Privatization of Knowledge: Did the U.S. Get It Right?*

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Abstract

Brilliant ideas are key to economic growth. They often emerge from scientific discoveries with no immediate commercial value – so rewards may not be aligned to effort. To foster innovation and growth should basic research be publicly or privately funded? Post 1980, the US intellectual property institutions facilitated the patentability of basic research. We build a Schumpeterian model and match it to the data to re-assess this important turning point. *Keywords*: R&D and Growth, Sequential Innovation, Research Tools, Patent Laws, Kremer Mechanism. *JEL Classification*: O31, O34, O41.

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1 Introduction

Over the last 25 years, U.S. Court decisions switched from the doctrine limiting the patentability of early-stage scientific findings - lacking in current commercial value - to the conception that also fundamental basic scientific discoveries - with no current tradeable application (such as genetic engineering procedures) - fall in the general applicability of the patent system.

The year 1980 marked an important turning point in US patentability requirements, as summarized by the following:

1 the Diamonds *v.* Chakrabarty case, of 1980, in which the Supreme Court of United States ruled that microorganism produced by genetic engineering could be patented.

2. the Bayh-Dole Act of 1980, which facilitated universities in patenting innovations[1].

After the second world war, universities and public laboratories have always been the main performers of basic R&D in the United States and in Europe. Though an important reason for the relatively low private contribution to basic R&D is often found in the high degree of uncertainty that this activity involves in terms of future commercial application and success, the legal permission to appropriate the fruits of years of investigations is making a big difference between pre-1980 and post-1980 US innovation systems. Hence the 1980's jurisprudential and juridical reforms opened the way to a flow of private funds into the academia in search of promising research projects, as well as facilitated professors in patenting their own research without incurring in legal obstacles linked to their direct or indirect involvement in the public system.

Jensen and Thursby (2001) studied the more recent licensing practices of 62 US universities. They found that "Over 75 percent of the inventions licensed were no more than a proof of concept (48 percent with no prototype available) or lab scale prototype (29 percent) at the time of license!". Moreover, most of the inventions licensed were in such an embryonic state of development, that it was difficult to estimate their commercial potential and the inventor's cooperation was required to get a successful commercial development.

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[1] Prior to the Bayh-Dole act, the public co-funding of research - which is now pervasive in the academia - posed a serious legal problem to the patentability of basic research. The Bayh-Dole act allowed the patentability of research that benefited from an albeit limited amount of public money.

In a more general definition of research tools, the US National Institute of Health (1998) is "embracing the full range of tools that scientists use in the laboratory", and includes "cell lines, monoclonal antibodies, reagents, animal models, growth factors, combinatorial chemistry libraries, drugs and drug targets, clones and cloning tools... methods, laboratory equipment and machines, databases and computer software". Nearly all research tools are patentable in the US, thanks to the juridical innovations that took place in the last 25 years. As recent clarified by *Madey v. Duke University* Federal Circuit decision (2002), the common law fair use doctrine does not even allow universities to infringe patents on research tools for teaching or experimental purposes[2]. According to evidence reported by Mueller (2004, p.944-945), "corporations have signed reach-through licenses with universities, which give the corporations rights to control down-stream products that may be developed through the university's technology...Some corporations are asking for complete ownership of the innovations made by university professors, while others are demanding pre-approval of professors' publication of research results."

The agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs), article 27, encourages countries to extend patentability to"any inventions, whether products or processes, in all fields of technology, provided that they are new, involve an inventive step and are capable of industrial application", and a footnote follows specifying: "For the purposes of this Article, the terms "inventive step" and "capable of industrial application" may be deemed by a Member to be synonymous with the terms "non-obvious" and "useful" respectively." Hence a "useful" research tool should be patentable. Though to ".. make all research activities free of patent infringement would make all research tool patents worthless, and would be contrary to TRIPs", (Thouret-Lemaitre[3], 2006), the adoption of TRIPs by several countries is still controversial, as strong research exemptions to patent infringements are

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[2] In the US patent law the main exeption is the Hatch-Waxman Act of 1984, which allows an experimental use exception for testing drugs and medical devices for purposes reasonably related to regulatory data gathering. This limited use has been further narrowed by the Integra *v.* Merck case of 2006.

[3] Elisabeth Thouret-Lemaitre, Vice President, Head of Patent Operations, Sanofi-Synthelabo, Paris, WIPO Presentation October 11, 2006.

in place in countries such as Japan[4], China[5], Belgium[6], Germany[7], India[8], Brazil[9], Mexico[10], and Korea[11]. Even if the European Directive on Biotechnology of 1998 should extend patentability to many research tools, it is still being implemented in contradictory ways, leading to a situation in the middle between the pre- and post-1980 US. Statutory research exemptions and compulsory licensing render patent claims much weaker.

We believe that an economic analysis of the US turning point may give good insight to start a scientific debate rich of relevant policy implications. This paper, by taking the R&D sequentiality into the Schumpeterian paradigm, investigates the relation between the cumulative uncertainty involved in the two-stages innovation process and the inefficiency in the public research system. As a theoretical framework from which to assess patent institutions, we share the decomposition of each innovation into (at least) two stages of *research* and *development* with the oligopolistic patent race literature pioneered by Fudenberg et al. (1983), Reinganum (1985), Grossman and Shapiro

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[4] Japan: art 69 (1): " the effects of the patent right shall not extend to the working of the patent right for the purposes of experiment or research."

[5] Article 62 of the Patent Law of the People's Republic of China: "None of the following shall be deemed an infringement of a patent right:...5. Use of the patent in question solely for the purposes of scientific research and experimentation".

[6] Where since 2005 the new Article 28(1)(b) of the Belgian Patent Act states that a patent holder's claims “do not extend to acts that are committed on and/or with the subject of the patented invention for scientific purposes”.

[7] The German Constitutional Court (2000) stated that patent holders must "accept such limitations on their rights in view of the development of the state of the art and the public interest". Thus the patent claims become controversial when the commercial interest of the unauthorized use of a patented innovation is not clear.

[8] Section 47 of the Patent Act states that The patented product or process "may be used, by a person for the purpose merely of experiment or research."

[9] Article 43 of the Brazilian Industrial Property Law: "The provisions of the preceding Articles shall not apply:...II. to acts carried out for experimental purposes by unauthorized third parties if related to study or to scientific and technological research."

[10] Article 22 of the Industrial Property Law: "The right conferred by a patent shall not have any effect against: (I) a third party who, in the private or academic sphere and for non-commercial purposes, engages in scientific or technological research activities for purely experimental, testing or teaching purposes, and to that end manifactures or uses a product or a process identical to the one patented".

[11] Section 96(1) of the Patent Law states: "The effects of the patent right shall not extend to the following: (i) working of the patented invention for the purpose of research or experiment…".

(1986) and (1987), and, more recently, Denicolò (2000). We contribute with several new insights, by adding free entry, endogenous multisector industrial dynamics and general equilibrium determination of all variables. Moreover, we provide a new theory of public sector inefficiencies in research. Our general equilibrium analysis allows a consistent numerical calibration of our theory to the true US data. The only alternative macroeconomic predecessor is Aghion and Howitt (1996), which identified basic research with horizontal innovation. Since in the real world all sectors need basic research not just once, we adopt the complementary view that basic research pervades all sectors, which forces us to substantially modify the standard multisector framework with vertical innovation. We will assume that basic research can be "curiosity driven", but that it could also be motivated by its potentially socially useful applications.

