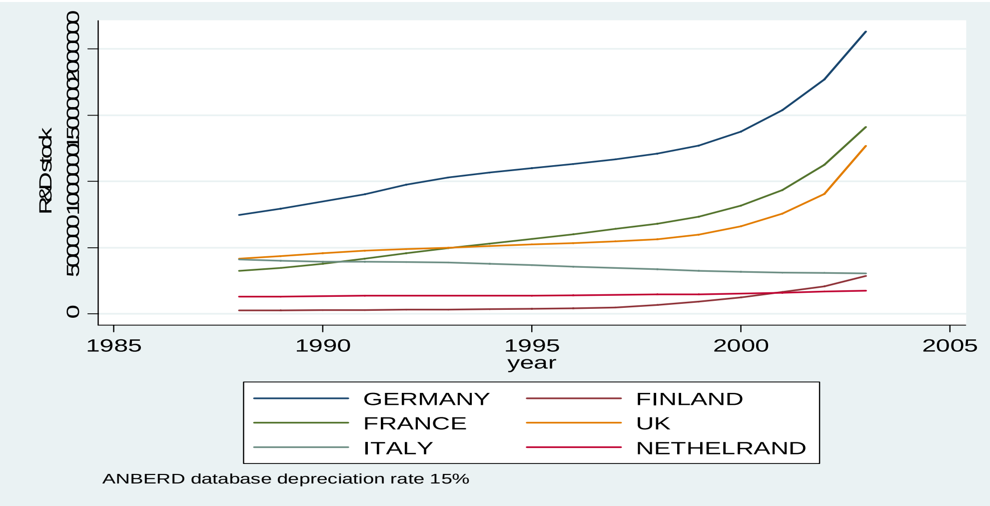
R&D_S denotes the R&D capital stock in the business sector and R&DV is business sector R&D expenditure in constant 1995 prices valued at US purchasing power parity. The rate of depreciation δ is set at 0.15[22]. The benchmarks are calculated as:

$R\&D\_S_{1988} = R\&DV_{1988}/(\,g_v + \delta)$

$g_v$ is the annual average logarithmic growth rate of R&D spending over the period 1988-2003, i.e., $g_v = \log(R\&D_{2003}/R\&D_{1988})/15$.

Figure 3 shows the R&D stocks for six European countries: in particular it is worthwhile to note that as time goes by all the countries but Italy are characterized by increasing R&D stocks.

**Figure 3. R&D stocks by country**




[22] We also use different rates of depreciation such as 8%, 10%, 12%, but the results do not change.

# 5. Empirical results

In the first part of this section we estimate a simple static knowledge production function. We use different measures of foreign R&D capital stock to evaluate the relative performance of different proxies for knowledge flows.

## 5.1 Descriptive statistics

Table 3 shows average values (yearly) of the main variables we use in the econometric analysis. As we can see, Germany has the greatest values for all the values, nevertheless it is interesting to note the sensible number of foreign co-inventors for UK, with the highest number of co-inventors per patent. Moreover, France has the greatest number of citations per patent.

**Table 3. Descriptive statistics: average values (yearly) by countries**

| Country | patents | R&D domestic stock | Co-inventors | citations | total imports |
|---|---|---|---|---|---|
| GERMANY | *1424.729* | *13533.42* | *160.8446* | *746.5668* | *1.51e+07* |
| FINLAND | *78.54063* | *910.706* | *10.08636* | *52.32443* | *1118451* |
| FRANCE | *528.521* | *7431.55* | *102.7247* | *373.1335* | *1.17e+07* |
| ITALY | *256.3639* | *4076.256* | *35.6733* | *164.4634* | *8663268* |
| NETHERLAND | *210.0713* | *1647.24* | *54.82955* | *161.9091* | *6257028* |
| UK | *414.1693* | *7349.762* | *150.1705* | *313.546* | *1.22e+07* |

## 5.2 Baseline model

We start estimating equation (6) using Fixed Effect. As it is well known FE is less efficient than RE because it uses only the variation in the data within each group (country-industry) through time. However the group specific component in the error term is plausibly correlated with a group' strategy in terms of patenting activity, implying that the RE estimates are inconsistent with the assumption of zero correlation between regressors and error term.

Heteroskedasticity robust standard errors are applied. We take the log to have the variables more closely distributed to normality and estimated coefficients expressed in terms of elasticity. In all the specifications we also include time dummies to control for economic changes that indifferently impact on all the countries and sectors.

As shown in Table 4 and consistent with previous literature, domestic R&D capital stock is the most important variable in explaining domestic innovative activity. Moreover all the specifications explain more than 97% of the variation in international patenting. Column 2 provides evidence of positive spillovers from the foreign R&D capital stock. The total foreign R&D is statistically significant at 1 percent level: an increase of 1% of in total foreign R&D stock increases by 0.033% the innovative activity in terms of international patenting. In columns 3-5 we look at different specifications with three different measures of foreign R&D capital stock. In column 3, the foreign R&D capital stock weighted by bilateral patent citations shares is statistically significant at 1 percent level with an estimated elasticity of 0.042%, greater than the simply foreign R&D stock. Moreover column 4 shows co-inventorship patterns are relevant channels of knowledge flows: the estimated coefficient is less than the previous channel but positive (0.013) and significant at 5% level. This late result could be seen as consistent with the fact that citations and co-inventor relationships measure different kind of knowledge flows. In column 5, the foreign R&D stock weighted by bilateral import shares has not a significant and positive impact on international patenting. Finally, trade (measured by bilateral import) has not a significant impact on the production of knowledge. This is not a surprising result if we underline the fact that in literature scholars emphasize the role of trade on technology diffusion evaluating the effect on productivity (in particular, Total Factor Productivity) and not on the production of innovative ideas. For this reason we run an auxiliary regression where the dependent variable is a measure of productivity (Total Factor Productivity) and not the international patenting[23]. Finally in column 6 we test the robustness of our results running a Fixed Effect Negative Binomial in order to take into account that patents are a count variable (non negative). The previous results do not change substantially: we find evidence of international knowledge spillover through pattern of citations and co-inventorship.

[23] See Appendix 6 for details on TFP construction

**Table 4. Spillover determinants of patents (robust standard errors in parenthesis)**

| | (1) WITHIN | (2) WITHIN | (3) WITHIN | (4) WITHIN | (5) WITHIN | (6) FE Negative Binomial | (7) WITHIN |
|---|---|---|---|---|---|---|---|
| Dependent variable: | Log (patents) | Log (patents) | Log (patents) | Log (patents) | Log (patents) | Number of patents | Log (TFP) |
| Domestic R&D | *0.11**** | *0.056** | *0.10**** | *0.10**** | *0.10**** | *0.11**** | *0.371**** |
| | *(0.026)* | *(0.032)* | *(0.029)* | *(0.029)* | *(0.029)* | *(0.020)* | *(0.048)* |
| Foreign R&D_TOT | | *0.033**** | | | | | |
| | | *(0.0065)* | | | | | |
| Foreign R&D_CIT | | | *0.042**** | *0.041**** | *0.040**** | *0.017*** | *.008* |
| | | | *(0.015)* | *(0.015)* | *(0.015)* | *(0.0084)* | *.005* |
| Foreign R&D_CO-INV | | | | *0.013*** | *0.013*** | *0.0082*** | *.002* |
| | | | | *(0.0058)* | *(0.0058)* | *(0.0041)* | *.003* |
| Foreign R&D_TRADE | | | | | *-0.037* | *-0.032* | *0.067** |
| | | | | | *(0.030)* | *(0.025)* | *(0.035)* |
| Constant | *6.42**** | *1.09**** | *2.28**** | *2.26**** | *2.44**** | *2.52**** | *3.63**** |
| | *(0.28)* | *(0.27)* | *(0.30)* | *(0.30)* | *(0.30)* | *(0.21)* | *.245* |
| Year dummies | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* |
| Observations | *1044* | *984* | *984* | *984* | *984* | *984* | *940* |
| Cross-sections | *66* | *66* | *66* | *66* | *66* | *66* | *66* |
| total R square | *0.978* | *0.979* | *0.979* | *0.979* | *0.979* | - | *0.5557* |

Robust standard errors in parentheses
All variables in logarithms
*** p<0.01, ** p<0.05, * p<0.1
R&D depreciation rate 15%

## 5.3 Differences across countries and sectors

Differences across countries and sectors are displayed in table 5. First of all, as pointed out by literature, the greater is the distance from the technological frontier, the greater is the benefit from external knowledge: in the column 1 and column 2 we report estimated elasticity of international spillovers for countries characterized by more R&D expenditures (Germany, France, and UK) and for other countries, that is Finland, Italy and Netherland. We find positive and significant international spillovers only for the second group. Second, we run two separate regressions for two different groups of technologies, finding that the effects of domestic R&D and international spillovers differ across sectors. In sector with a low share of patents (Food, Textile, Wood, Paper, Basic metals) domestic R&D do not appear to have any positive impact on new knowledge creation: only the spillover measured through citations has a positive impact with an estimated elasticity of 0.051. On the other side in industries with a greater share of patents (Chemical and Pharmaceutical, Plastics, Machinery, Electronics and Transport) R&D domestic appear to be the engine for creation of new Knowledge: an increase of 1% in domestic R&D stock increases by 0.91% the innovative activity in terms of international patenting.

**Table 5. Differences across countries and sectors (robust standard errors in parenthesis)**

| | (1) WITHIN Germany, France and UK | (2) WITHIN Finland, Italy and Netherland | (3) WITHIN Food, Textile, Wood, Paper, Basic metals, Other non metallic mineral | (4) WITHIN Chemical and Pharma, Plastics, Machinery, Electronics, Transport |
|---|---|---|---|---|
| Dependent variable: | Log (patents) | Log (patents) | Log (patents) | Log (patents) |
| Domestic R&D | *0.14**** | *0.10**** | *-0.040* | *0.091*** |
| | *(0.035)* | *(0.038)* | *(0.037)* | *(0.036)* |
| Foreign R&D_CIT | *-0.0090* | *0.049**** | *0.051**** | *0.031* |
| | *(0.013)* | *(0.017)* | *(0.015)* | *(0.021)* |
| Foreign R&D_CO-INV | *-0.0069* | *0.017*** | *0.0059* | *0.019*** |
| | *(0.0066)* | *(0.0076)* | *(0.0059)* | *(0.0094)* |
| Foreign R&D_TRADE | *-0.063*** | *-0.058* | *-0.026* | *0.034* |
| | *(0.031)* | *(0.051)* | *(0.051)* | *(0.038)* |
| Constant | *5.76**** | *4.70**** | *7.81**** | *4.16**** |
| | *(0.38)* | *(0.66)* | *(0.43)* | *(0.56)* |
| Year dummies | *Yes* | *Yes* | *Yes* | *Yes* |
| Observations | *492* | *492* | *504* | *480* |
| Cross-sections | *33* | *33* | *36* | *30* |
| total R square | *0.990* | *0.964* | *0.982* | *0.978* |

Robust standard errors in parentheses
All variables in logarithms

*** $p<0.01$, ** $p<0.05$, * $p<0.1$
R&D depreciation rate 15%

## 5.4 First Robustness check

Because we are interested in the long-run relationship between foreign R&D and patenting activity, we diminish the time variation on the panel by calculating the mean for all variables every 4 years. Then we run the same specification as before (6).

Results are displayed in Appendix 5. Results do not change substantially even if co-inventors-weighted R&D is no more significant: the elasticity of domestic R&D is more or less the same as well as trade-weighted R&D which remains not significant. It is worthwhile to note that the coefficient associated to the spillover measured by citation is greater than the baseline case: in particular a 1% increase in citation-weighted R&D generates around 0.07% increase in the domestic innovative output.

## 5.5 Stationarity issues and dynamic panel

The results for tests for unit roots are displayed in Table 6. Because we have some missing values for a few sector in some years we have un unbalanced panel. We therefore use the Fisher method which was proposed by Maddala and Wu (1999). As Table 6 shows unit root tests rejected the hypothesis for all time series but foreign R&D weighted by bilateral trade share, which proved to be trend stationary.

**Table 6. Results for the Fisher-type unit root test for panel data**

| Variable | $P_\lambda$-Statistic | P-Value |
|---|---|---|
| Patents | *238.3752* | *0.0012* |
| Domestic R&D | *256.4323* | *0.0000* |
| Foreign R&D_CIT | *328.9808* | *0.0000* |
| Foreign R&D_CO-INV | *373.1872* | *0.0000* |
| Foreign R&D_TRADE | *160.6304* | *0.7906* |

**1 lag and trend included; all variables are in Log**

Because of the persistence of patenting activity over year (cumulative and past-dependent process) we present an alternative specification which includes a lagged dependent variable. Accordingly we assume that the production of patents is an AR(1) process.

We concentrate on stationary variables and we have therefore the following dynamic specification:

$$\ln P_{h,j,t} = a_0 P_{h,j,t-1} + a_1 \ln R_{h,j,t} + \beta_1 \ln IS_1 + \beta_2 \ln IS_2 + \beta_3 \ln IS_3 + \theta_t + \varsigma_{h,j,t} \quad (12)$$

One implication of model (12) is that the lagged dependent variable is correlated with the idiosyncratic disturbance - even if the disturbance is itself not serial correlated – because of a possible bias by the omitted individual specific effects (Greene, 2003).

The Ordinary Least Squares (OLS) estimator of $\alpha_0$ in the equation (11) is inconsistent, since the explanatory variable is positively correlated with the error term due to the presence of the individual effects. We follow two different procedures.