The rest of this paper is organized as follows. Section 2 explains the modifications in Schumpeterian theory needed to analyse the two-stage innovation process stylizing the innovative mechanism in the presence of research tools. It focusses on the most original aspects of the model, leaving the most standard parts to the Appendix 1, in order to facilitate readability. Section 3 applies this new framework to a stylized pre-1980 US scenario: basic research findings are conceived in public institutions and put into the public domain, triggering patent races by freely entering perfectly competitive private R&D firms aiming at inventing a better quality product. Section 4 studies a stylized post-1980 US scenario, where basic R&D achievements are patented and, afterwards, developed into tradable applications within a completely privatized economy. Free entry patent races only occur in the basic research, whereas as soon as a research tool is discovered it will be developed by its patent holder. Section 5 discusses the main insight of the paper and motivates the empirical analysis. Section 6 matches the model to the US data prevailing at the time of the jurisprudence and legislative change. We estimate the relevant technological parameter and we undertake numerical simulations[12] in order to assess if the reform could have enhanced innovation. In Section 7 we extend the privatized scenario depicted in section 5 to the debated existence of a "research exemption", which might give birth to reach-through patenting agreements after an infringement suit. Section 8 introduces into basic research the Kremer's (1998) mechanism by which the

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[12] Appendix 2 - available from the authors upon request - shows the details of the computations we have been performed.

government buys out patents and renders them freely accessible. The main results are summarized in Section 9.

2 The Model

2.1 Overview

Consider an economy with a continuum of differentiated final good sectors with corresponding differentiated research and development (R&D) sectors, along the lines of Grossman and Helpman (1991). Product improvements occur in each consumption good industry, and within each industry, firms are distinguished by the quality of the final good they produce. When the state-of-the-art quality product in an industry $\omega \in [0,1]$ is $j_t(\omega)$, R&D firms compete in order to learn how to produce the $j_t(\omega) + 1$st quality product. We extend the standard quality ladders model by introducing a two-stage innovation path, so first a researcher catches a glimpse of innovation through the $j_t(\omega) + \frac{1}{2}$th inventive half-idea and then other researchers engage in a patent race to implement it in the $j_t(\omega) + 1$st quality product. Of course half ideas could be as difficult to get as Nobel prizes, as shown in the Cohen-Boyer patents on the basic method and plasmids for gene cloning (granted in 1990). The best real world interpretation of the "half ideas" are the research tools.

As in Grossman and Helpman (1991), time is continuous with an unbounded horizon and there is a continuum of infinitely-lived dynasties of expanding households with identical intertemporally additive preferences. Heterogeneous labour, skilled and unskilled, is the only factor of production. Both labour markets are assumed perfectly competitive. In the final good sectors $\omega \in [0,1]$ monopolistically competitive patent holders of the cutting edge quality good produce differentiated consumption goods by combining skilled and unskilled labour, whereas research firms employ only skilled labour. To facilitate the exposition, the most standard analytical details of the model can be found in the Appendix 1.

2.2 The Mechanics of the R&D, Scale Effects, Preliminary Results

In each industry, the R&D activity is a two stage process by which, first a new idea is invented upstream - a first "half-idea" - and then it is used to find the way to introduce a higher quality product. A first half-idea is a new, non-obvious, non-tradeable finding, necessary to research on the final product innovation: hence upstream half-ideas are *research tools*. In the words of Grossman and Shapiro (1987, p.373), the "two stages may be thought of as research and development, respectively."

In our economy the whole set of industries $\{\omega \in [0,1]\}$ gets partitioned into two subsets of industries: at each date t, there are industries $\omega \in A_0$ with (temporarily) no half-ideas and, therefore, with one quality leader (the final product patent holder), no applied (downstream) research and a mass of basic (upstream) researchers, and the industries $\omega \in A_1 = [0,1] \backslash A_0$, with one half-idea and, therefore, one quality leader (the final product patent holder) and a mass of applied (downstream) researchers directly challenging the incumbent monopolist. Firms engage in basic R&D only in $\omega \in A_0$ industries and engage in applied R&D activity aimed at a direct product innovation only in A_1 industries. When a quality improvement occurs in an A_1 industry, the innovator becomes the new quality leader and the industry switches from A_1 to A_0. Similarly, when an inventive half-idea discovery arises in an industry $\omega \in A_0$ this industry switches to A_1. Figure 1 illustrates the flow of industries from a condition to the other:

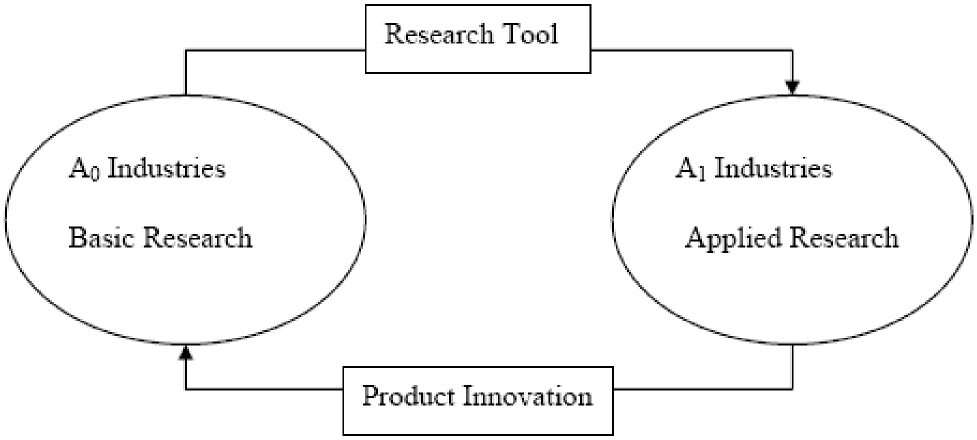

FIGURE 1: REPRESENTATION OF THE ECONOMY BY FLOWS OF INDUSTRIES

Notice that in our multisector two-stage environment with perpetual innovation basic (upstream) R&D alternates with applied (downstream) R&D in all sectors of the economy. The two sets A_0 and A_1 change over time, even if the economy will eventually tend to a steady state. At any instant we can measure the mass of industries without any half-idea as $m(A_0) \in [0,1]$, and the mass of industries with an uncompleted half-idea as $m(A_1) = 1 - m(A_0)$. Clearly, in the steady state these measures will be constant, as the flows in and out will offset each other. However, the endogenous nature of the steady state equilibrium distribution of sectors allows us to study the effects of different institutional scenarios - patentability regimes, public sector inefficiencies - to technological dynamics and growth. Let $i = B, A$ denote

basic or applied research. $N_i(\omega, t)$,indicates the mass of basic research skilled labor employment and, respectively, applied research skilled labour in sector $\omega \in [0,1]$ at date t. A researcher's Poisson process probability intensity to succeed in inventing a half-idea, or completing one (i.e. introducing the product innovation), is $\theta_i\left(N_i(\omega,t), P(t), \omega, t\right)$, decreasing in the aggregate sectoral R&D labor, $N_i \geq 0$. In particular, we specify the per-unit time Poisson probability intensity to succeed for a basic and an applied research labour unit respectively as

$$\theta_B(N_B(\omega,t), P(t), \omega, t) \equiv \frac{\lambda_0}{P(t)}\left(\frac{N_B(\omega,t)}{P(t)}\right)^{-a}, \ \omega \in A_0 \tag{1}$$

$$\theta_A(N_A(\omega,t), P(t), \omega, t) \equiv \frac{\lambda_1}{P(t)}\left(\frac{N_A(\omega,t)}{P(t)}\right)^{-a}, \ \omega \in A_1 \tag{2}$$

where $\lambda_k > 0$, $k = 0, 1$, are R&D productivity parameters and constant $0 < a < 1$ is an intra-sectoral congestion parameter, capturing[13] the risk of R&D duplications, knowledge theft and other diseconomies of fragmentation in the R&D. Each Poisson process - with arrival rates described by (1)-(2) - governing the assumed two-stage innovative process is supposed to be independent across researchers and across industries. Hence the total amount of probability per unit time of inventing a basic half idea in a sector $\omega \in A_0$ at date t is $N_B\theta_B$ and the total amount of probability per unit time of completing a basic half idea in a sector $\omega \in A_1$ is $N_A\theta_A$.

Eq.s (1)-(2) state that the probability intensity of the invention of a half-idea decreases with population. This assumption, shared by Dinopoulos and Segerstrom (1999), captures the complexity of improving a good in a way

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[13] As in Jones and Williams's (1998 and 2000) specification of the R&D technology.

that renders a larger population happier[14]. Notice that also the congestion externality is assumed to decrease with population, as we deem it reasonable that the risk of R&D duplications declines with the difficulty of duplications, that the industrial espionage activities are rendered more complicated with the technological complexity of the ideas being targeted, etc. The specific form postulated for increasing technological complexity is sufficient to guarantee that the equilibrium long run percapita growth rates do not increase with population, thereby rendering our model immune to the embarrassing strong scale effect (Jones 2003) that plagued the early generation endogenous growth models, without leading to "semi-endogenous" growth (Jones 1995, Segerstrom 1998), as consistent with recent empirical evidence (Madsen, 2008). Motivated from this important debate in R&D-driven growth theory, from now on, we will work directly on the relevant percapita variables. In particular, we define $n_B(\omega,t) \equiv \frac{N_B(\omega,t)}{P(t)}$ and $n_A(\omega,t) \equiv \frac{N_A(\omega,t)}{P(t)}$ - where $P(t)$ denotes total population at time t - as the skilled labor employment in each basic and, respectively, applied R&D sector.

Moreover, in all our scenarios, symmetric equilibria exist, allowing us to simplify notation: $n_B(\omega,t) \equiv n_B(t)$ and $n_A(\omega,t) \equiv n_A(t)$. Notice that there is no loss of generality if in what follows the more microeconomic-oriented reader interpretes our derivations under the assumption of constant population, implying that researchers' probability intensities are normalized to $\theta_B \equiv \lambda_0 n_B^{-a}$ and $\theta_A \equiv \lambda_1 n_A^{-a}$.

2.2.1 More General Interpretation

The reader may rightly wonder that it would be wrong to associate each basic innovation with only one single applied innovation coming after it. We here show that the framework we construct is more general than how we have just illustrated. In fact, each basic innovation can have generate than just one applied innovation. We can rewrite basic research parameter λ_0 as $\lambda_0 = \nu\lambda_0^p$, where $\nu > 0$ is the *number* of potential applications the basic innovation could have and $\lambda_0^p > 0$ pertains to the probability per unit time that the basic innovation be invented. Hence the basic research probability intensity $\theta_B \equiv \lambda_0 n_B^{-a} = \nu\lambda_0^p n_B^{-a}$ now describes the (population adjusted)

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[14] Despite its semplicity, this assumption is equivalent to eliminating the strong scale effect by means of an R&D "dilution effect" over an increasing range of varieties, as proved by Peretto (1998), Young (1998), Dinopoulos and Thompson (1998) and (1999), and Howitt (1999).

research unit of labour probability per unit time that a basic discovery is made that opens the door for ν new industrial innovations. In this case, the invention will cause ν sectors previously in A_0 to become A_1. Since we assume a continuum of sectors, notice that ν can be any number. Under this interpretation, basic research targeting an innovation can indirectly challenge ν leading edge products. Hence the aggregate innovation rate $m(A_0)\lambda_0 n_B^{1-a}$ - deterministic by the law of large numbers - entails a flow $m(A_0)\lambda_0^p n_B^{1-a}$ of ν new inventions each. Each of the existing A_0 sectors is equally affected by an innovation with probability $\nu m(A_0)\lambda_0^p n_B^{1-a}/m(A_0) = \lambda_0 n_B^{-a}$, formally the same as under the previous more restrictive interpretation. This is a simple way to allow some flexibility despite symmetric aggregate variables, as some sectors might be assumed to have higher values of ν and lower values of λ_0^p and viceversa, despite their product being the same. For $\nu \to \infty$ and $\lambda_0^p \to 0$ in such a way that $\lambda_0 = \nu\lambda_0^p$ stays constant the reader can view our model as formally capturing Aghion and Howitt's (1996) idea that basic research is able to generate an unboundedly large number of applications. However, unlike their model[15], here if basic research were to stop, applied research could not eventually persist forever.

2.2.2 Manufacturing

Our macroeconomic approach will allow to consider endogenous labour allocations: this captures the general equilibrium feedbacks between basic R&D policy, manufacturing, and functional income distribution. Adopting the unskilled labour as the numeraire, we will endogenously determine the skill premium, as summarized by the (relative) skilled wage w_s.

In all our equilibria, the per-capita mass of skilled labour employed in manufacturing sector $\omega \in [0, 1]$ at time t, labeled $x(\omega, t)$, will be constant across sectors and equal to $x(\omega, t) = x(t)$. In fact, in the Appendix 1 we prove that the manufacturing employment of the skilled labour obeys the following decreasing function of the relative skilled wage w_s:

$$x(\omega, t) = \frac{1}{w_s(t)} \left(\frac{\alpha}{1-\alpha} \right) M \equiv x(t),$$

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[15] In which the steady state general knowledge (and therefore productivity) growth rate is positive also if the flow of fundamental innovation (i.e. basic research) is zero.

where $0 < \alpha < 1$ and M is the share of unskilled labour. Since the total mass of sectors in the economy is normalized to 1, $x(t)$ also denotes the aggregate employment in manufacturing.

In light of the previous discussion and dropping time indexes for simplicity[16], we can express the skilled labor market equilibrium in percapita terms as:

$$L = \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right) M + m(A_0)n_B + m(A_1)n_A. \tag{L}$$

Eq. (L) states that, at each date, the aggregate supply of skilled labor, L, finds employment in the manufacturing firms of all $[0,1]$ sectors, x, and in the R&D laboratories of the A_0 sectors, n_B, and of the A_1 sectors, n_A.

The more micro-oriented reader may regard eq. (L) as stating that the supply of R&D resources is described by an upward sloping curve - $L - x$ - in unit R&D cost.

3 Unpatentable Research Tools

In this section we assume unpatentable basic scientific results, in order to depict a pre-1980 US normative environment. Interestingly, this is closer to the current Chinese, Brazilian, Mexican, Japanese, Korean, and Indian patenting regimes. Also the current European patenting regime - still heterogeneous[17], with more restricted patent subject matter[18] - shares many features of this scenario.

Lacking the patent protection of the first half-ideas, the innovative process would need to resort to non-profit motivated R&D organizations to take place: publicly funded universities and laboratories have often been motivated by the induced scientific spillover on potentially marketable future technical applications.

In our model, public R&D is liable to an important form of moral hazard: since researchers get paid regardless of the profitability of their discoveries,

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[16] Of course time dependence is implicit, as employment variables, wage, and the mass of sectors in which a half idea is present, respectively absent, keep changing over time, except in the steady state.

[17] Strong research exemptions being present in countries, such as Belgium and Germany.

[18] Unlike the US Patent Code, stressing the "utility" of a protected idea, the European Patent Convention stresses the clearly defined "industrial applicability" of the patented object. This renders the patentability of each research tool more disputable.

their activity is "curiosity driven", and their rewards are not aligned to downstream needs. Hence their efforts might, from a social viewpoint, be wrongly targeted. To stylize the partially "un-focussed" research behavior of the public researchers, we assume that public researchers are totally indifferent to sectorial profitability: when in a sector ω that lacked a half-idea, i.e. belonged to A_0, a research tool appears, i.e. it becomes A_1, the public R&D workers keep carrying out basic research in that sector. Given our technological assumptions, this labour is redundant from the economic view point. This may represent the case of university researchers who keep investigating along intellectual trajectories even when they know that no private firm will ever profit from adapting to their market the new knowledge they may create. Unguided by the invisible hand, researchers will keep devoting their efforts just to prove that they are able to re-invent a second, third, ..., n^{th} genial - but socially useless - idea aimed at enriching their *cv* and justifying their academic carrier.

Formally, we will assume from here on that the public researchers are allocated across different industries according to a uniform distribution. This assumption emphasizes in a simple way the role of markets in providing the R&D laboratories with the right incentive and to urge them to divert their resources from the temporarily unimportant projects and quickly reallocate them towards more profitable aims.

We also make the assumption that the government exogenously sets the fraction, $\bar{L}_G \in [0, L]$, of population of skilled workers to be allocated to the heterogenous research activities conducted by universities and other scientific institutions and funds it by lump sum taxes on consumers. The assumption of lump sum taxation guarantees that government R&D expenditure does not imply additional distortions on private decisions.