First, the Within Group estimator eliminates this source of inconsistency by transforming the equation in order to eliminate the individual (country-sector) effect $\eta_{h,j}$. Specifically the mean values of the variables are calculated across the T-1 observations for each unit, and the original observations are expressed as deviations from these means. Since the mean of the time invariant $\eta_{h,j}$ is itself $\eta_{h,j}$, these individual effect are eliminated. Then we use OLS to estimate the transformed equation. Nevertheless this transformation induces a possible correlation between the transformed lagged dependent variable and the transformed error term, especially in panels where the number of time periods available is small, so that the WITHIN estimator could be also inconsistent (Bond, 2002).

**Table 7. DOLS. Dep. Variable Log of Patents**

| COEFFICIENT | (1) WHITIN | (2) GMM |
|---|---|---|
| Log(patents) t-1 | *0.48**** | *0.84**** |
| | *(0.03)* | *(0.13)* |
| Domestic R&D | *0.03* | *0.11* |
| | *(0.03)* | *(0.09)* |
| Foreign R&D_CIT | *0.02**** | *0.02*** |
| | *(0.01)* | *(0.01)* |
| Foreign R&D_CO-INV | *0.01*** | *0.01*** |
| | *(0.00)* | *(0.01)* |
| Constant | *2.21**** | *-0.17* |
| | *(0.24)* | *(0.11)* |
| Observations | *918* | *918* |
| Number of i | *66* | *66* |
| Year dummies | *Yes* | *Yes* |
| R-squared | *0.652* | . |
| sarganp | . | *0.19* |
| sargan | . | *6.14* |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
For GMM: 14th, 15th and 16th lag of dependent variable are used; other variables serve as their instruments. System GMM

Second, in order to obtain consistent estimates, we apply GMM-system where sequential moment conditions are used and lagged variables of the dependent variable are instruments. The choice of lag structure depends crucially on the standard tests for the quality of the instruments. In particular, in Table 7 we report the P-value of Hansen's J-Statistic of overidentifying restrictions. Some experiments indicate that distant lags ($14^{th}$ -$16^{th}$) provide valid instrument for past patenting activity.

Results are displayed in Table 7. Our findings suggest that indeed it is important to control for a lagged dependent variable that is always statistically significant: international patenting seems to be a cumulative and past-dependent process. Moreover the estimated coefficients (within and GMM) indicate that the spillover effects measured both by citations and co-inventorship are still positive and statistically significant: this result is important because it emphasises the role played in international technological transmission by collaboration and person-to-person contact.

# 6. Conclusions

We use international patent applications at the European Patent Office (EPO) as proxy of innovation and technology productivity for 6 European countries (France, Finland, Germany, Italy, Netherland and UK) and estimate the elasticity of innovation to domestic and foreign R&D, emphasizing different channels of knowledge flows. Analysing a panel data set at industry level, with 6 European countries from 1988 to 2003, we find evidence of foreign technological spillover effect, where spillovers are measured by patterns of citations, co-inventors and bilateral imports. In particular, foreign R&D capital stock weighted by bilateral patent citations share is statistically significant at 1 percent level with an estimated elasticity of 0.042%, while the co-inventors channel has an elasticity of 0.013. These externalities we estimate could be respectively the results of diffusion of codified (by citations) and non-codified (by co-inventors) knowledge between people and country.

Moreover we estimate the effect of bilateral imports on innovative activity and find a non significant effect. However the behaviour of bilateral imports should not surprise because additional estimates show a positive effect of trade on Total Factor Productivity (TFP): a 1% increase in R&D spending abroad raises TFP of 0,067%.

We then estimate an alternative specification which takes into account the dynamic of patenting activity due to the cumulative and past-dependent process. The estimated coefficients (within and

GMM) indicate that the spillover effects measured both by citations and co-inventorship are still positive and statistically significant: this result is important because it emphasises the role played in international technological transmission by collaboration and person-to-person contact.

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# APPENDIX

**Appendix 1. COINV matrix for Germany and Uk: share by countries and sectors (years 1988-2003)**

| Country | Sector | TOTAL_inv | CA_share | DE_share | FI_share | FR_share | GB_share | IT_share | JP_share | NL_share | US_share |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DE | Food, beverages and tobacco | *8661,8* | 0% | ***89%*** | 0% | 2% | 1% | 0% | 0% | 2% | 6% |
| DE | Textiles, leather and footwear | *13420,2* | 0% | ***91%*** | 0% | 1% | 1% | 0% | 0% | 1% | 5% |
| DE | Wood and Cork | *2088* | 0% | ***99%*** | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| DE | Pulp, paper, printing and publishing | *10126,5* | 0% | ***94%*** | 0% | 0% | 1% | 0% | 0% | 1% | 3% |
| DE | Chemicals and Pharmaceuticals | *168227,7* | 0% | ***93%*** | 0% | 1% | 1% | 0% | 1% | 1% | 4% |
| DE | Rubber and Plastics | *169878,5* | 0% | ***93%*** | 0% | 1% | 1% | 0% | 1% | 1% | 4% |
| DE | Other non metallic mineral products | *180222,85* | 0% | ***93%*** | 0% | 1% | 1% | 0% | 1% | 1% | 3% |
| DE | Basic metals and fabricated metals products | *230194,75* | 0% | ***94%*** | 0% | 1% | 1% | 0% | 1% | 0% | 3% |
| DE | Machinery and Equipment | *247508,75* | 0% | ***94%*** | 0% | 1% | 1% | 0% | 1% | 0% | 3% |
| DE | Electrical and Optical Equipment | *273575,4* | 0% | ***96%*** | 0% | 1% | 0% | 0% | 0% | 0% | 2% |
| DE | Transport Equipment | *61798,1* | 0% | ***97%*** | 0% | 1% | 0% | 0% | 0% | 0% | 1% |
| UK | Food, beverages and tobacco | *5412,6* | 1% | 3% | 0% | 2% | ***74%*** | 0% | 0% | 4% | 16% |
| UK | Textiles, leather and footwear | *1098* | 0% | 3% | 0% | 1% | ***90%*** | 0% | 0% | 0% | 5% |
| UK | Wood and Cork | *400,4* | 0% | 2% | 0% | 0% | ***94%*** | 0% | 0% | 1% | 3% |
| UK | Pulp, paper, printing and publishing | *2966,25* | 1% | 2% | 1% | 0% | ***88%*** | 0% | 0% | 1% | 6% |
| UK | Chemicals and Pharmaceuticals | *55885,25* | 1% | 4% | 0% | 2% | ***79%*** | 1% | 1% | 1% | 12% |
| UK | Rubber and Plastics | *537,9* | 0% | 1% | 0% | 1% | ***91%*** | 0% | 0% | 1% | 6% |
| UK | Other non metallic mineral products | *2655,2* | 0% | 3% | 0% | 1% | ***89%*** | 1% | 0% | 1% | 5% |
| UK | Basic metals and fabricated metals products | *10087,4* | 0% | 2% | 0% | 1% | ***90%*** | 0% | 0% | 1% | 6% |
| UK | Machinery and Equipment | *10132,5* | 0% | 1% | 0% | 1% | ***82%*** | 0% | 1% | 0% | 14% |
| UK | Electrical and Optical Equipment | *72445,35* | 1% | 2% | 0% | 1% | ***88%*** | 0% | 1% | 0% | 7% |
| UK | Transport Equipment | *79055,95* | 1% | 2% | 0% | 1% | ***88%*** | 0% | 1% | 0% | 7% |

**Appendix 2. Variables, Definitions and Sources**

| *Variable* | *Definition* | *Source* |
|---|---|---|
| International Patenting | | |
| $Patents_{i,j,t}$ | Patent applications in country i, sector j and year t | Epo-Cespri Database |
| Ideas production function inputs and spillover | | |
| R&D Capital Stock | Millions of current PPP dollars, deflated Measured as stock: $R_{f,j,t} = (1-\delta)R_{f,j,t-1} + R^{flow}_{f,j,t-1}$ | Anberd – Oecd Data |
| Foreign R&D Capital Stock | $\sum_{i \neq j} \lambda_{i,j,k,t} R\&D_{i,k,t}$ <br> $\lambda_1$ = relative number of citations flowing from country i to a foreign country j, in sector k at time t. <br> $\lambda_2$ = relative number of co-inventors from country i for patents of country j, in sector k at time t. <br> $\lambda_3$ =bilateral import share, in sector k at time t. | |
| Macroeconomic variables | | |
| Bilateral Imports | | Oecd Stan Database |
| Countries: | France, Germany, Uk, Italy, Finland, Netherlands (and Canada, Japan, US) | |
| Sectors: | Food, beverages and tobacco; Textiles, leather and footwear; Wood and cork; Pulp, paper, printing and publishing; Chemicals and pharmaceuticals; Rubber and plastics; Other non metallic mineral products; Basic metals and fabricated metals products; Machinery and equipment; Electrical and optical equipment; Transport equipment | |

**Appendix 3. Correlation matrix**

| | log (patents) | Domestic R&D | Total foreign R&D | Foreign R&D_citations | Foreign R&D_co-inventors | Foreign R&D_trade |
|---|---|---|---|---|---|---|
| log (patents) | *1* | | | | | |
| Domestic R&D | *0.8074** | *1* | | | | |
| Total foreign R&D | *0.6415** | *0.7430** | *1* | | | |
| Foreign R&D_citations | *0.5368** | *0.4122** | *0.5490** | *1* | | |
| Foreign R&D_co-inventors | *0.5792** | *0.4168** | *0.4590** | *0.5779** | *1* | |
| Foreign R&D_trade | *0.5281** | *0.6180** | *0.8939** | *0.4856** | *0.5540** | *1* |

**Appendix 4. Concordance table**

| *Isic (rev.2)* | *Isic (rev.3)* | *sector (aggregation)* |
|---|---|---|
| 310 | 15, 16 | FOOD, BEVERAGES AND TOBACCO |
| 320 | 17, 18, 19 | TEXTILES, LEATHER AND FOOTWEAR |
| 330 | 20 | WOOD AND CORK |
| 340 | 21, 22 | PULP, PAPER, PAPER PRODUCTS, PRINTING AND PUBLISHING |
| 351, 352 | 24 | CHEMICALS AND PHARMACEUTICALS |
| 355, 356 | 25 | RUBBER AND PLASTICS |
| 360 | 26 | OTHER NON METALLIC MINERALS PRODUCT |
| 370, 381 | 27, 28 | BASIC METALS AND METAL PRODUCTS |
| 3825 | 29 | MACHINERY AND COMPUTER |
| 382, 383, 385 | 30, 31, 32, 33 | ELECTRICAL AND OPTICAL EQUIPMENT |
| 384 | 34, 35 | TRANSPORTATION |

## Appendix 5. Robustness Check: average values (4 years)

| COEFFICIENT | (1)<br>model1<br>M_log_pa | (2)<br>model2<br>M_log_pa | (3)<br>model3<br>M_log_pa | (4)<br>model4<br>M_log_pa |
|---|---|---|---|---|
| M_Domestic_RD | *0.12*** | *0.12*** | *0.12*** | *0.12*** |
| | *(0.054)* | *(0.055)* | *(0.055)* | *(0.056)* |
| M_RD_estero_cit | | *0.072*** | *0.072*** | *0.072*** |
| | | *(0.033)* | *(0.033)* | *(0.034)* |
| M_RD_estero_coinv | | | *0.0090* | *0.0089* |
| | | | *(0.014)* | *(0.014)* |
| M_RD_estero_trade | | | | *-0.026* |
| | | | | *(0.064)* |
| Constant | *3.99**** | *3.65**** | *3.63**** | *3.80**** |
| | *(0.39)* | *(0.41)* | *(0.42)* | *(0.60)* |
| Observations | *241* | *241* | *241* | *241* |
| R-squared | *0.992* | *0.992* | *0.992* | *0.992* |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
All variables are in logaritm.R&D depreciation rate 15%

## Appendix 6. Total Factor Productivity

Since the TFP variable is not available, we have to construct it by using labour, physical capital and value-added data. For these variables the OECD STAN (2005) database is the basic source. It provides internationally comparable data on industrial activity by sectors. This dataset includes data on labour input, labour compensation, investment, production and value-added for up to 49 3-digit ISIC industries (revision 3). The STAN figures are not the submissions of member countries to the OECD, but the OECD estimates based on them. In particular, the OECD has tried to ensure greater international comparability.

In constructing the TFP variable, we consider only inputs of labour and physical capital (unfortunately there is no data on human capital by industry). Data on labour inputs is taken directly from the STAN database (total number of workers engaged). This variable of labour input includes employees, the self-employed, owner proprietors and unpaid family workers.

The physical capital stock data is not available in the STAN database. To construct it we use the gross fixed capital formation data in current prices. We first convert the investment flows into constant 1995 prices. The deflators are derived from figures on value-added both in current and costant 1995 prices, both included in the STAN database. The capital stocks are then estimated using the perpetual inventory method:

$K_t = (1-\delta) K_{t-1} + INV_{t-1}, \quad t = 2,........,16$

K is the physical capital stock, INV is gross fixed capital formation deflated (land, buildings, machinery and equipment) and δ the capital depreciation rate. The benchmarks are calculated as:

$K_{1988} = INV_{1988}/(g_{inv}+\delta)$

$g_{inv}$ is the annual average logarithmic growth rate of INV over the period 1988-2003, i.e., $g_v = \log(INV_{2003}/INV_{1988})/15$. We use country-specific depreciation rate, taken from Jorgenson and Landau (1993), Table A-3: Canada: 8.51%, France: 17.39%, Germany: 17.4%, Italy: 11.9%, United Kingdom: 8.19% and the United States with 13.31%. These numbers which are used throughout, are estimates for machinery in manufacturing in the year 1980. For Finland and Netherlands the depreciation rate is set at 8%. We assume a capital rate of depreciation constant over industries. Finally, the labour share of income is calculated as ratio of total labour compensation to value-added (revenue based factor share), both included in the STAN database.