The fixed amount of skilled workers, $\bar{L}_G$, hired in the basic public R&D being uniformly spread over the product space is also equal the per sector amount of R&D. Therefore, each basic research labour unit[19] has a probability per unit of time of making a discovery equal to $\theta_O \equiv \lambda_0 \bar{L}_G^{-a}$. Therefore the probability that in any given A_0 sector a useful half idea will appear is $\bar{L}_G \theta_B \equiv \bar{L}_G^{1-a} \lambda_0$, whereas the probability that an existing half idea generates a new marketable product is $n_A \theta_A = n_A^{1-a} \lambda_1$. For clarity of interpretation, we stress that every university is full of faculty who invent things that are directly

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[19] Adjusted for population, according to the macroeconomic model detailed in the Appendix.

useful in production: electrical engineers, mechanical engineers, aeronautical engineers, civil engineers, materials scientists, horticultural scientists, soil scientists, plant geneticists, crop scientists, poultry scientists, chemists, and applied mathematicians, etc. In our framework the time they devote to applied R&D - patentable in all regimes - is formally equivalent to their running their own applied R&D firms. Hence the basic research figures only select the relevant research input for inventing non-directly applicable ideas.

Let us define v_L^0 as the value - normalized by population - of a monopolistic firm producing the top quality product in a sector $\omega \in A_0$, and v_L^1 as the value - normalized by population - of a monopolistic firm producing the top quality product in a sector $\omega \in A_1$. These two types of quality leaders - competing instantaneously a la Bertrand - both earn the same profit flow[20], π, but the first type has a longer expected life, before being replaced by the new quality leader, i.e. by the patent holder of the next version of the kind of product it is currently producing. In sectors that are currently of type A_0 the applied R&D firms cannot enter because there is no half idea to be exploited: they shall wait until the public researcher invent one, causing that sector to switch into A_1. Instead, in an A_1 sector applied R&D firms hire skilled workers in order to complete the freely available half idea. Since there is free entry into applied research, the R&D firm's expected profits are dissipated[21] and transferred to skilled workers.

In equilibrium - after defining r as the relevant interest rate - the following equations will hold at any date:

$$\begin{aligned} w_s &= \lambda_1 n_A^{-a} v_L^0 && \text{(3a)} \\ r v_L^0 &= \pi - \bar{L}_G^{1-a} \lambda_0 \left(v_L^0 - v_L^1 \right) + \frac{d v_L^0}{dt} && \text{(3b)} \\ r v_L^1 &= \pi - n_A^{1-a} \lambda_1 v_L^1 + \frac{d v_L^1}{dt}. && \text{(3c)} \end{aligned}$$

Eq. (3a) is the free entry condition[22] in downstream research in any given

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[20] In the Appendix we prove that in equilibrium in each sector and at any date the population-adjusted profit flows are constant and equal to $\pi = (\gamma - 1) \frac{1}{1-\alpha} M$, where $\gamma > 1$ is the size of each product quality jump, $0 < \alpha < 1$ is the skilled labour elasticity of output and M is the per-capita mass of unskilled labour.

[21] Due to perfecly efficient financial market that completely diversify the portfolios of risk averse savers.

[22] As Aghion and Howitt's (1992) R&D arbitrage equation.

sector $\omega \in A_1$, equalizing the unit cost of R&D (the skilled wage) to the marginal expected gains - the per unit time probability flow $\lambda_1 n_A^{-a}$ of inventing the next version final product multiplied by the value[23] of its patent, v_L^0. Eq. (3b) states that perfectly efficient financial markets lead v_L^0 to the unique value such that the risk free interest income[24] achievable by selling the stock market value of a leader in an A_0 industry, rv_L^0, equals the flow of profit π minus the expected capital loss from being challenged by a half-idea on a better product in the case a follower appears, $\bar{L}_G^{1-a}\lambda_0\left(v_L^0 - v_L^1\right)$, plus gradual appreciation in the case of such event[25] not occurring, $\frac{dv_L^0}{dt}$.

Eq. (3c) equals the risk free income per unit time deriving from the liquidation of the stock market value of a leader in an A_1 industry, rv_L^1, and the relative flow of profit π minus the expected capital loss deriving from the downstream applied researcher firm's endeavour, $n_A^{1-a}\lambda_1 v_L^1$, plus the gradual appreciation if replacement does not occur, $\frac{dv_L^1}{dt}$.

The jump processes occurring at the industry level are independent across industries. But the law of large number transforms flow probabilities into deterministic flows. Hence, after aggregating over the set of sectors, the dynamics of the mass of industries is described by the following first order ordinary differential equation:

$$\frac{dm(A_0)}{dt} = \left(1 - m(A_0)\right) n_A^{1-a}\lambda_1 - m(A_0)\bar{L}_G^{1-a}\lambda_0. \tag{4}$$

From the skilled labor market clearing condition:

$$x + \bar{L}_G + (1 - m(A_0))n_A = L, \tag{5}$$

and the definition of x, we get to the equilibrium mass of per-sector challengers:

$$n_A^* = \frac{L - \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right)M - \bar{L}_G}{(1 - m(A_0))}. \tag{6}$$

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[23] Normalized by population.

[24] The reader may view r as the real interest rate, exogenous in a microeconomic framework, or equal to the constant subjective rate of time preference in an alternative macroeconomic framework with linear instantaneous utility function (e.g. Aghion and Howitt 1992, or Howitt 1999). According to our macroeconomic model detailed in the Appendix, the reader can easily verify that we have used the Euler equation (32) and the derivative of the population-adjusted firm value with respect to time in order to get to the simplified expression of safe rate of returns in terms of $r = i - g$ instead of i.

[25] Let us remind the reader that in continuous time the probability of this event tends to 1 as $dt \to 0$. This is why this probability does not appear in the equation.

Hence the dynamics of this economy is completely characterized by the differential equation system (3a)-(3c) and (4), with cross equation restriction (6).

In the steady state $\frac{dv_L^0}{dt} = \frac{dv_L^1}{dt} = \frac{dm(A_0)}{dt} = 0$. In the stationary distribution the flow of industries entering the A_0 group must equal the flow of industries entering the A_1 group.

Given the complexity of our problem, we performed numerical simulations in Matlab[26]. In all simulations a unique economically meaningful steady state equilibrium exists and it is determinate.

4 Patentable Research Tools

In this section, stylizing a post-1980 US scenario, we assume that once a research tool is invented in an A_0 sector, it gets protected by a patent with infinite legal life. The effective life of a patent will be dictated by its idea's obsolescence, which is expected finite in any equilibrium we are studying. This fully privatized basic research scenario does not of course exclude the presence of public universities which patent their discoveries: in so far as it spurs innovation, private patent races determine equilibrium quantities[27] anyway. Post-1980, thanks to the Bayh-Dole and Stevenson-Wydler acts the "boundaries between public and profit-motivated science are correspondingly fuzzy." (Maurer and Scotchmer, 2004b).

The stock value of all firms is determined by privately arbitraging between risk free consumption loans, firm bonds and equities, viewed as perfect substitutes also due to the ability of financial intermediaries to perfectly diversify portfolios and eliminate risk[28]. As in the previous section, the value of the manufacturing monopolistic firms is related to their profits, their expected

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[26] The files .mod used to simulate the model in Dynare are available from the authors on request. A full description of the numerical analysis performed is provided in Appendix 2.

[27] This is similar to introducing public R&D into Aghion and Howitt's (1992) model: the equilibrium value of n would not change, provided public research is not higher than the equilibrium amount determined by a fully private R&D scenario.