# Inventing Together: Exploring the Nature of International Knowledge Spillovers in Latin America

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**Abstract**

This paper studies the nature, sources and determinants of international patenting activity in Latin American countries (LACs) and examines the extent to which LACs benefit from R&D that is performed in the G-5 countries (France, Germany, Japan, United Kingdom, and United States). By using patents and patent citations at the United States Patent and Trademark Office we trace intra-sectoral knowledge flows from G-5 countries to LACs. We study the impact of three channels of spillovers: pure spillovers, patent citations related spillovers, and face-to-face contact spillovers. Our results, based on data for Argentina, Brazil, Chile, Colombia, and Mexico, suggest that international knowledge spillovers from the G-5 countries are a significant determinant of inventive activity over the period 1988-2003. In particular we find that the stock of ideas produced in the US has a strong impact on the international patenting activity of these countries. Moreover controlling for US-driven pure spillover effects, bilateral patent citations and face-to-face relationships between inventors are both important additional mechanisms of knowledge transmission. Some of our results suggest that the latter mechanism is more important than the former.

**Jel Codes:** O30, O10, O11

**Keywords:** Innovation, R&D Spillover, Knowledge flows, Latin America, Patents, Citations, Inventors

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# 1. Introduction

The international flows of technological knowledge affect importantly developing countries' ability to learn and innovate. Knowledge transmission from developed countries creates the conditions for developing countries to catch up with the technological frontier, on the contrary technological isolation slows down the development process and is conducive to technological and economic divergence. This paper studies the importance of patents and inter-personal links for technology diffusion across countries and asks to what extent international technology spillovers are mainly driven not only by the free flow of knowledge but also by interpersonal links and face-to-face contacts across countries.

This has important policy implications. If international interpersonal links and person-to-person contacts play a prominent role in fostering innovative domestic capacity, R&D subsidies could be effective only as long as they favour the international expansion of the network relations of local inventors. This has relevant implications for the effectiveness of science and technology policies.

This paper is one of the first attempts to extend the economic analysis of R&D knowledge spillovers (at country and industry level) to developing countries and investigates empirically the determinants of the international patent production in a selected number of Latin American countries (LACs). We ask whether foreign R&D activity affects innovative performance of LACs at industry level via different channels of international knowledge flows. In particular we focus on three mechanisms: pure spillovers, patent citations related spillovers, and face-to-face contact spillovers based on co-inventorship relations[24]. Of course there are also other important channels of technological transmission we do not deal with, such as FDIs and bilateral trade. These channels affect in particular countries' total factor productivity.

However we are interested in studying whether the *international patenting activity* of LACs responds to international knowledge flows and we measure knowledge flows using patent citations and analysing the network of co-inventors from the patent documents. Assuming that inventors listed on the same patent know each other, if knowledge has at least a degree of tacitness we expect a positive effect on innovative activity of personal contacts. This in turn implies that the international mobility of inventors may play a crucial role in domestic innovative performance.

We use data for five big industrial sectors (Textile and Food, Chemicals and Pharmaceuticals, Metals, Instruments Electronic and Non-Electrical Machinery, and Transportation), five Latin American countries (Argentina, Brazil, Chile, Colombia and Mexico) and the G-5 countries (France Germany,

[24] Keller (2004) provides a survey of the literature on international technology diffusion. Among others, Coe et al. (1997) find empirical evidence that total factor productivity in developing countries is positively related to R&D preformed in industrialized countries and that the flows of knowledge is captured by bilateral trade.

Japan, UK and US) in the years between 1988 and 2003. We process the information contained in the US Patent and Trademark Office (USPTO) patent documents and their citations to build the different indexes of R&D spillovers. Also we match USPTO patent data with economic data taken from different sources at the sectoral level and control for the dynamics of domestic value added and past innovative activity.

Overall this paper provides a detailed account of the nature, sources and determinants of international patenting activity in Latin American countries at the descriptive level. We show that a large part of the Latin American invented patents belong to foreign companies with a foreign address or to a foreign subsidiary with a Latin American address, and top applicants at the USPTO and EPO are mainly US and German multinationals and the big Latin American patenters are active in a set of heterogeneous sectors of activity that are not considered very R&D intensive (e.g. Oil, Glass, Electric, Metals and Machinery). Secondly the econometric analysis shows that international knowledge spillovers from the G-5 countries are a significant determinant of inventive activity in the period considered. In particular we find that, controlling for pure spillovers effects, bilateral patent citations and face-to-face relationships between inventors are both important *additional* mechanisms of knowledge transmission. Some of our results suggest that the latter is more important than the former.

The reminder of the paper is as follows. In Section 2 we provide a quick overview of the theoretical background of this study and justify the use of patent-based data to measure knowledge spillovers. In Section 3 we perform a descriptive analysis of the international patent activity in Latin American countries and network of knowledge relations across countries using patent citations and co-inventorship behaviours. To have a clearer picture we use data from different sources (i.e. the US *and* European Patent Office). In Section 4 we construct our empirical model and in Section 5 we describe the data we will use and our empirical strategy. More details are provided in the Appendix. Section 6 reports the main results from the estimation of different econometric specifications. In the last Section we conclude, discuss some important limitations and propose some directions for future work.

## 2. Background

This paper extends the current studies on the economic impact of knowledge spillovers to developing countries and in particular to Latin American countries. We assess directly the determinants of innovative activity using a knowledge production function (KPF) (Pakes and Griliches 1984). The KPF is a methodological tool that tries to map research efforts into new knowledge. In the KPF baseline version, patent counts are used to approximate the production of new knowledge and R&D expenditure measures the R&D effort. However in dealing with developing country external sources of knowledge - that originates spillover or is transferred to developing countries - are particularly important. Actually much of the current debate about technology policy in developing countries is based on the assumption that a country's innovative performance depends significantly on its relative technological capacities, ability to absorb foreign (costly and specialized) knowledge and learn how to adapt it to local needs (Cimoli et al. 2005; Dosi and Cimoli, 1995).

There is a vast literature that assesses international knowledge spillovers among developed countries[25]. Estimated international R&D spillovers effects are typically significant and positive[26]. Recent empirical works show that extremely relevant sectoral knowledge flows cross national borders (Malerba et al. 2007). Bottazzi and Peri (2007) find that internationally generated ideas affect significantly innovation in a country. Branstetter (2006) uses a patent function to estimate firm level spillovers. Based on a panel of 205 firms in five high R&D/sales ratio industries in the period 1985-1989, he provides strong evidence for Japanese intra-national knowledge spillovers and limited evidence that Japanese firms benefit from knowledge produced by American firms[27].

In the case of developing country there is a large literature on the microeconomic effects of FDIs spillovers on total factor productivity[28] but still there is scant aggregate evidence of R&D spillovers on countries' innovative output at sectoral and national level. This paper focuses on two specific vehicles of knowledge spillovers: patent citations and collaboration via co-inventorship.

### *Patent citations as channel of knowledge flows*

Patent citations are included in a patent document to delimit the scope of the property right and mention the relevant prior art. Citations are particularly reliable because they have a legal value. If patent A cites patent B it can be reasonably assumed that B is a technological antecedent of A and that the knowledge embedded in B has been developed by A. Albert et al. (1991) and Trajtenberg (1990) are among the first scholars who empirically demonstrated that highly cited patents have higher

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25 Three channels of knowledge spillovers are typically emphasized: international trade that assures free access to knowledge embodied in imported goods (Coe and Helpman 1995) and knowledge in global export markets through "learning by exporting" (Bernard and Jensen 1999) and the contact with advanced foreign firms; labour mobility that is source of knowledge exchange because workers are endowed with specific know-how (Rhee 1990, Pesola, 2007); and finally foreign direct investment (Blomstrom and Kokko 1998, Aitken and Harrison 1999, Crespo and Fontoura 2007) represents an important source of technological spillovers although the empirical evidence remains mixed with regards to the distributions of benefits between the multinational and domestic companies (Katrak 2002).

26 Some recent empirical works have analyzed whether knowledge flows cross national borders in a knowledge production framework (KPF) in order to test the existence of international spillover. Bottazzi and Peri (2003) estimate the elasticity of innovation to R&D done in other regions at various distance, finding that the effects of R&D in generating innovation are quite localized (see also Keller 2002, Maruseth and Verspagen 2002, Peri 2005).

27 For a survey see also Breschi et al. 2005.

28 For a survey see also de Mello (1997)

economic and technological importance. If a patent is cited it can also generate technological spillovers. Jaffe et al. (2000) tested this conjecture using USPTO patents and surveyed approx 380 citing and cited inventors. Their results suggest that "communication between inventors is reasonably important, and that patent citations do provide an indication of communication, albeit one that also carries a fair amount of noise" (p. 215). In addition a consolidate stream of literature uses patent citations to track knowledge flows and spillovers (Jaffe et al. 1993, Jaffe and Trajtenberg 1996, Jaffe and Trajtenberg, 1999; Maurseth and Verspagen 2002, Malerba and Montobbio 2003, Peri 2005).
Provided that knowledge flows are inherently difficult to measure and that is often problematic to assess the relevance of the source of knowledge and to evaluate the direction and the impact of the generated knowledge, patent citations have been often used to identify the direction of these knowledge spillovers among countries. If, for example, a patent with an inventor's address from Argentina cites a patent with an inventor's address in US, we could assume that some knowledge created in the US has been used in Argentina and as a result patent citations could track the direction of knowledge spillovers among the two inventors and the two countries.

### *Patent co-inventors as channel of knowledge flows*

The second major channel of knowledge transfer we consider in this paper passes through collaborations and face to face contacts. Processes of knowledge creation are importantly affected by the inventors' community and network relationships (Breschi and Lissoni 2001). Similarly research collaborations create fundamental social networks, in particular for developing countries: inventors that have studied or worked abroad, not only benefit from the high standard of top international universities and companies, but also continue to rely on free information in subsequent research projects after the collaboration itself is finished. Therefore research collaborations can indicate relational proximity and capture the spillover stemming from collaboration networks between regions and countries (Hoekman et al. 2008).
Singh (2005) has examined whether social networks of inventors are a significant mechanism for diffusion of knowledge and found that the existence of co-inventorship relations is associated with higher probability of knowledge flows (measured in terms of citations): the probability of knowledge flows between inventions is a decreasing function of the social distance. Gonzalez-Brambilla et al. (2008) emphasized the relationship between social capital and knowledge creation, underlying the role of exchange and combination processes. In particular, by using a database of international scientific publications and citations they found that scientists in embedded networks have superior success because of better communication skills.
Citation patterns and co-inventor relations measure different kinds of disembodied knowledge flows. On the one side citations are able to measure flows of codified knowledge, that is, knowledge acquired

by direct reading and comprehension of written and available documents such as publications and patents. On the other side, if we assume that inventors listed on the same patent know each other, co-inventor relationships can be seen as a diffusion mechanism of non-codified knowledge (e.g. technical know-how, non-standardized production procedures etc.). In fact diffusion of non-codified knowledge requires, at least periodically, face-to-face interactions and it is likely to have a great impact on the inventive activity.

In this paper we apply this theoretical background to analyse international patenting in Latin America and the impact of international knowledge spillovers. We are aware that international patenting is a tiny portion of the innovative activity of these countries and, exactly for this reason, it is important to stress the peculiarities and specificities of international patenting before laying down the details of the empirical exercise. The next session is therefore dedicated to the precise understanding of the object of enquiry of this paper (see Montobbio, 2007 for a broader discussion and comparison with other developing countries).

# 3. International Patenting in Latin America

For this analysis we use standard patent data sources from the European and US patent offices. Data sources and sectors of analysis are carefully explained in Appendix. Table 1 shows the total number of Latin American granted patents at the USPTO by year (the country is assigned using the residence of the inventors). These numbers are small relative to the overall numbers in other countries. Top patenters at the USPTO are Brazil and Mexico with respectively 1715 and 1783 patents granted in the period 1968 to 2001. Argentina and Venezuela follow with 881 and 640 patents. At the EPO, for the period 1978-2001, Brazil has the highest share with 1244 patent applications, Mexico, Argentina and Venezuela follow with 486, 445 and 160 patent applications, respectively (see table 2). In recent years no remarkable structural break is observable after the changes in domestic legislations due to the implementation of the TRIPs agreement in many countries.

It is important to underline that an increasing share of the total Latin American invented patents filed in the US are the result of a collaborative activity with foreign (in particular US see below section 3.4) laboratories, companies and inventors (Figure 1). It is worthwhile noting that these patents are mainly owned by US companies (like Syntex USA, Delphi Technologies, Procter & Gamble, IBM, Hewlett-Packard and General Electric). Moreover there is a non negligible number of patents owned by US universities and research laboratories (e.g. University of Pennsylvania, California and Texas).