[28] Hence, despite individuals' being risk averse, average returns will be deterministic, the risk premia will be zero, and agents will only compare expected returns. As usual in this class of models, we invoke the law of large numbers, which allows individuals who invest in a continuum of sectors with idiosyncratic risk, thereby transforming probabilities into frequencies.

capital losses (due to obsolescence) and stock market gains. In particular, let v_L^0, and v_L^1 denote respectively the stock market values of an A_0 industry quality leader and of an A_1 industry quality leader. Let v_A, denote the - population adjusted - present expected value of being a research tool patent holder running a downstream applied R&D firm, operating in an A_1 industry and aiming at becoming a new quality leader. Such a firm - similarly to Grossman and Shapiro's (1986) monopolist - will optimally choose to hire an amount n_A of skilled research labour in order to maximize the difference between its expected gains from completing its own half idea - probability of inventing, $(n_A)^{1-a}\,\lambda_1$, times the net gain from inventing the final product, $(v_L^0 - v_A)$ - and the implied labour cost $w_s n_A$. From its first order conditions, we easily obtain the optimal applied R&D employment in an A_1 sector:

$$n_A^* = \left[\frac{(1-a)\lambda_1(v_L^0 - v_A)}{w_s}\right]^{\frac{1}{a}}. \tag{7}$$

Unlike the previous section, now only the research tool patent holder can undertake applied R&D in its industry, whereas free entry is relegated to the basic research stage, where researchers vie for inventing the half idea that will render the winner the only owner of a research tool patent worth v_A. Hence their freely entering and exiting mass will dissipate any excess earning, by equalizing wage to the probability flow $\lambda_0 n_B^{-a}$ times the value of a patent on a half idea[29], v_A.

Costless arbitraging between risk free loans and firms' equities implies that at each instant the following arbitrage equations must hold in equilibrium:

$$
\begin{aligned}
w_s &= \lambda_0 n_B^{-a} v_A && \text{(8a)}\\
r v_A &= (n_A^*)^{1-a}\,\lambda_1(v_L^0 - v_A) - w_s n_A^* + \frac{dv_A}{dt} && \text{(8b)}\\
r v_L^0 &= \pi - (n_B)^{1-a}\,\lambda_0\left(v_L^0 - v_L^1\right) + \frac{dv_L^0}{dt} && \text{(8c)}\\
r v_L^1 &= \pi - (n_A^*)^{1-a}\,\lambda_1 v_L^1 + \frac{dv_L^1}{dt} && \text{(8d)}
\end{aligned}
$$

---

[29] Unlike Grossman and Shapiro (1987), the research tool patent holder has no incentive to license, because in our framework the scale diseconomies are assumed at the industry level but not at the firm level.

The first equation, (8a), is the free entry condition in the upstream basic research sector. The second equation equalizes the risk free income deriving from the liquidation of the expected present value of the research tool patent holder in an A_1 industry, rv_A, and the expected increase in value from becoming a quality leader (i.e. completing the product innovation process), $(n_A^*)^{1-a}\lambda_1(v_L^0 - v_A)$, minus the relative R&D cost, $w_s n_A^*$, plus the gradual appreciation in the case of R&D success not arriving, $\frac{dv_A}{dt}$.

The third equation determines the stock value of a quality leader monopolist in an A_0 sector by equalizing its expected profits and capital appreciations to the risk free interest earning, rv_L^0, in case of anticipated liquidation.

Finally, equation (8d) must be satisfied by the stock value of a quality leader monopolist in an A_1 sector by equalizing its expected profits and capital appreciations to the alternative risk free interest earning.

We are assuming that even in case of licensed research tool, the licensee is required to pay a sunk cost to use the tool, which guarantees that R&D activity is non-discouraged. This avoids to impose any impediments to downstream research other than the monopolistic patentee's expected profit maximization. Section 7, on reach-through patents, analyzes an opposite case.

Plugging $w_s = \lambda_0 n_B^{-a} v_A$ into the expression of the skilled labour wage ratio (eq. 39, in the Appendix 1) and using percapita notation, we obtain:

$$x = \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right)M = \min\left(\frac{n_B^a}{\lambda_0 v_A}, 1\right)\left(\frac{\alpha}{1-\alpha}\right)M. \tag{9}$$

Therefore the skilled labor employment in the manufacturing sector is inversely related to the market value of patented research tools. In fact, anticipating higher valued research tools draw more skilled labor from the manufacturing plants into the basic research laboratories, thereby increasing the manufacturing unskilled/skilled labor ratio and consequently raising skilled labor marginal productivity and the relative wage. Since the patent on a half-idea derives its value from the expectation of future direct production of a marketable good, v_A is in turn pinned down by v_L^0. Therefore, the equilibrium value of the skilled wage is indirectly related to the stream of profits expected from the future commercialization of the product of the completed idea. Unlike the traditional Schumpeterian innovative process, the skilled wage here does not immediately incorporate the discounted expected value of the next commercially fruitful patent, but it does so only one step ahead: the value of the future monopolist is scaled down to current R&D labor wage by the composition of two innovation probabilities.

Let us remind that the skilled labor market clearing condition states:

$$x + m(A_0)n_B + (1 - m(A_0))\, n_A^* = L \tag{10}$$

Hence, since wages are pinned down by the optimal firm size and by the zero profit conditions in the perfectly competitive basic R&D labor markets, the unique equilibrium per-sector mass of entrant basic R&D firms consistent with skilled labor market clearing (10) is determined by solving equation (10) for n_B:

$$n_B = \frac{L - x - (1 - m(A_0))n_A^*}{m(A_0)}. \tag{11}$$

Notice that unlike the public researchers, in this completely privatized scenario, basic researchers target their activity only in the A_0 sectors.

To complete our analysis, let us look more closely at the inter-industry dynamics depicted by Figure 1. In the set of basic research industries a given number of perfectly competitive (freely entered) upstream researchers, n_B^*, have a flow probability of becoming applied researchers, while in the set of the applied R&D industries each of the n_A^* per-industry applied researchers has a flow probability to succeed. Hence the industrial dynamics of this economy is described by the following first order ordinary differential equation:

$$\frac{dm(A_0)}{dt} = (1 - m(A_0))\, \lambda_1 \left(n_A^*\right)^{1-a} - m(A_0) \left(n_B\right)^{1-a} \lambda_0. \tag{12}$$

System (8b)-(8d) and eq. (12) - jointly with cross equation restrictions (9) and (11) - form a system of four first order ordinary differential equations, whose solution describes the dynamics of this economy for any admissible initial value of the unknown functions of time v_L^0, v_L^1,v_A, and $m(A_0)$.

In a steady state, $\frac{dv_L^1}{dt} = \frac{dv_L^0}{dt} = \frac{dv_A}{dt} = \frac{dm(A_0)}{dt} = 0$.

Given the analytical complexity of such system we resorted to numerical analysis[30]. In all numerical simulations, the steady state exists, it is unique and it is saddle point stable for any set of parameter values[31]. Therefore, given an initial condition for $m(A_0)$, there is (locally) only one initial condition for v_L^0, v_L^1, and v_A such that the generated trajectory tends to the steady state vector: the equilibrium is determinate.

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[30] The files .mod used to simulate the model in Matlab are available from the authors on request. Appendix 2 describes all the main steps of our numerical analysis.

[31] Sensitivity analysis has not been shown for the sake of conciseness. However, all code files and data are available.

Interestingly, the introduction of R&D subsidies is easily done by replacing w_s with $w_s(1-s)$ - where subsidy rate is $0 \leq s \leq 1$ - in equations (8a), (8b), and (7), but not in equation (9).

4.1 Does Privatization Really Kill "Curiosity"

In our previous model of unpatentable research tools we assumed that non-profit motivated basic researchers, being driven only by "curiosity", would explore potentially interesting scientific ideas on the whole product space, with the risk of discovering smart but inapplicable ideas in A_1. Instead, in the patentable research tools case, we have assumed that as soon as basic researchers - or the universities where they work - feel pressed to investigate only where profitable patents could be obtained, they will immediately decide to always target their research on A_0. This is a very strong assumption. In fact, despite employer's pressures and university patent promotion offices, everyday life gives plenty of examples of basic researchers still following "curiosity" and not pursuing profitable opportunities. Therefore, a more realistic assumption to work with in the patentable research tools regime is the following: at each date, a basic researcher with probability χ chooses to research on A_0 and with probability $1-\chi$ chooses to research on $[0,1]$, with $\chi \in [0,1]$ indicating the degree of targetness of market oriented research institutions.

Notice that in this formulation, the probability that the researcher would end up researching on A_0 endogenous, which is a desirable property, as we want to explain the equilibrium intersectoral dynamics. Such probability is $\chi + (1-\chi)m(A_0)$, which increases in $m(A_0)$: when scientific ideas are the relatively scarce resource, also "curiosity driven" research is very useful.

We can now extend the previous privatized scenario to this more realistic set up, by changing only eq.s (8a), (8c) and (12) into:

$$w_s = \lambda_0 n_B^{-a} \left[\chi + (1-\chi)m(A_0)\right] v_A \tag{13a}$$

$$r v_L^0 = \pi - \left[\left(\chi + (1-\chi)m(A_0)\right) n_B\right]^{1-a} \lambda_0 \left(v_L^0 - v_L^1\right) + \frac{dv_L^0}{dt} \tag{13b}$$

$$\frac{dm(A_0)}{dt} = \left(1-m(A_0)\right) \lambda_1 \left(n_A^*\right)^{1-a} - m(A_0) \left[\left(\chi + (1-\chi)m(A_0)\right) n_B\right]^{1-a} \lambda_0 \tag{13c}$$

Notice that since $\chi + (1-\chi)m(A_0) < 1$, we conjecture that the skill premium and the completion rate fall as χ decreases, thereby leading A_1 to increase and A_0 to shrink. In turn this should dilute research downstream and congest it upstream.

The model presented in this section contemplates the previous section one as an extreme case in which $\chi = 1$. It is important to remark that $\chi < 1$ could not only be due to the inability of profit seeking basic research institutions to force scientists to direct their inventive activity in the right way, but it could also represent a fundamental impossibility in doing so due to the unpredictable direction of scientific discoveries. Hence, a low level of χ, far from stigmatizing the "curiosity driven" feature of basic research, should emphasize its important where research is fundamentally unpredictable. The crucial point is that *not all* basic research is undirectable, which gives scope to its privatization to potentially improve the system's innovative performance.

4.2 Blocking Patents

If upstream findings are patentable downstream research can be blocked if the patent holder neither undertakes research nor licenses the protected research tool. In this Schumpeterian framework the incumbent monopolist in the corresponding final good sector is the natural suspect of such anti-innovative behaviour. In fact, by appropriating the patent on a research tool and stopping R&D it will eliminate expected obsolescence on its product, causing its stock market value to jump up to $\frac{\pi}{r}$. Hence, at least in the steady state, the incumbent monopolist will buy the patent in order to block innovation in that sector if its willingness to pay for the research tool is higher than the outsiders' reservation price, that is if and only if

$$v_A < \frac{\pi}{r} - v_L^0.$$

Simple algebra show that this holds if and only if:

$$\left(\frac{\lambda_1}{\lambda_0}\right)^{\frac{1}{a}} \left(\frac{v_L^0 - v_A}{v_A}\right)^{\frac{1}{a}} (1-a)^{\frac{1-a}{a}} a < \frac{v_L^0 - v_L^1}{v_A}. \tag{14}$$

Since v_L^0, v_L^1, and v_A are endogenous, we cannot reach an analytical conclusion. Our numerical simulations of the privatized economy show that this is certainly satisfied at realistic values[32] of the parameters, which points to

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[32] In Section 7 we will show how we have obtained them.

a potentially serious blocking patent concern, which, by coupling static inefficiency with dynamic inefficiency, practically vanishes the beneficial side of the Schumpeterian dilemma. Fortunately the usual practice addresses the well know problem[33] of broad intellectual property rights, as, according to Maurer and Scotchmer (2004a, p.90) courts "usually approve arrangements that remove blocking patents so that firms can bring technologies to market." The typical arrangement is compulsory licensing of the patented innovative tool.

5 Numerical Comparisons

Our simulations[34] suggest that an economy in which public basic research is conducted in a non-profit oriented manner can induce less or more innovations than an economy in which basic R&D is privately carried out. The privatized economy outgrows the public basic research economy when the applied R&D productivity parameter, λ_1, becomes very low: in such cases the equilibrium innovative performance of the private economy with patentable research tools becomes better than the equilibrium growth performance of the economy with a public R&D sector. In fact, if λ_1 is very small or λ_0 is high, the flow out of A_1 will be scarce, whereas the flow out of A_0 will be intense. Therefore in the steady state $m(A_0)$ will be small, thereby exalting the wasteful nature of the public R&D activity uniformly diluted over $[0,1]-A_0$: in this case the social cost of a public R&D blind to the social needs signalled by the invisible hand would overwhelm the social costs of the restricted entry into the applied R&D sector induced by the patentability of research tools.

Patent data are indicators for the innovative performance of the economic system. Well known data suggest that in the U.S. the ratio of the patents granted each year to US residents on applied R&D expenditure per year (in year 2000 dollars) decreased by about four fifths from 1953 to 1982. This suggests the existence of an increasing complexity in the applied R&D, because prior to 1980 most patents were applied. A reader may conjecture that

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[33] This is an old problem in the history of patents. As reported by Scotchmer (2004, p. 14), "James Watt (d. 1819) used his patents to block high-pressure improvements... Watt's refusal to license competitors froze steam-engine technology for two decades." Fortunately, patent legal life was not as long as assumed in our model!

[34] The codes we have used are available upon request.

a public innovation infrastructure poor of selective economic incentives could have been acceptable in a world in which the industrial applications of basic scientific discoveries were rather straightforward. In the modern industry, in which applications of science are eagerly searched by often highly sophisticated downstream researchers, curing the inefficiencies of basic research may become the top priority for a steadily growing economy. This might have motivated the switch in the US patenting rules in the early Eighties and at the same time may provide an explanation for the growing relative disadvantage of the European, Asian and Latin American systems of innovation, in which the protection of research tools is not guaranteed. The next section tests this conjecture to the data.

6 Calibration Analysis

In this section we calibrate our model with U.S. data from 1975 to 1981. Our exercise, among other things, will obtain an estimation of the complexity of basic R&D, summarized in our model by the basic/applied productivity parameters, λ_0 and λ_1, whose evolution cannot be inferred by patent statistics, also because in the Seventies basic R&D outcomes could hardly be patented in the US. Consistently with our theoretical model, we use only skilled and unskilled labour as inputs and numbers of qualified innovations as R&D output, as represented by patents. Moreover, all variables are normalized by population.

6.1 Productivity Parameters

By solving for the steady state values of the variables in a way consistent with the data[35] we are able to get the values for the basic/applied R&D productivity parameters, λ_0 (figure 2) and λ_1(figure 3).

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[35] See Appendix 2 - available from the authors upon request - for a complete desription of the data we have used.

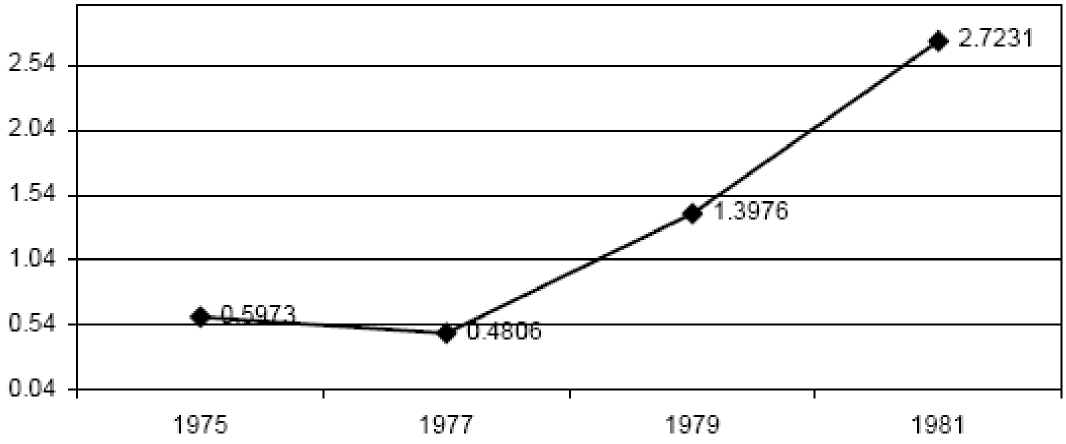

FIGURE 2: BASIC RESEARCH PRODUCTIVITY
Calibration for the US data from 1975 to 1981