**Table 1. Patents at the USPTO by inventor's country.**

| *Year** | AR | BR | CL | CO | CU | MX | UY | VE |
|---|---|---|---|---|---|---|---|---|
| *1968* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *1969* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *1970* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| *1971* | 0 | 2 | 1 | 0 | 0 | 3 | 1 | 0 |
| *1972* | 7 | 5 | 0 | 0 | 0 | 10 | 0 | 1 |
| *1973* | 11 | 12 | 4 | 1 | 0 | 38 | 1 | 5 |
| *1974* | 27 | 21 | 6 | 7 | 0 | 72 | 0 | 3 |
| *1975* | 24 | 30 | 2 | 2 | 2 | 70 | 1 | 10 |
| *1976* | 23 | 25 | 3 | 8 | 1 | 45 | 1 | 9 |
| *1977* | 26 | 30 | 2 | 10 | 1 | 42 | 0 | 12 |
| *1978* | 22 | 32 | 5 | 4 | 1 | 46 | 0 | 13 |
| *1979* | 22 | 27 | 4 | 2 | 1 | 47 | 0 | 15 |
| *1980* | 25 | 31 | 2 | 6 | 0 | 43 | 1 | 14 |
| *1981* | 19 | 22 | 3 | 4 | 1 | 48 | 0 | 6 |
| *1982* | 16 | 27 | 2 | 7 | 1 | 49 | 0 | 10 |
| *1983* | 12 | 27 | 2 | 9 | 1 | 31 | 1 | 15 |
| *1984* | 15 | 34 | 4 | 3 | 0 | 42 | 0 | 17 |
| *1985* | 15 | 36 | 3 | 3 | 2 | 41 | 1 | 19 |
| *1986* | 21 | 38 | 9 | 5 | 0 | 52 | 0 | 29 |
| *1987* | 28 | 41 | 1 | 4 | 1 | 35 | 2 | 26 |
| *1988* | 13 | 38 | 3 | 9 | 0 | 42 | 2 | 17 |
| *1989* | 13 | 73 | 9 | 2 | 1 | 47 | 3 | 19 |
| *1990* | 29 | 46 | 7 | 9 | 0 | 45 | 1 | 30 |
| *1991* | 25 | 63 | 8 | 5 | 3 | 46 | 2 | 34 |
| *1992* | 27 | 66 | 13 | 13 | 3 | 55 | 2 | 34 |
| *1993* | 39 | 71 | 10 | 3 | 1 | 50 | 2 | 31 |
| *1994* | 49 | 115 | 5 | 13 | 6 | 70 | 2 | 28 |
| *1995* | 42 | 92 | 12 | 12 | 2 | 93 | 2 | 30 |
| *1996* | 53 | 90 | 24 | 5 | 4 | 91 | 2 | 34 |
| *1997* | 58 | 126 | 19 | 7 | 4 | 92 | 2 | 42 |
| *1998* | 63 | 124 | 13 | 9 | 4 | 113 | 0 | 43 |
| *1999* | 49 | 154 | 19 | 13 | 6 | 130 | 4 | 34 |
| *2000* | 76 | 163 | 13 | 15 | 10 | 138 | 2 | 40 |
| *2001* | 82 | 166 | 20 | 14 | 4 | 148 | 4 | 42 |
| *2002* | 60 | 191 | 20 | 9 | 3 | 108 | 4 | 28 |
| *2003* | 46 | 137 | 19 | 6 | 0 | 117 | 0 | 14 |
| *TOTAL* | 1037 | 2155 | 267 | 219 | 63 | 2102 | 43 | 704 |

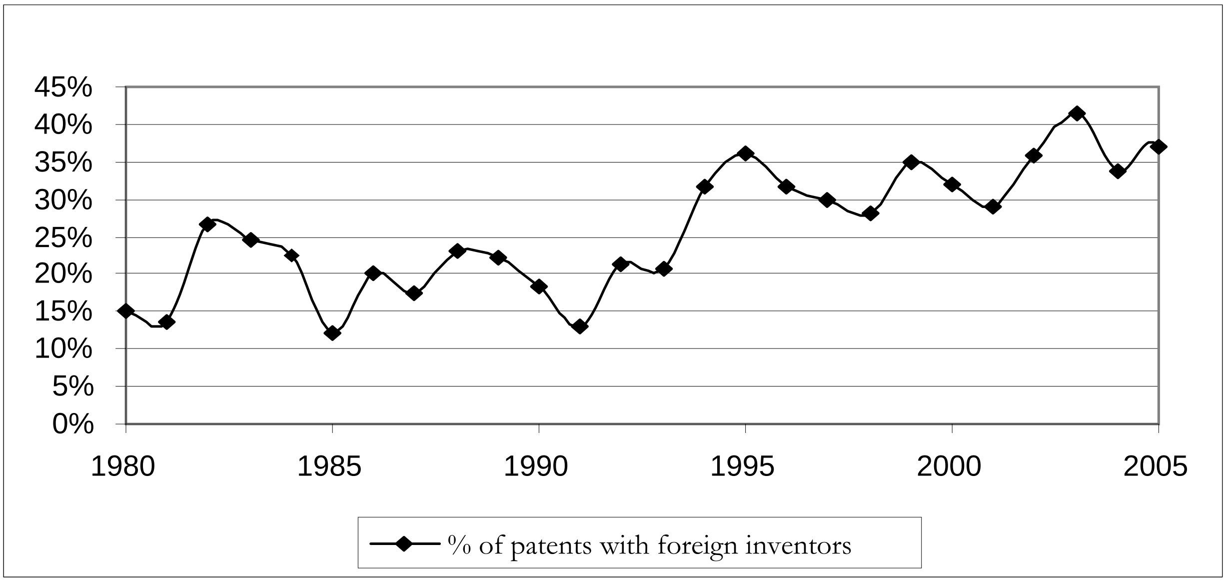
Note: when the patent is a co-invention by inventors from different countries it is counted more than once
*application year
Source: USPTO-CESPRI

**Table 2. Patents at the EPO by inventor's country.**

| *Year** | AR | BR | CL | CO | CU | MX | UY | VE |
|---|---|---|---|---|---|---|---|---|
| *1977* | 0 | 6 | 0 | 1 | 0 | 1 | 0 | 1 |
| *1978* | 0 | 15 | 0 | 0 | 0 | 1 | 1 | 1 |
| *1979* | 1 | 18 | 0 | 0 | 0 | 8 | 0 | 2 |
| *1980* | 14 | 16 | 1 | 1 | 0 | 7 | 0 | 2 |
| *1981* | 5 | 22 | 1 | 2 | 0 | 4 | 0 | 1 |
| *1982* | 6 | 23 | 0 | 7 | 0 | 14 | 0 | 1 |
| *1983* | 6 | 21 | 1 | 9 | 0 | 4 | 2 | 2 |
| *1984* | 6 | 24 | 4 | 0 | 0 | 4 | 0 | 4 |
| *1985* | 7 | 36 | 2 | 1 | 0 | 13 | 1 | 2 |
| *1986* | 7 | 18 | 1 | 1 | 0 | 9 | 1 | 5 |
| *1987* | 6 | 27 | 3 | 2 | 1 | 17 | 0 | 2 |
| *1988* | 10 | 27 | 2 | 0 | 0 | 18 | 1 | 6 |
| *1989* | 14 | 26 | 5 | 4 | 1 | 18 | 1 | 6 |
| *1990* | 19 | 51 | 6 | 3 | 9 | 14 | 1 | 3 |
| *1991* | 15 | 35 | 5 | 1 | 3 | 16 | 0 | 12 |
| *1992* | 17 | 58 | 1 | 5 | 3 | 24 | 0 | 4 |
| *1993* | 24 | 59 | 2 | 4 | 8 | 22 | 1 | 5 |
| *1994* | 16 | 46 | 6 | 6 | 6 | 35 | 0 | 9 |
| *1995* | 21 | 76 | 9 | 5 | 5 | 32 | 1 | 8 |
| *1996* | 40 | 68 | 11 | 2 | 5 | 56 | 2 | 10 |
| *1997* | 36 | 108 | 14 | 6 | 10 | 48 | 2 | 20 |
| *1998* | 48 | 115 | 6 | 5 | 6 | 55 | 4 | 17 |
| *1999* | 52 | 141 | 5 | 10 | 4 | 39 | 5 | 18 |
| *2000* | 59 | 136 | 12 | 9 | 14 | 59 | 5 | 14 |
| *2001* | 38 | 171 | 18 | 11 | 11 | 68 | 4 | 12 |
| *2002* | 53 | 152 | 17 | 6 | 20 | 78 | 7 | 2 |
| *2003* | 55 | 193 | 17 | 11 | 15 | 14 | 7 | 7 |
| *TOTAL* | 575 | 1688 | 149 | 112 | 121 | 678 | 46 | 176 |

Note: when the patent is a co-invention by inventors from different countries it is counted more than once
*priority date
Source: EPO-CESPRI

**Figure 1. Latin American Patents by inventors (USPTO): patterns of collaboration over time.**



### 3.1 Latin American owned vs. Latin American invented patents

The patent count based on the inventor's address reflect more directly the inventive activity of laboratories and researchers in a given country. If a country's patents are counted using the applicant's address, results reflect "ownership". Of course, this counts the inventive activity of a given country's firms, even if their research facilities are located elsewhere. Typically, countries like the United States or the Netherlands, where many multinational companies are located, have a relatively higher patent share when country is assigned on the basis of the applicant's address (Dernis et al., 2001). The opposite occurs in most developing countries.

USPTO data do not report the applicant's country, however it is possible to use EPO data on patent applications to understand what difference does it make to count patents using the applicant's address[29]. As expected counting patents with the applicant's address reduces the number of patents in the main countries of approx. 41% (from 2636 to 1565, in the period 1977-2001, EPO data) with respect to patents with inventor's address. It is worthwhile noting that out of 2636 Latin American invented patents there are only 1520 (56%) Latin American owned patents[30] (i.e. patents in which the applicant's address is in a Latin American country). The rest is owned by foreign companies (1213 – 44%)[31] (i.e. the company's address is not in a Latin American country). Finally it is important to note that if we consider Latin American 'owned' patents the share of patents with at least a foreign inventor is significantly lower (9%) than in the case of Latin American 'invented' patents. This points at a low degree of internationalization of patenters resident in LACs.

Colombia, Mexico and Venezuela have the highest percentage difference between Latin American owned and Latin American invented patents. This means that in particular for these countries a considerable part of the national inventors' activity is performed in companies or institutions that do not have a legal address in the country. This asymmetry may partly reflect the internationalisation of research and the location of research and legal facilities by multinational firms and partly the fact the some Latin American inventors may be temporarily (or in some cases even permanently) active abroad and declare their address in Latin America.

29 For simplicity we use the term 'Latin American owned patents' to refer to patents assigned to countries using the applicants' address and the term 'Latina American invented patents' to refer to patents assigned to countries using the inventors' address. It has to be emphasized that the use of the term 'Latin American owned patent' refers to the *legal address* of the owner and not to the nationality of *ownership of the company*.

30 The difference between this number (1520) and the total number of Latin America owned patents (1565) is generated by 45 Latin American owned patents that have not Latin American inventors.

31 The sum is not 2636 because we counted the patents more than once in case of co-applicants from different countries.

### 3.2 Sectoral differences

Patents are classified according to very specific technological classes and therefore can be used to measure innovative activities in specific sectors of economic activity[32]. Table A1 shows the number and distribution of patents granted at the USPTO at the sectoral level. We observe that Chemicals and Pharmaceuticals and Instruments, Electronics and non Electrical Machinery are the two sectors that capture the 80% of the total patents in Latin America, while, not surprisingly in traditional sectors such as Textile and Food the number of patents represents only 4% of the total. Table A1 shows also the number and distribution of patents by country: Chile seems to have a comparative good production of patents in Metals, while Brazil displays a considerably high share of patents in Transportation.

### 3.3 Individual inventors

A more detailed look at these patents shows that many patents' assignees are individual inventors. If we assign a patent to a country using the applicant's address, 41.5% of Latin American patents at the EPO are owned by individual inventors. At the USPTO 37.3 % of the "Latin American invented" patents granted are 'individually owned' [33]. These shares are considerably higher than average, considering that for all patents at the USPTO and at the EPO the shares of individually owned patents are respectively 23% and 11%[34]. Typically less developed countries and regions have a relatively higher share of individual inventors because firms, universities and research centres are less aware of the patent system and have relatively less resources to invest (relatively to firms in the advanced countries). Therefore it is more likely that individuals decide to bear the expenses and file their own patents. Typically these patents are considered less economically and technologically valuable because they are often the result of occasional activities and do not originate from well funded R&D projects.

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[32] We use the US Patent Classification in order to re-aggregate patents in five classes (Textile and Food, Chemicals and Pharmaceuticals, Metals, Machinery, and Transportation) and match them with data on economic activity (see Table A4 in Appendix for the concordance table)

[33] Moreover in LACs there is a quite high heterogeneity across countries. The countries with the highest share of patents owned by individual inventors are Argentina (72%), Colombia (73 %) and Chile (59%). Of course if we look again at the EPO data and consider Latin American invented patents, we discover that the share of Latin American invented drops to 25.2 %. Again the countries with the highest share are Argentina (46 %), Chile (40.5%), Colombia (37.7%) and Uruguay (33.3%). This means that very few foreign assignees of Latin American invented patents are individual inventors. Looking at the USPTO data Argentina (61.7 %), Colombia (55.1 %), Uruguay (52.5%) and Mexico (42.4%) have 'individually owned' patent shares that are higher than the average

[34] The higher share of individually owned patents at the USPTO is due to the 'first to invent' rule. The assignee can be declared in a second stage after the registration at the patent office.