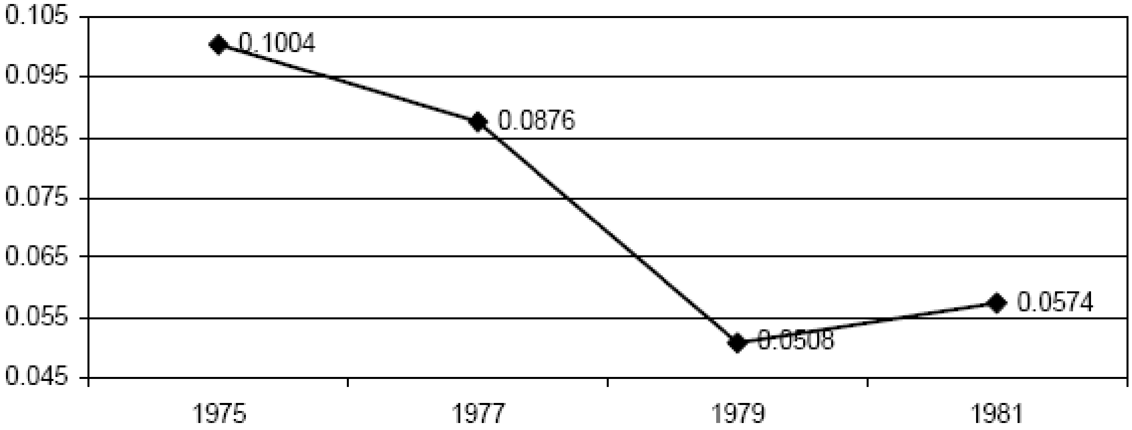

FIGURE 3: APPLIED RESEARCH PRODUCTIVITY
Calibration for the US data from 1973 to 1981

As the reader can notice, during the Seventies R&D complexity increased in applied R&D whereas it decreased in basic R&D. Hence, in principle, the relative advantage for the patentability of research tools over the public basic R&D system was getting more and more desirable.

In this section we utilise the previously estimated values of the technological parameters as well as all the previously described relevant exogenous data to compute the hypothetical steady state equilibrium of the two scenarios - unpatentable research tools versus patentable research tools - for each other year from 1975 to 1981. Data were available only for these years, but this matches our interest in the steady state computations, that we assumed approximated in a couple of years. If the simulated privatized economy outgrew the unpatentable R&D scenario in the relevant period immediately before and a little after the US turning point we could say that the 1980 US normative change was the rational institutional response to underlying technological modifications, as if politicians literally simulated the effects of the reformation within their minds before deciding to change the laws.

In our exercise, we compare the steady state equilibrium innovative performance of the patentable research tool scenario not only with the actual performance in those years, but also with a hypothetical public scenario constrained to employ the same number of basic researchers as would the privatize system have done. This allows us to purge the comparison from different levels of employment and allows us to focus on the induced efficiency gains from research tool patentability. In fact, the endogenous relative public sector inefficiency in channelling researcher's effort only in the sectors where firms need a research tool is compared with the under-incentive effect of the patented research tools in the downstream research.

The following Figure 4 lists the comparative innovation rates in the two scenarios:

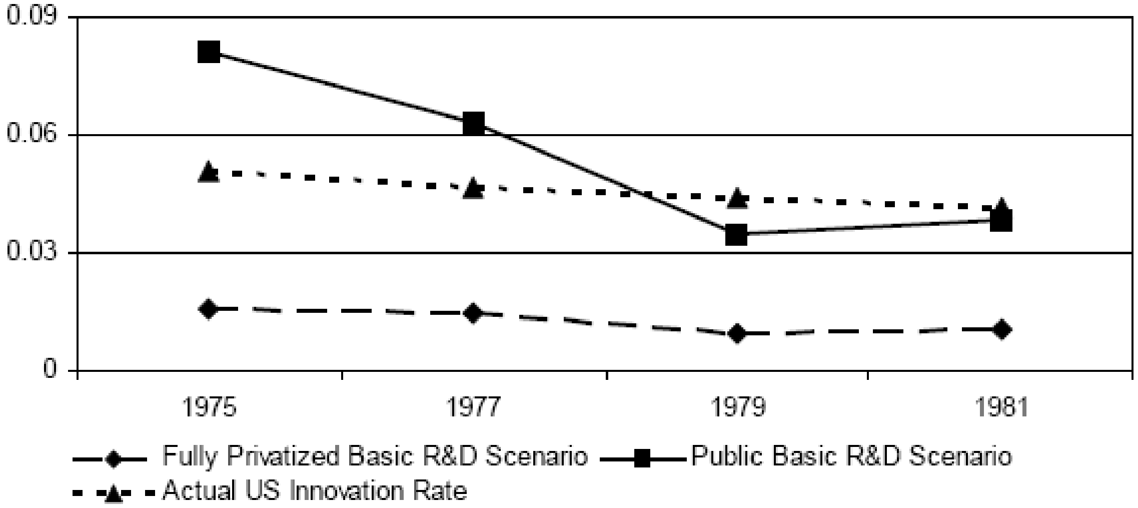

FIGURE 4: COMPARISON BETWEEN THE INNOVATIVE PERFORMANCES
Calibration on the US data from 1973 to 1981

(15)

We can notice from Figure 4 that throughout the decade the unpatentability of the basic scientific findings imposed less inefficiency to the US innovation system than the monopolization of research tool use would have implied. Had the policy makers or the courts been aware of this probably they would have postponed the patentability of research tools, which instead prevailed at the beginning of the Eighties. Therefore our analysis suggests that the policy change in favour of the research tools patentability occurred in the United States from the early Eighties was not the best institutional reaction to the increase in R&D complexity.

6.2 Partially Undirectable Basic Research

How robust are our results to the impossibility to avoid "curiosity driven" basic research? We could repeat our comparative simulations for the case depicted in Section 4.1. Since we have no prior assumption on the degree of impossibility for market driven universities to target basic researcher's creativity towards sectors A_0, we cannot assume $\chi = 1$. Simulating the model an intermediate set of parameters can be important to gain realism as well as to test the robustness of our results. Our general algorithm is a straightforward extension of the one just followed, with the only difference of computing the benchmark privatized values by means of eq.s (13a), (13b) and (13c) instead of eq.s (8a), (8c) and (12). We avoid reporting our detailed results to save space, however in all our attempts the performance of the privatized basic research scenario was worse than that associated with $\chi = 1$.

7 Research Exemption and Reach-Through Licenses

A patent gives the inventor the exclusive rights to manufacture, use or sell the invention. But it is more important to stress that all these rights are *veto*-rights. In this section we develop a third scenario that emphasizes the effect of ex-post bargaining between an upstream patent holder and its downstream developer: an innovation (a completed half idea) can be patented and yet infringe another patent (the patented research tool). This kind of strategic R&D environment is known as "Research Exemption", and it is subject to intense juridical controversies[36], following the famous Supreme Court decision on Madey *v.* Duke University suit, which practically eliminated the possibility of appealing to it, except under very narrow circumstances. In cases where access to research tools through the marketplace is highly problematic, a research exemption is deemed desirable (Mueller, 2004).

Green and Scotchmer's (1995) model pioneered microeconomic research on this important issue[37]. In order to cast their insight in our general equilibrium framework, we assume that the new final product is patentable but infringes its research tool. Ex post bargaining is rationally expected to transfer to the basic research patent holder a fraction $0 < \beta < 1$ of the value of the final product patent, representing its relative bargaining power. Unlike Green and Scotchmer's (1995) assumption of a unique downstream researcher, we here assume that the downstream unauthorized research with a patented research tools can be carried out by a multitude of freely entrant R&D firms, thereby implying a demand effect on R&D inputs dissipating expected profits. Our analysis is also valid in the case of reach-through licensing agreements, which seem pervasive in the US. "For research tools ... [r]oyalities would be

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[36] See Mueller (2004) for a detailed discussion of the research exemption debate in the US.

[37] See Scotchmer (2004, section 5.2) for an accessible exposition of this complex issue.

pass-through royalties from the product developed to the tool." Maurer and Scotchmer (2004b, p. 236). We first analyze non-exclusive licenses, while the next subsection will study exclusive pass-through licensing agreements. In all our cases, we assume that the ultimate patent on the final product improvement can be granted to only one firm: the first to invent it.