Some of such patents may actually belong to companies but have been put under the name of the owner as the applicant. This could be the case of micro companies, family companies or partly-informal companies. Given the great uncertainty of survival of small and medium companies - in a macro-economic context that often is unstable - companies prefer not to have the patent registered under the name of the company but rather under the name of the owner (for Argentina see López et al. 2005). There might be some exceptions to this negative interpretation, though. Some inventors, active abroad, keep the address of their home country. This inventive activity could be valuable, and these individual patents could signal co-operation with foreign countries and be important vehicle of knowledge transfer[35] as emphasised in the previous sections.

### 3.4 Applicants

There is not a very high concentration of the assignees or applicants of international patents at the USPTO and EPO in Latin America. Many assignees or applicants are, in a large number, different individual inventors[36] and among top applicants we find many US and German multinational companies. There are some big Latin American patenters, like Petrobras, Embraco or Intevep-Pdvsa, that are active in a set of heterogeneous sectors of activity that are not considered very R&D intensive (e.g. Oil, Glass, Electric, Metals and Machinery). Almost no Latin American companies are active in high tech and high growth sectors like Electronics, Telecommunications or Pharmaceuticals.

The top 10 Latin American applicants (inventor's country) at the EPO (for the period 1978-2001; in parenthesis company's country address) are: Empresa Brasileira De Compressores (Brazil), Petroleo Brasileiro s.a. – Petrobras (Brazil), Centro de Ingenieria Genetica y Biotecnologia (Cuba), Bayer (Germany), Unilever (UK and Netherland), Hylsa (Mexico), Praxair Technology (US), Procter and Gamble (US), INTEVEP (PDVSA - Venezuela) and finally Johnson and Johnson (Brazil and US). Table 3 shows the top 16 applicants and their number of patents.

The top ten patenting companies at the USPTO are (for the period 1978-2001; excluding 'individually owned patents'; in parenthesis there is the country of the inventors not the address of the company which is not available in the USPTO database) INTEVEP (Venezuela), Petroleo Brasileiro s.a. – Petrobras (Brazil), Empresa Brasileira De Compressores (Brazil), Hylsa (Mexico), Carrier (Brazil), Syntex USA (Mexico), Vitro Tec Fideicomiso (Mexico), Hewlett-Packard (Mexico), Bayer (Brazil,

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[35] See for example the case of Dr. Juan Carlos Parodi at the Washington School of Medicine in St. Louis (US) with the following highly cited patents: "Aortic graft for repairing an abdominal aortic anurysm – US005360443A" and "A ballon device for implanting an aorta [...] - US5219355".

[36] Individually owned patents remain dispersed across a large number of individuals with few patents. This suggests that they patent occasionally. The individual inventor owning the largest number of patents at the EPO is Juan Carlos Parodi with 13 patents and the second one is Luiz Carlos, Oliveira Da Cunha Lima with 6 patents.

Mexico and few from Colombia and Argentina), Delphi Technologies (Mexico). The picture at the USPTO is quite similar to the EPO with a lower presence of German firms and a higher presence of US companies like HP, IBM, Carrier or Colgate-Palmolive.

**Table 3. Top 16 applicants at the Uspto (1978-2001) and relative number of patents.**

| **Company** | **# of patents** |
|---|---:|
| INTEVEP | 243 |
| PETROLEO BRASILEIRO S.A. PETROBRAS | 157 |
| EMPRESA BRAZILEIRA DE COMPRESSORES S/A EMBRACO | 70 |
| HYLSA | 66 |
| CARRIER | 51 |
| HEWLETT-PACKARD | 41 |
| BAYER AKTIENGESELLSCHAFT | 37 |
| DELPHI TECHNOLOGIES | 37 |
| SYNTEX U.S.A | 34 |
| VITRO TEC FIDEICOMISO | 33 |
| METAL LEVE | 30 |
| PROCTER & GAMBLE | 30 |
| METAGAL INDUSTRIA E COMERCIO | 30 |
| INTERNATIONAL BUSINESS MACHINES | 24 |
| PRAXAIR TECHNOLOGY | 19 |
| GENERAL ELECTRIC | 18 |

### 3.5 Citations

In order to address the issue of knowledge flows, in this section we track the citation flows between Latin American countries and other geographical areas in the world. Using USPTO citation data in the period 1975-2000, we build a matrix of citation flows across areas ($CIT$). Each element of this matrix $\{CIT_{jk}\}$ represents the number of patent citations flowing from country j into country k (i.e. the number of times patents with the inventors' address in country j cite the patents with the inventors' address in country k). Note that $CIT$ is squared and asymmetric and the elements on the main diagonal $\{CIT_{jj}\}$ are the number of citations that remain in the same specific country. Table 4 illustrates the matrix from the USPTO dataset. Each column represents the citing country and the rows are the cited countries[37] (e.g. Latin American patents cite ten times Chinese patents equivalent to the 3% of the total Latin American backward citations).

Table 4 shows a very low share of citations among Latin American countries (4.29% of citations). This is similar to other countries like China and India. Approximately 70% of the citations done and received are from US patents[38]. Finally it can also be noted that knowledge flows from Latin American patents to patents invented in other regions are also extremely low. Our evidence shows that citations to Latin America from EU and US patents appear to be equal to the 0.14% of the total outflow of their citations.

### 3.6 Co-inventors

Our second measure of knowledge flows is based on collaboration patterns between inventors. Table 5 shows the number of co-inventors and share by countries and sectors at the USPTO for five LACs (Argentina, Brazil, Chile, Colombia, and Mexico). In column (1) and (2) we show the number of inventors of USPTO patents that declare their residence respectively in the Latin American country and in a foreign country. In the other columns the share of co-inventors resident in a foreign country is displayed. We consider only the co-inventors resident in the G-5 countries (US, Japan, Germany, UK, and France).

Mexico has more international collaborations than the other LACs in terms of patenting activities: the G-5 co-inventors represent the 31% of the total inventors of Mexican patents. At the opposite end we find Argentina where the G-5 co-inventors represent only the 22% of the total number of inventors.

[37] When patents have inventors from different countries, patents have been assigned to all the different countries listed in the inventors' addresses.

[38] We have also build the same matrix using EPO data. Interestingly these shares drop to approximately 36% if we consider EPO patents. At the same time within the USPTO data knowledge flows with Europe are approximately 12% of the total, and at the EPO are approximately 42% of the total. This my be the result of a home bias effect by patent examiners. For a discussion on this point see Montobbio (2007) and Bacchiocchi and Montobbio (2008).

Looking at the bilateral relationship it is worthwhile noting that the great majority of foreign inventors comes from the US: in all the LACs considered the lower share is for Brazilian patents with 56%. However it is possible to distinguish different patterns of *co-inventorship*. Brazil has a higher co-inventors network with Germany (31%) and France (6%) with respect to other LACs, while Chile seems to have a significant collaboration with UK (especially in Chemicals and Pharmaceuticals). Finally, if we consider sectoral differences, we find that more or less in all the countries Chemicals and Pharmaceuticals and Instruments, Electronic and non Electronic Machinery are the sectors with more international co-inventors.

**Table 4. Citations matrix: citations distribution by cited country for each citing country (USPTO data).**

| | Citing Country | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cited Country_ | **Latin_America** | CA | EU_4 | JP | US | Australia_N | East_Europe | Four_Tigers | India | Malaysia_Th | China |
| **Latin_America** | **4,29** | 0,17 | 0,14 | 0,06 | 0,14 | 0,28 | 0,22 | 0,13 | 0,22 | 0,37 | 0,25 |
| CA | 2,53 | **10,85** | 1,68 | 0,96 | 2,06 | 3,27 | 1,98 | 1,81 | 1,80 | 1,83 | 1,97 |
| EU_4 | 14,34 | 11,26 | **30,30** | 9,69 | 9,88 | 13,10 | 17,11 | 7,56 | 16,71 | 10,04 | 11,20 |
| JP | 9,08 | 9,60 | 14,66 | **50,01** | 11,12 | 9,66 | 13,60 | 16,35 | 13,44 | 15,66 | 14,56 |
| US | *67,70* | *66,22* | *51,86* | *38,15* | ***75,21*** | *66,31* | *57,34* | *55,06* | *63,16* | *64,71* | 60,54 |
| Australia_N | 0,87 | 0,78 | 0,44 | 0,20 | 0,47 | **6,19** | 0,49 | 0,42 | 0,51 | 0,43 | 0,44 |
| East_Europe | 0,16 | 0,15 | 0,19 | 0,09 | 0,12 | 0,16 | **8,72** | 0,05 | 0,30 | 0,06 | 0,23 |
| Four_Tigers | 0,89 | 0,88 | 0,64 | 0,78 | 0,92 | 0,95 | 0,36 | **18,37** | 0,76 | 4,92 | 8,01 |
| India | 0,07 | 0,04 | 0,04 | 0,02 | 0,04 | 0,04 | 0,10 | 0,03 | **2,96** | 0,06 | 0,05 |
| Malaysia_Th | 0,04 | 0,02 | 0,02 | 0,01 | 0,02 | 0,02 | 0,01 | 0,09 | 0,01 | **1,83** | 0,13 |
| China | 0,03 | 0,04 | 0,03 | 0,03 | 0,03 | 0,02 | 0,07 | 0,15 | 0,13 | 0,11 | **2,61** |
| ***Total*** | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* | *100,00* |

Source: own elaboration on USPTO-CESPRI

**Table 5. Number of co-inventors and share by countries and sectors.**

| *country* | *sector* | *Domestic inventors (a)* | *Foreign co-inventors(b)* | *SHARE of foreign inv. (b/a+b)* | *Share_Germany* | *Share_France* | *Share_Uk* | *Share_Japan* | *Share_Usa* |
|---|---|---|---|---|---|---|---|---|---|
| AR | Textile and Food | 46 | 6 | 12% | 0% | 17% | 0% | 0% | 83% |
| AR | Chemicals and Pharma | 277 | 115 | 29% | 17% | 6% | 1% | 1% | 75% |
| AR | Metals | 4 | 0 | 0% | 0% | 0% | 0% | 0% | 0% |
| AR | Instruments, electronics and non electr. machinery | 306 | 113 | 27% | 0% | 1% | 0% | 0% | 99% |
| AR | Transportation | 63 | 0 | 0% | 0% | 0% | 0% | 0% | 0% |
| AR | Other | 178 | 13 | 7% | 0% | 0% | 0% | 0% | 100% |
| **AR** | **total** | **874** | **247** | **22%** | **8%** | **4%** | **0%** | **0%** | **87%** |
| BR | Textile and Food | 50 | 23 | 32% | 0% | 4% | 4% | 0% | 91% |
| BR | Chemicals and Pharma | 666 | 487 | 42% | 43% | 6% | 4% | 1% | 47% |
| BR | Metals | 112 | 10 | 8% | 20% | 0% | 10% | 0% | 70% |
| BR | Instruments, electronics and non electr. machinery | 566 | 185 | 25% | 10% | 8% | 3% | 9% | 70% |
| BR | Transportation | 230 | 50 | 18% | 38% | 6% | 4% | 0% | 52% |
| BR | Other | 560 | 75 | 12% | 15% | 7% | 7% | 0% | 72% |
| **BR** | **total** | **2184** | **830** | **28%** | **31%** | **6%** | **4%** | **3%** | **56%** |
| CL | Textile and Food | 19 | 2 | 10% | 0% | 0% | 0% | 0% | 100% |
| CL | Chemicals and Pharma | 112 | 57 | 34% | 11% | 0% | 12% | 0% | 77% |
| CL | Metals | 39 | 6 | 13% | 0% | 0% | 0% | 0% | 100% |
| CL | Instruments, electronics and non electr. machinery | 51 | 17 | 25% | 12% | 0% | 0% | 0% | 88% |
| CL | Transportation | 19 | 0 | 0% | 0% | 0% | 0% | 0% | 0% |
| CL | Other | 29 | 7 | 19% | 0% | 0% | 0% | 0% | 100% |
| **CL** | **Total** | **269** | **89** | **25%** | **9%** | **0%** | **8%** | **0%** | **83%** |
| CO | Textile and Food | 6 | 3 | 33% | 0% | 0% | 0% | 0% | 100% |
| CO | Chemicals and Pharma | 83 | 42 | 34% | 36% | 0% | 2% | 0% | 62% |
| CO | Metals | 3 | 2 | 40% | 0% | 0% | 0% | 0% | 100% |
| CO | Instruments, electronics and non electr. machinery | 56 | 13 | 19% | 0% | 15% | 8% | 0% | 77% |
| CO | Transportation | 4 | 0 | 0% | 0% | 0% | 0% | 0% | 0% |
| CO | Other | 28 | 8 | 22% | 0% | 0% | 0% | 0% | 100% |
| **CO** | **total** | **180** | **68** | **27%** | **22%** | **3%** | **3%** | **0%** | **72%** |
| MX | Textile and Food | 94 | 31 | 25% | 0% | 0% | 0% | 0% | 100% |
| MX | Chemicals and Pharma | 622 | 383 | 38% | 18% | 4% | 2% | 3% | 72% |
| MX | Metals | 172 | 40 | 19% | 0% | 0% | 10% | 0% | 90% |
| MX | Instruments, electronics and non electr. machinery | 554 | 270 | 33% | 5% | 2% | 1% | 3% | 90% |
| MX | Transportation | 101 | 66 | 40% | 11% | 0% | 0% | 0% | 89% |
| MX | Other | 386 | 81 | 17% | 1% | 2% | 1% | 1% | 94% |
| **MX** | **total** | **1929** | **871** | **31%** | **11%** | **3%** | **2%** | **2%** | **83%** |

## 4. The Empirical Model

This section outlines the empirical model we use to estimate international knowledge spillovers and in particular the effects of R&D performed in industrialized countries on the innovative activity of Latin American countries. Following Griliches (1984) and Malerba et al. (2007) we start from the following KPF that relates R&D investments and the production of technological output:

$$Q_{h,i,t} = f(\bar{R}_{h,i,t}, \alpha, v_{h,i}) = \bar{R}^{\alpha}_{h,i,t}\, v_{h,i} \tag{1}$$

where $Q_{h,i,t}$ is some latent measure of technological output in field $i$ (i=1,..5), country $h$ and period $t$. In addition $\alpha$ represents the unknown technological parameter, and $v_{h,i}$ captures the country and technological field specific effects. We assume that R&D is composed of domestic R&D efforts and international R&D efforts that produce usable knowledge at the international level. As emphasised in the previous section we compare three different modes of knowledge flows. The first mode is pure spillover ($IS_1$), the second one is knowledge spillover through patent citations ($IS_2$) and, finally, the third one is knowledge spillover that is related to collaboration activities and face-to-face contacts (i.e. co-inventorship) ($IS_3$):

$$\bar{R}^{\alpha}_{h,i,t} = R^{\alpha 1}_{h,i,t} IS^{\beta 1}_{1h,i,t} IS^{\beta 2}_{2h,i,t} IS^{\beta 3}_{3h,i,t} \tag{2}$$

Moreover we use patents as a noisy indicator of technological output:

$$P_{h,i,t} = Q_{h,i,t} e^{\theta_t} u_{h,i} \tag{3}$$

We take into consideration possible common time effects in patenting ($\theta_t$) and differences in country specific propensity to patent in each technological field ($u_{h,i}$). Combining equation (3) with (2) and (1) results in the following patent equation:

$$P_{h,i,t} = R^{\alpha 1}_{h,i,t} IS^{\beta 1}_{1h,i,t} IS^{\beta 2}_{2h,i,t} IS^{\beta 3}_{3h,i,t} e^{\theta_t} \xi_{h,i} \tag{4}$$

We cannot directly estimate (4) because we do not have data on national R&D effort at the sectoral level over time. However even if we are interested in the effect of international spillovers on international patenting, we have to take into account some economic measure related with the trend in the size of the different industries in each country and national R&D investment in order to avoid omitted variable problems in the econometric approach. For this reason we control national economic activity with data on value added (an additional specification includes the lagged dependent variable, see below), captured by the variable $X_{h,i,t}$:

$$P_{h,i,t} = X_{h,i,t}^{\alpha 1} IS_{1h,i,t}^{\beta 1} IS_{2h,i,t}^{\beta 2} IS_{3h,i,t}^{\beta 3} e^{\theta_t} \xi_{h,i} \qquad (5)$$

In its general formulation international knowledge spillovers are typically expressed as follows:

$$IS_{h,i,t} = \prod_f R_{f,j,t}^{\lambda_{h,f,j,t}} \qquad (6)$$

where $\lambda_{h,f,j,t}$ weights the impact of R&D expenditures from foreign countries. R is the knowledge source and λ is the vehicle of knowledge spillovers. In our case subscript *f* refers to US, UK, Japan, France, and Germany, and *h* to Argentina, Brazil, Chile, Colombia, and Mexico. Our weights are sector-specific (sector *j*) and vary over time. Note that we adopt very large sectors and therefore we feel legitimate to focus only on intra-sectoral R&D spillovers neglecting inter-industry knowledge flows.

## 5. Data and Methodology

Our econometric exercise uses different databases for five Latin American countries (Argentina, Brazil, Chile, Colombia, Mexico) and five industrial sectors (Textile and Food, Chemicals and Pharmaceuticals, Metals, Instruments Electronic and Non Electrical Machinery, and Transportation) in the period 1988-2003. In particular we use the USPTO-CESPRI database for patents and patent citations, the PADI-CEPAL database for value added and the OECD-ANBERD database for R&D data. Data sources and sectoral aggregations are thoroughly explained in Appendix. Equation (5) captures the effect of the R&D effort performed in foreign countries on the production of USPTO patents by Latin American inventors. Taking logs of (5) we propose to estimate the following logarithmic specification:

$$\ln P_{h,i,t} = \alpha_1 \ln X_{h,i,t} + \beta_1 \ln IS_1 + \beta_2 \ln IS_2 + \beta_3 \ln IS_3 + \theta_t + \varsigma_{h,i,t} \tag{7}$$

where the dependent variable is the log of the number of USPTO patents in county *h (h*=1,..5), sector *i(i*=1,..5), and time *t* (t=1,..16 for the period 1988-2003). Note that our observational unit refers to industries (sectors) in different countries for a total of 25 different groups.

The R&D stock in country *f* and sector *i* is calculated using the *perpetual inventory method* and, following the standard practice in the literature, we set the rate of depreciation δ at 0.12 (see Appendix)[39]. Central to this paper is the calculation of the international spillover variables. We measure three different channels of international knowledge spillovers. The first international spillover variable measures knowledge spillovers when knowledge is a public good and once it is produced it is freely available. Under this assumption 1$ in R&D will have a direct impact on the knowledge production in other countries. We call this variable:

$$\ln IS_1 = foreignR\&D\_tot_{h,j,t} = \sum_f \ln R\&D_{f,j,t} \tag{8}$$

*foreignR&D_tot* is equal to the sum of the logarithm of R&D stocks in the main G-5 industrialized countries: US; JP, UK, FRA and DE. In this case all weights $\lambda_{h,f,j,t}$ are set equal to 1. In addition we have shown that the USPTO activity of Latin American countries is tightly linked to the activity of US companies and universities. Therefore R&D expenditures in the US are particularly important in terms of spillovers generated to Latin American countries. Therefore in our regressions we control for this aspect and consider also only the *US R&D stock*.

The second spillover effect is captured by patent citations. Patent citations are a paper trail that may signal that some knowledge flow occurs. Knowledge remains a public good but travels embedded in codified documents such as patents. We use USPTO citations to build a set of matrices that map citations between our five LACs countries and the G5 countries we considered. Each cell of the matrix is the number of citations in patents with at least an inventor resident in a LAC country to patents with at least an inventor resident in a specific G5 country. We build these matrices for each

[39] It is important to remark that the arbitrary assumption on the size of the depreciation rate does not affect importantly the results. We have re-run all the regressions with δ=0.08 but results do not change. The estimated values with a R&D stocks calculated with δ=0.08 are not displayed but are available from authors.

sector and for each year. Then we construct the weight $\lambda_{h,f,j,t}=cit_{h,f,j,t}$, which is the ratio of the number of citations flowing from country *h* to country *f* in sector *j* at time *t* over the total number of citations flowing from country *h* to all the G-5 countries in sector *j* at time *t*. As a result our index of citation-based international knowledge spillover (*foreignR&D_cit*) is calculated as follows:

$$\ln IS_2 = foreignR\&D\_cit_{h,j,t} = \sum_f cit_{h,f,j,t} \ln R\&D_{f,j,t} \tag{9}$$

The third spillover effect we consider is related to interpersonal links and possibly face-to-face contacts. In this case the signal that some knowledge flow occurs is that inventors have worked together on the same invention. We use USPTO patent data to build a second set of matrices. In this case each cell *(h,f)* of the matrix is the number of patents with at least an inventor resident in country *h* *and* an inventor resident in country *f*. Again we build these matrices for each sector *i* and for each year *t* in the sample. Then we construct the weight $\lambda_{h,f,j,t}=coinv_{h,f,j,t}$, as the ratio of the number of patents with co-inventors in country *h* and country *f* in sector *j* at time *t* over the total number of patents with inventors in country *h* and all the G-5 industrialized countries in sector *j* at time *t*. As a result our index of international knowledge spillover (*foreignR&D_coinv*) based on co-inventorship behaviours is calculated as follows:

$$\ln IS_3 = foreignR\&D\_coinv_{h,j,t} = \sum_f coinv_{h,f,j,t} \ln R\&D_{f,j,t} \tag{10}$$

Table 6 displays summary statistics on the economic and patent data variables.

**Table 6. Summary statistics.**

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Patents | 400 | 7.9475 | 11.99121 | 0 | 69 |
| ForeignR&D_tot | 400 | 51.35638 | 4.972934 | 43.33293 | 61.94098 |
| US R&D | 400 | 11.58586 | 1.398821 | 9.921598 | 14.11394 |
| ForeignR&D_cit | 400 | 8.559491 | 5.028881 | 0 | 13.78447 |
| ForeignR&D_coinv | 400 | 5.317824 | 5.824937 | 0 | 14.11394 |
| Value added | 400 | 5830.125 | 5984.256 | 101 | 24424 |

# 6. Estimation results

Our estimation strategy follows three steps. First we run simple fixed effect OLS regressions. We use fixed effects because they ensure consistency in the presence of correlation between the explanatory variables and the individual effects[40]. Therefore we start with a set of *static* regressions using fixed effect model. Secondly we control for possible spurious results due to common trends and test for the stationarity of the time series in the panel. Third we use a lagged dependent variable to control for domestic innovative activity. In this last step we estimate a *dynamic* panel using Within Group (Fixed Effect) estimation and GMM following Arellano and Bond (1991). Results are based on the assumption of stationarity consistently with the second step of this econometric exercise.

## 6.1 Static panel

We start then estimating equation (7) using Fixed Effect. Heteroskedasticity robust standard errors are applied. We take the log to have the variables more closely distributed to normality and estimated coefficients expressed in terms of elasticity. In some cases the number of patents is zero and the log of zero is not defined, therefore we set zeroes equal to one and allow the corresponding observations to have a separate intercept (zero dummy) as in Pakes and Griliches (1984). In Section 6.2 we also perform a robustness check in this respect. In all specifications we also include time dummies to control for common overall economic changes.

Table 7 reports the robust Fixed Effect estimates of the parameters. All the specifications explain approximately the 90% of the variation in international patenting. The first column includes only total foreign R&D stock (i.e. US, Japan, Germany, UK, and France) as input of the innovation function: an increase of 1% in total foreign R&D stock increases by 0.095% the innovative activity in terms of international patenting of our LACs. In Column 2 we assume that only R&D expenditures in the US have a spillover effect on international patenting. The result shows a strong positive spillover effect from US R&D stock: the estimated coefficient is equal to 0.3 and statistically significant at 1 percent level. Note that the size of this estimated coefficient is three time higher than in the case of total foreign R&D. This variable controls for pure spillover effects as in Bottazzi and Peri (2007): US generated ideas widen the basis of usable knowledge and generate further innovation based in LACs. Controlling for the effects of available ideas in a specific industry measured by the US R&D stock we proceed in columns (3), (4), and (5) adding as regressors the other 'embedded' international spillover

[40] Random effects estimates are more efficient, but require the individual specific effect to be uncorrelated with the explanatory variables. In any case the Hausman test (not reported) supports fixed-effects specification rather than random-effects model.

mechanisms measured by the variables $IS_2$ and $IS_3$. These coefficients show that external R&D has a significant additional impact on patent production and in particular that *citations* and *co-inventorship* patterns are relevant channels of knowledge flows. The two estimated coefficients have similar size being respectively 0.032 and 0.027 and are significant at the 1% level. Our results suggest that a significant portion of international knowledge spillovers is embedded or in codified documents, such as patents that publicly available, or in interpersonal links and contacts, such as cross-country collaborative efforts on specific innovations.

**Table 7. Spillover determinants of patents (robust standard errors in parenthesis).**

| COEFFICIENT | (1)<br>Fixed Effect<br><br>Log (patents) | (2)<br>Fixed Effect<br><br>Log (patents) | (3)<br>Fixed Effect<br><br>Log (patents) | (4)<br>Fixed Effect<br><br>Log (patents) | (5)<br>Fixed Effect<br><br>Log (patents) | (6)<br>FE Negative Binomail<br>Number of patents |
|---|---|---|---|---|---|---|
| Total foreign R&D | 0.095*** | | | | 0.081*** | |
| | (0.018) | | | | (0.017) | |
| US R&D | | 0.301*** | 0.289*** | 0.246*** | | 0.060 |
| | | (0.065) | (0.064) | (0.065) | | (0.071) |
| Foreign R&D_cit | | | 0.034*** | 0.032*** | 0.032*** | 0.064*** |
| | | | (0.009) | (0.008) | (0.008) | (0.012) |
| Foreign R&D_coinv | | | | 0.027*** | 0.027*** | 0.028*** |
| | | | | (0.005) | (0.005) | (0.008) |
| Value added | 0.191 | 0.251 | 0.286** | 0.263* | 0.213 | 0.182 |
| | (0.150) | (0.146) | (0.145) | (0.145) | (0.143) | (0.130) |
| Constant | --4.99*** | -3.83** | --4.60*** | -4.05** | -4.66*** | -0.670 |
| | (1.45) | (1.46) | (1.55) | (1.59) | (1.40) | (1.35) |
| Observations | 400 | 400 | 400 | 400 | 400 | 400 |
| Number of i | 25 | 25 | 25 | 25 | 25 | 25 |
| Year dummies | yes | yes | Yes | Yes | Yes | Yes |
| R-squared (total) | 0.8990 | 0.8971 | 0.9014 | 0.9086 | 0.9103 | - |
| R-squared (within) | 0.5062 | 0.4967 | 0.5177 | 0.5529 | 0.5612 | - |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
All variables are in logarithm.
R&D depreciation rate 12%

Finally in column (6) we test the robustness of our results running a *Fixed Effect Negative Binomial model* in order to take into account that patents are a count variable, but the results related to citation-based spillovers and co-inventorship based spillovers do not change substantially. Conversely the US R&D stock is smaller and not statistically significant. But as we will see in the next paragraph this variable is non stationary and this may crucially affect the results.

### 6.2 First Robustness Check

We have 85 observations over 400 in which the number of patents is zero: in this case when the spillover effect passes through patent citations or patent co-inventors the source of external R&D is zero by definition (it is not possible to have citations or co-inventors without patents). In order to check if the previous results are driven by this effect we have run the fixed effect model dropping the observations where the number of patents is zero. Results do not change substantially. The coefficients associated to the spillover measured by citations and by co-inventors are significant and positive. In particular a 1% increase in citation-weighted R&D generates a 0.029% increase in the domestic innovative output, while for the co-inventors-weighted R&D we get a significant coefficient of 0.024%. The R&D performed in US has the greater impact with a estimated elasticity of 0,24% (see Table A4 in the Appendix).

### 6.3 Stationarity tests

Our estimates rely on the assumption that our variables are stationary or cointegrated and it is in fact possible that serial correlation is spuriously driving the above results. We therefore perform the panel unit root test developed by Im, Pesaran, and Shin test (2003)[41]. Under the assumption that the time series are independent across $i$, the null hypothesis is that all the series are non-stationary; under the alternative some of individual time series have unit roots. Table 8 shows the results. We find that the dependent variable and our measures of R&D spillovers weighted by citations and co-inventors are indeed stationary[42]. At the same time the null hypothesis of unit root cannot be rejected for the other measures of foreign R&D we have used. Total foreign R&D stock and US R&D stock are therefore both non-stationary. For this reason the estimations presented in Table 7 may be biased. In the following section we check the robustness of our results excluding Total Foreign R&D and US R&D in order to obtain consistent estimates. In addition we add a lagged dependent variable in order to estimate a the dynamic version of our empirical model.

**Table 8. Results for the IPS(2003) unit root test for panel data.**

| Variable | lags | t-bar | W[t-bar] | Obs. | P-value |
|---|---|---|---|---|---|
| Log of patents | *1* | *-2.358* | *-4.399* | *350* | *0.000* |
| US R&D | *1* | *1.866* | *17.679* | *350* | *1.000* |
| Foreign R&D_cit | *1* | *-2.120* | *-3.156* | *350* | *0.001* |

[41] This test has the advantage of elasticity regarding the specification of individual time trend and length of time lags.
[42] The stationarity of R&D weighted by citations is accepted if we do not consider two lags.

| | | | | | |
|---|---|---|---|---|---|
| Foreign R&D_coinv | *1* | *-2.042* | *-2.749* | *350* | *0.003* |
| value_added | *1* | *-2.095* | *-3.027* | *350* | *0.001* |
| Total foreign R&D | *1* | *3.532* | *26.388* | *350* | *1.000* |
| Log of patents | *2* | *-1.908* | *-2.440* | *350* | *0.007* |
| US R&D | *2* | *1.265* | *13.678* | *350* | *1.000* |
| Foreign R&D_cit | *2* | *-1.352* | *0.385* | *350* | *0.650* |
| Foreign R&D_coinv | *2* | *-2.007* | *-2.940* | *350* | *0.002* |
| value_added | *2* | *-2.084* | *-3.331* | *350* | *0.000* |
| Total foreign R&D | *2* | *1.389* | *14.309* | *350* | *1.000* |

### 6.4 Dynamic panel

This section is therefore devoted to control the robustness of our results. We control for an additional potential source of omitted variable bias including a lagged dependent variable. This leads us to estimate a more general dynamic version of our empirical model. It is reasonable to think that international patenting is a cumulative and past-dependent process. Accordingly we assume that the production of patents is a AR(1) process, and the number of patents at time *t* is also function of the number of patents produced in the previous period, *ceteris paribus*. This helps controlling together with value added for domestic past innovative effort. Include a lagged dependent variable we have therefore the following dynamic specification:

$$\ln P_{h,i,t} = \gamma \ln P_{h,i,t-1} + \alpha_1 \ln X_{h,i,t} + \beta_1 \ln IS_1 + \beta_2 \ln IS_2 + \beta_3 \ln IS_3 + \theta_t + \varsigma_{h,i,t} \qquad (11)$$

The errors $\varsigma_{h,i,t}$ are decomposed into time invariant individual specific effects $\eta_{h,i}$ (in our case the 25 country-sector pairs), and the random noise $v_{h,i,t}$ so that $\varsigma_{h,i,t} = \eta_{h,i} + v_{h,i,t}$. One implication of model (11) is that the lagged dependent variable is correlated with the idiosyncratic disturbance - even if the disturbance is itself not serial correlated – because of a possible bias by the omitted individual specific effects (Greene, 2003). The Ordinary Least Squares (OLS) estimator of γ in the equation (11) is inconsistent, since the explanatory variable is positively correlated with the error term due to the presence of the individual effects. The Within Group estimator eliminates this source of inconsistency by transforming the equation in order to eliminate the individual (country-sector) effect $\eta_{h,i}$. Specifically the mean values of the variables are calculated across the T-1 observations for each unit, and the original observations are expressed as deviations from these means. Since the mean of the time invariant $\eta_{h,i}$ is itself $\eta_{h,i}$, these individual effect are eliminated. Then we use OLS to estimate the transformed equation. Nevertheless this transformation induces a possible correlation between the transformed lagged dependent variable and the transformed error term, especially in panels where the number of time periods available is small, so that the WITHIN estimator could be also inconsistent (Bond, 2002).

Arellano and Bond (1991) propose an alternative estimation technique based on the GMM that corrects the bias introduced by the lagged dependent variable. In a dynamic panel model with unobserved individual heterogeneity the idea is first-differencing the equation (11) in order to eliminate the individual dummies (unobserved individual and time-invariant effects). However this transformation implies that OLS estimates in the first-differenced model is inconsistent because of the dependence with the disturbance. So sequential moment conditions are used where lagged variables or lagged differences of the dependent variables are instruments for the endogenous differences, while the other variables can serve as their instruments. Instruments are required to be correlated with the instrumented variable and not correlated with the disturbance. In Arellano and Bond estimators the instruments are "internal", that is based on lags of the instrumented variables. In particular in our case lags of the dependent variables or lags of first differences must be correlated with the first difference and uncorrelated with the disturbance [43].

**Table 9. Dynamic panel. Dep. Variable Log of Patents.**

| | (1)<br>WITHIN GROUP | (2)<br>WITHIN GROUP | (3)<br>GMM DIFF | (4)<br>GMM DIFF |
|---|---|---|---|---|
| log_patents (t-1) | 0.221*** | 0.240*** | 0.252* | 0.211* |
| | (0.051) | (0.050) | (0.129) | (0.125) |
| Foreign_RD_cit | 0.030*** | 0.029*** | 0.022 | 0.022 |
| | (0.009) | (0.008) | (0.017) | (0.016) |
| Foreign_RD_coinv | | 0.029*** | | 0.032*** |
| | | (0.005) | | (0.006) |
| Value added | 0.392* | 0.312 | 0.308 | 0.203 |
| | (0.220) | (0.212) | (0.266) | (0.248) |
| Observations | 375 | 375 | 350 | 350 |
| Number of i | 25 | 25 | 25 | 25 |
| Year dummies | Yes | Yes | Yes | Yes |
| R-squared (within) | 0.5087 | 0.5522 | - | |
| Sargan p-value | - | - | 0.757 | 0.315 |
| Sargan | - | - | 25.24 | 34.24 |
| Test AR(1) [p-value] | - | - | 0.000 | 0.000 |
| Test AR(2) [p-value] | - | - | 0.524 | 0.359 |

Standard errors in parentheses

GMM results are one-step estimates. 4th, 5th, and 6th lags of dependent variable are used; other variables serve as their instruments.

*** p<0.01, ** p<0.05, * p<0.1

[43] Only 4th, 5th and 6th lags of dependent variable are used.

Table 9 shows the results. We compare WITHIN estimations with GMM estimations. Since GMM estimations are based on the assumption of stationarity we cannot include in the specification foreign R&D stocks and US R&D stocks. This would return biased results. Sargan test of over-identifying restrictions satisfies the underlying assumptions of the Arellano and Bond approach suggesting that estimates reported are consistent and efficient[44]. Our results suggest that indeed it is important to control for a lagged dependent variable that is always statistically significant. International patenting is cumulative and past-dependent process. Moreover the estimated coefficients indicate that on the one hand the spillover effect measured by citations is still positive but not statistically significant, on the other hand the estimated coefficient for international spillover captured by co-inventors is still positive and significant. This result is important because it emphasises the role played in international technological transmission by collaboration and person-to-person contact.

## 6.5 Differences across sectors

In this section we enquiry the differences in terms of types of knowledge spillovers across sectors. We assume therefore that parameters $\gamma, \alpha_1, \beta_1, \beta_2$ and $\beta_3$ in equation [11] are industry specific. Table 10 shows therefore the spillover estimates obtained from separate regressions on our five sectors. We run both a static fixed effect model and a dynamic model using the GMM technique used in the previous section. Due to the limited number of observations these results have to be taken with care. However we show that the effects of international spillovers may differ across sectors. Focusing in particular on the more general dynamic specifications, our GMM results show that citation based spillovers are positive and significant in all sectors. The values of the estimated coefficients range between 0.05 and 0.07. Secondly, knowledge flows measured through co-inventorhip plays a sensible and positive role mainly in the Chemical and Pharmaceutical sector, Instruments and Machinery and Metals with estimated elasticities equal respectively to 0.06, 0.04 and finally 0.03. It's worthwhile noting that value added affects importantly international patenting only in Metals.

**Table 10. Spillover determinants of patents by sectors (robust standard errors in parenthesis).**

| COEFFICIENT | Textile and food | | Chemicals and pharma | | Metals | | Machinery | | Transports | |
|---|---|---|---|---|---|---|---|---|---|---|
| | static model (FE) | dynamic model (GMM) | static model (FE) | dynamic model (GMM) | static model (FE) | dynamic model (GMM) | static model (FE) | dynamic model (GMM) | static model (FE) | dynamic model (GMM) |
| log_patents (t-1) | - | 0.23* | - | 0.07 | - | -0.08 | - | -0.14 | - | 0.02 |
| | | (0.14) | | (0.14) | | (0.13) | | (0.12) | | (0.18) |

44 We have run also "System GMM" obtaining similar results: the estimated values are not displayed but are available from authors. This Blundell-Bond (1998) estimator makes the additional assumption that first differences of instrumenting variables are not correlated with the unobserved fixed effects. This allows the introduction of more instruments improving efficiency.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Foreign R&D_cit | 0.035*** | 0.07*** | 0.035 | 0.05*** | -0.0061 | 0.05*** | 0.057** | 0.07*** | 0.058*** | 0.07*** |
| | (0.012) | (0.01) | (0.021) | (0.02) | (0.0099) | (0.01) | (0.028) | (0.01) | (0.021) | (0.01) |
| Foreign R&D_coinv | -0.0019 | -0.00 | 0.050*** | 0.06*** | 0.018 | 0.03** | 0.025** | 0.04*** | 0.025** | 0.01 |
| | (0.011) | (0.01) | (0.015) | (0.01) | (0.015) | (0.01) | (0.012) | (0.01) | (0.012) | (0.01) |
| Value added | -0.15 | 0.18 | 0.40 | 0.70 | 0.96* | 2.48*** | 0.13 | 0.47 | 0.24 | 0.06 |
| | (0.32) | (0.89) | (0.42) | (0.86) | (0.48) | (0.61) | (0.27) | (0.37) | (0.18) | (0.29) |
| Constant | 2.03 | | -2.12 | | -6.77* | | 1.06 | | -0.92 | |
| | (2.94) | | (3.24) | | (3.91) | | (2.06) | | (1.33) | |
| Observations | 80 | 70 | 80 | 70 | 80 | 70 | 80 | 70 | 80 | 70 |
| Number of i | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Year dummies | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sargan (p-value) | | 0.022 | | 0.18 | | 0.10 | | 0.017 | | 0.0038 |
| R-squared (within) | 0.656 | | 0.631 | | 0.637 | | 0.735 | | 0.705 | |
| R-squared (total) | 0.8530 | | 0.8593 | | 0.9077 | | 0.9219 | | 0.8965 | |

*** p<0.01, ** p<0.05, * p<0.1

All variables are in logarithm.

GMM results are one-step estimates, following Arellano-Bond (1991). $4^{th}$, $5^{th}$, and $6^{th}$ lags of dependent variable are used; other variables serve as their instruments.

# 7. Conclusions

A large body of literature emphasizes that international flows of technological knowledge affect importantly countries' ability to learn and innovate. This paper provides one of the first attempts to study different mechanisms of knowledge transmission from developed countries to developing countries at industry level. In particular we focus on the determinants of international patent production in a selected number of Latin American countries (LACs) and explore the role of three channels of R&D spillovers: pure spillovers, patent citations related spillovers, and face-to-face contact spillovers based on co-inventorship relations. In the econometric analysis we use data for five big industrial sectors (Textile and Food, Chemicals and Pharmaceuticals, Metals, Instruments Electronic and Non-Electrical Machinery, and Transportation), five LACs (Argentina, Brazil, Chile, Colombia and Mexico) and the G-5 countries (France Germany, Japan, UK and US) in the years between 1988 and 2003.

Overall this paper provides a detailed description of the nature and characteristics of international patenting (EPO and USPTO) in LACs. We show that a large part of the Latin American invented patents belong to foreign companies with a foreign address or to a foreign subsidiary with a Latin American address, and top applicants at the USPTO and EPO are mainly US and German multinationals and the big Latin American patenters are active in a set of heterogeneous sectors of activity that are not considered very R&D intensive (e.g. Oil, Glass, Electric, Metals and Machinery). We show also that individual inventors play a prominent role that is difficult to interpret but it's linked to the fragile structure of many innovative activities in these countries.

Secondly we apply GMM methods to estimate the effect of the three different types of knowledge spillovers. We find that international knowledge spillovers from the G-5 countries are a significant determinant of inventive activity in the period considered. In particular the stock of ideas produced in the US seems to have a strong impact of the international patenting activity of these countries. Moreover, controlling for these US-driven pure spillovers effects, bilateral patent citations and face-to-face relationships between inventors are both important *additional* mechanisms of knowledge transmission. Some of our results suggests that the latter is more important than the former. Finally we find some sectoral differences: knowledge flows measured through co-inventorhip plays a particularly important role mainly in the Chemical and Pharmaceutical sector, Instruments and Machinery and Metals.

This has relevant policy implications. The relative weakness in many sectors of the LACs' technological capabilities goes hand in hand with the lack of international integration of their inventive activities and the effectiveness of science and technology policies may depend upon the degree of internationalization of inventors activity and their international mobility. If international face-to-face contacts and collaborations display a positive marginal effect on domestic innovative activity, R&D subsidies and fiscal R&D policies should be complemented with policies oriented at the international expansion of the network relations of local inventors and companies.

However these policy conclusions have to be handled with extreme care due to some important limitations of this study. First of all we consider an extremely tiny portion of the LACs innovative activities. The absolute numbers displayed in Section 3 clearly indicate that few companies and individuals patent their technologies internationally. An alternative strategy could be to look at national patents at domestic patent offices. A first attempt to look at Brazilian data is provided in Laforgia et al. (2008). National patents are however heavily influenced by changes in national patent legislations.

A second important limitation of the paper, which is left to be addressed by future work, relates to the analysis of the other important channels of technological transmission we do not consider, such as FDIs and bilateral trade. Future work should be able to compare the relative importance of these different channels. Finally this paper addresses only the R&D impact on international patenting. More evidence is needed to fully understand the final impact on fundamental economic variable like labour or total factor productivity or patterns of trade. Montobbio and Rampa (2005) describe different types of relations between technological activity (using a similar set of USPTO patents) and export gains in different big developing countries and show that are importantly influenced by the sectoral structure of the economy. In this respect important complementarities should be developed with the large number of qualitative and quantitative studies that address the issues of knowledge transmission at the micro level (e.g. Crespo Fontuora, 2007 and footnote 2).

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## Appendix.

*Data.*

Our study starts using different databases for eight Latin American countries (Argentina, Brazil, Chile, Colombia, Cuba, Mexico, Uruguay, Venezuela) and five industrial sectors. In the econometric analysis we consider only 5 countries: Argentina, Brazil, Chile, Colombia, Mexico. Patent data are collected from EPO-CESPRI and USPTO-CESPRI database, R&D expenditure in the private business sector from OECD-ANBERD, and OECD STAN (2005) database. Economic data are taken for the PADI-CEPAL database (Programa de Análisis de la Dinámica Industrial) that processes consistently economic data at the sectoral level from national statistical sources. In particular we use the value added in real terms (millions of $1985).

Manufacturing sectors are defined following the International Standard Industrial Classification (ISIC – Rev.3). Our analysis is at industry level and we consider 5 technological fields [see Table A4 for details on conversion from US patent classification to ISIC 3 classification]. This analysis uses the patent and citation databases from the USPTO-CESPRI database and from the EP-CESPRI database. The USPTO database contains 3,583,811 patents from 1963 to 2002. The EP-CESPRI database contains 1,391,350 from 1978 to 2002.

The following characteristics of patents are particularly relevant. Firstly, patents are dated with the priority date which is the closest date to the year of invention. Priority dates are used for the EPO patents. For the USPTO-CESPRI database priority dates are not available and therefore the application date has been used. Secondly, the country of a patent, as explained in Section 3, could refer to the address of the inventors or to the address of the applicants (or assignees). In this study we use both, inventors and applicants' addresses, as the results obtained are different and enable us to draw some interesting conclusions (in the econometric analysis we refer to inventors' address). It should also be noted that patents include information on the stated address (and country of residence) of the inventor rather than her or his nationality. Thirdly, patents are classified using classification systems which facilitate the identification of the technological field. In this study, the International Patent Classification (IPC) is used for EPO patents, while the US patent classification is used for USPTO patents.

*R&D Capital stock*

Total business enterprise expenditure on R&D at industry level comes from OECD-ANBERD (2005) dataset. We use the R&D flows, valued in US purchasing power parity, and convert them into constant 1995 prices. The deflators used for that are output deflators. The output deflators are derived from figures on value-added both in current as well as constant 1995 prices, both included in the OECD STAN-Industry database. The R&D capital stocks are then estimated using the perpetual inventory method[45]:

$$R\&D\_stock_t = (1-\delta)R\&D\_stock_{t-1} + R\&Dflow_{t-1}$$
$t=1,2..16$,

where $R\&D\_stock$ denotes the R&D capital stock in the business sector and $R\&Dflow$ is business sector R&D expenditure in constant 1995 prices valued at US purchasing power parity. The rate of depreciation δ is set at 0.12[46]. The benchmarks are calculated as:

$$R\&D\_stock_{1988} = \frac{R\&Dflow}{(g+\delta)}$$

where $g_v$ is the annual average logarithmic growth rate of R&D spending over the period 1988-2003.

**Table A1. Number and distribution of USPTO patents by sector and country.**

| | Textile and Food | Chemicals and Pharmaceuticals | Metals | Instruments, Electronics and non Electr. Machinery | Transportation | Total |
|---|---|---|---|---|---|---|
| Argentina | *34* | *226* | *3* | *261* | *50* | *574* |
| | *(6%)* | *(39%)* | *(1%)* | *(45%)* | *(9%)* | *(100%)* |
| Brazil | *34* | *521* | *68* | *464* | *158* | *1245* |
| | *(3%)* | *(42%)* | *(5%)* | *(37%)* | *(13%)* | *(100%)* |
| Chile | *8* | *91* | *15* | *46* | *16* | *176* |
| | *(5%)* | *(52%)* | *(9%)* | *(26%)* | *(9%)* | *(100%)* |
| Colombia | *4* | *51* | *2* | *53* | *5* | *115* |
| | *(3%)* | *(44%)* | *(2%)* | *(46%)* | *(4%)* | *100%)* |
| Mexico | *55* | *388* | *77* | *458* | *94* | *1072* |
| | *(5%)* | *(36%)* | *(7%)* | *(43%)* | *(9%)* | *(100%)* |
| **Total** | ***135 (4%)*** | ***1277 (40%)*** | ***165 (5%)*** | ***1282 (40%)*** | ***323 (10%)*** | ***3182*** |

Patent data refer to 1988-2003 period, for 5 LACS: Argentina, Brazil, Chile, Colombia, and Mexico.

45 Other studies (Bitzer and Stephan, 2007) show that different methods for constructing R&D capital stock give more robust estimates.

46 First estimates and previous empirical works [see for instance, Coe et al. (2008) and Keller (2000)] find that results are robust to different calibration of the depreciation rate.

**Table A2. Correlation matrix.**

| | Log (Pa) | ForeignR&D _Tot | US R&D | ForeignR&D _cit | ForeignR&D _coinv |
|---|---|---|---|---|---|
| Log (Pa) | - | | | | |
| ForeignR&D _Tot | *0.4881** | - | | | |
| US R&D | *0.4073** | *0.9598** | | | |
| ForeignR&D _cit | *0.6710** | *0.3318** | *0.3243** | - | |
| ForeignR&D _coinv | *0.7280** | *0.3813** | *0.3022** | *0.4674** | - |
| value_added | *0.3740** | *-0.3885** | *-0.3821** | *0.1696** | *-0.1922** |

**Table A3. Robustness check**

| COEFFICIENT | (1) Fixed effect | (2) Fixed effect | (3) Fixed effect | (4) Fixed effect | (5) Fixed effect | (6) FE Negative Binomail |
|---|---|---|---|---|---|---|
| Total foreign R&D | *0.084**** | | | | *0.075**** | |
| | *(0.019)* | | | | *(0.019)* | |
| US R&D | | *0.27**** | *0.26**** | *0.24**** | | *0.15*** |
| | | *(0.072)* | *(0.072)* | *(0.072)* | | *(0.070)* |
| Foreign R&D_cit | | | *0.031**** | *0.029**** | *0.029**** | *0.019** |
| | | | *(0.0099)* | *(0.0087)* | *(0.0087)* | *(0.011)* |
| Foreign R&D_coinv | | | | *0.024**** | *0.024**** | *0.021**** |
| | | | | *(0.0060)* | *(0.0060)* | *(0.0077)* |
| Value added | *0.36*** | *0.39*** | *0.43*** | *0.40*** | *0.37*** | *0.22** |
| | *(0.18)* | *(0.18)* | *(0.18)* | *(0.19)* | *(0.18)* | *(0.13)* |
| Constant | *-5.59**** | *-4.72**** | *-4.91**** | *-4.66*** | *-5.56**** | *-1.31* |
| | *(1.76)* | *(1.75)* | *(1.82)* | *(1.87)* | *(1.89)* | *(1.38)* |
| Observations | *315* | *315* | *315* | *315* | *315* | *315* |
| Number of i | *25* | *25* | *25* | *25* | *25* | *25* |
| Year dummy | *Yes* | *Yes* | *Yes* | *Yes* | *Yes* | *yes* |
| R-squared (within) | *0.350* | *0.342* | *0.365* | *0.404* | *0.411* | - |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
All variables are in logarithm. R&D depreciation rate 12%

**Table A4. Concordance table.**

| Class | SubCat | Cat | isic rev 2 | isic rev 3 | sector |
|---|---|---|---|---|---|
| 19, 43, 99, 127, 426, 442, 449, 452 | 11, 61 | 1, 6 | 310, 320 | 15-16-17-18-19 | TEXTILE AND FOOD |
| 8, 23, 34, 44, 48, 55, 71, 95, 96, 102, 106, 117, 118, 149, 156, 162, 196, 201, 202, 203, 204, 205, 208, 210, 216, 349, 351, 366, 401, 416, 422, 423, 424, 427, 430, 433, 435, 436, 494, 501, 502, 504, 510, 512, 514, 516, 518, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 534, 536, 540, 544, 546, 549, 552, 554, 556, 558, 560, 562, 564, 568, 570, 585, 588, 623, 800 | 11, 12, 13, 14, 15, 16, 19, 31, 33, 39. | 1, 3 | 351, 352 | 24 | CHEMICALS AND PHARMACEUTICALS |
| 29, 72, 75, 76, 140, 147, 148, 163, 164, 178, 228, 245, 266, 270, 333, 340, 342, 343, 358, 367, 370, 413, 419, 420, | 21, 52, 69 | 2, 5, 6 | 370-381 | 27-28 | METALS |
| 7, 16, 33, 42, 49, 51, 59, 60, 65, 73, 74, 81, 82, 83, 86, 89, 100, 124, 125, 128, 136, 141, 142, 144, 157, 173, 174, 178, 181, 184, 191, 193, 194, 198, 200, 209, 212, 218, 219, 221, 225, 226, 227, 234, 235, 236, 239, 241, 242, 250, 254, 257, 264, 267, 271, 290, 291, 294, 307, 310, 313, 314, 315, 318, 320, 322, 323, 324, 326, 327, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 340, 342, 343, 345, 346, 347, 348, 352, 353, 355, 356, 358, 359, 360, 361, 362, 363, 365, 367, 368, 369, 370, 372, 374, 375, 376, 377, 378, 379, 380, 381, 382, 384, 385, 386, 388, 392, 395, 396, 399, 400, 402, 406, 411, 407, 408, 409, 141, 425, 429, 438, 439, 445, 451, 453, 454, 470, 482, 483, 492, 493, 503, 505, 508, 600, 601, 602, 604, 606, 607, 700, 701, 702, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, | 21, 22, 23, 24, 32, 41, 42, 43, 44, 45, 46, 49, 51, 54, 59, 69 | 2, 3, 4, 5, 6 | 382-383-385 | 30-31-32-33 | INSTRUMENT, ELECTRONIC AND NON ELECTRONIC MACHINERY |
| 91, 92, 104, 105, 114, 123, 152, 180, 185, 187, 188, 192, 213, 238, 244, 246, 251, 258, 280, 293, 295, 298, 301, 303, 305, 410, 415, 417, 418, 440, 464, 474, 475, 476, 477 | 53, 55 | 5 | 384 | 34-35 | TRANSPORTATION |