Let v_B,v_L^0, and v_L^1 denote respectively the present expected value of a basic blocking patent (v_B), an A_0 industry quality leader (v_L^0), and an A_1 industry challenged leader (v_L^1).

Costless arbitrage between risk free activities and firms' equities imply that at each instant the following equations shall hold in equilibrium:

$$
\begin{aligned}
w_s &= \lambda_0 n_B^{-a} v_B && \text{(16a)}\\
r v_B &= \lambda_1 n_A^{1-a}\left(\beta v_L^0 - v_B\right) + \frac{dv_B}{dt} && \text{(16b)}\\
w_s &= \lambda_1 n_A^{-a}\left(1-\beta\right) v_L^0 && \text{(16c)}\\
r v_L^0 &= \pi - n_B^{1-a}\lambda_0\left(v_L^0 - v_L^1\right) + \frac{dv_L^0}{dt} && \text{(16d)}\\
r v_L^1 &= \pi - n_A^{1-a}\lambda_1 v_L^1 + \frac{dv_L^1}{dt} && \text{(16e)}
\end{aligned}
$$

Equation (16a) is the zero profit condition of a free entrant basic R&D firm in an A_0 industry, equalizing the skilled wage and the probability $\lambda_0 n_O^{-a}$ of inventing a half idea times the value v_B of the resulting blocking patent.

Equation (16b) states that financial arbitrage pins down the unique value of the blocking patent that equals the risk free income from its sale, rv_B, to the expected present value of maintaining it in an A_1 industry. These are the expected increase in value deriving from someone else's - the n_A downstream researchers' - discovering the industrial application, plus the gradual appreciation in the case of someone else's R&D success not arriving, $\frac{dv_B}{dt}$.

Equation (16c) is the free entry condition for downstream completers that rationally expect to appropriate only fraction $1-\beta$ of the value of the final good monopolist. Notice that unlike in Section 5, the expectation of ex-post bargaining or the presence of reach-through licenses introduces a negative incentive effect of downstream innovation, because the infringer's use of a research tool can appropriate only a fraction of the value of its marginal product.

The last two equations have the usual interpretation.

It is important to note that our results do not hinge on assuming that the first stage patent holder undertakes no applied R&D. In fact, the free entry condition (16c) dissipates all excess profits from doing so: the research tool patent holder, by hiring a marginal unit of skilled labour to complete its patent would increase its expected gains by $\lambda_1 n_A^{-a} (1-\beta) v_L^0 - w_s = 0$. Hence, it would just be equivalent to one of the free entrants into downstream R&D. Therefore, our model is consistent with an indeterminate R&D participation of the first stage blocking patent holder.

It is also important to notice that free entry into downstream research vanifies any attempt to resort to ex ante licensing, which would instead hold if, as Scotchmer and Green (1995), Scotchmer (1996), Denicolo (2000), and Aoki and Nagaoka (2007), we restricted entry to the second stage of R&D to one completing firm.

As in the previous sections, the industrial dynamics of this economy is described by the following first order ordinary differential equation:

$$\frac{dm(A_0)}{dt} = (1 - m(A_0))\, \lambda_1 \left(n_A\right)^{1-a} - m(A_0) \left(n_B\right)^{1-a} \lambda_0. \tag{17}$$

These equations, supplemented with the skilled labour market equilibrium condition

$$x + m(A_0) n_B + (1 - m(A_0))\, n_A = L \tag{18}$$

and by eq. (9) for x determine the equilibrium trajectories.

All numerical solutions we have searched show the existence of a unique and determinate steady state vector.

Also in this case, we simulated the private basic R&D scenario using the previously found exogenous parameters and compared it with a public upstream research scenario constrained to the same basic research employment as in the privatized case. The implied steady state equilibrium innovation rates are shown in the figure 5:

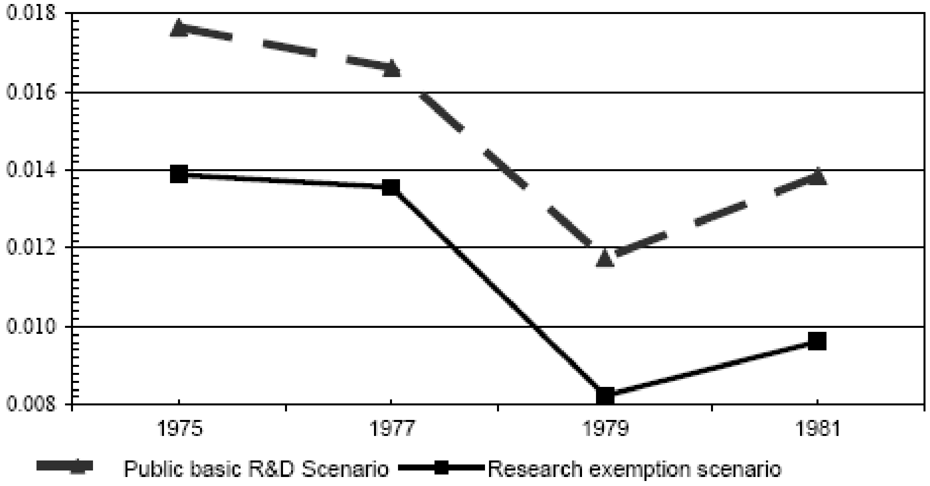

FIGURE 5: COMPARISON OF THE INNOVATIVE PERFORMANCES
Calibration on the US data from 1975 to 1981

As the reader can see, even coupled with research exemption and/or reach-through agreements would the patentability of basic knowledge not be desirable: despite correcting the public research inefficiency, it would have depressed applied R&D too much.

8 Kremer's Buy-Out Mechanism

Michael Kremer (1998) suggested a mechanism to encourage innovation without incurring in the efficiency losses associated with patent generated monopolies. The main focus of his paper was on final good monopolies. In this work we concentrate on the effects of intellectual property only on basic research findings, intended as research tools useful to invent new products. Hence to be consistent with the other scenarios, we will develop a scenario in which Kremer's mechanism is used only in the basic research outcomes.

Kremer (1998) imagines a mechanism in which the government elicits information in order to buy out the patent at a price that reflects the full innovation value. The market value of an invention is likely to be known by the rivals of the firm which has invented it. Hence the government appropriates the patent and auctions it to the rival firms. The winning bid will truthfully reveal the auctioneers' private values because with small probability the government commits to deliver the patent to the highest bidder. With the complementary probability, the government offers the patent back to the inventor at the winning bid price - to make sure the rivals' value is not too low - and, if the inventor does not buy the patent back, the government will transfer to the inventor a mark up times the winning bid and immediately thereafter it will put the innovation into the public domain. The mark up is meant to capture the ratio of total surplus to firm's profits. According to Kremer, this reward would better align the inventor's efforts to the approximate social benefits from the innovation.

We will adopt a conservative position, by assuming that the government pays the inventor the same price at which all the other firms would have bought the patent on its research tool. Clearly, assuming a higher mark up would stimulate more innovation, but we stress the lowest benchmark case due to its easier real world implementation.

Our computations are facilitated by the assumption of an infinite number of sectors, which allows the government to assign the patent to the highest bidder only in a zero measure set of industries, with no change in the resulting aggregate dynamics. This is a useful approximation of a multisectoral reality.

In our version of Kremer's mechanism, both the basic R&D and the downstream R&D have free entry, because both kinds of discoveries are publicly accessible. Yet, bidders will offer a positive value to the research tool by computing the stock market value of a research tool patent holder, in the (unlikely) event of the government's selling the innovation. This "theoretical" value of an applied R&D firm, v_{TA}, is what a successful basic researcher would earn (from the government). Hence the usual free entry condition will dissipate expected R&D profits upstream. Consequently, upstream researchers will target the right sectors, despite downstream research almost never being monopolized. Therefore, the following equations will hold in a

Kremer equilibrium:

$$\begin{aligned} w_s &= \lambda_0 n_B^{-a} v_{TA} && \text{(19a)} \\ r v_{TA} &= \lambda_1 \left(n_{TA}^*\right)^{1-a} \left(v_L^0 - v_{TA}\right) - w_s n_{TA}^* + \frac{d v_{TA}}{dt} && \text{(19b)} \\ w_s &= \lambda_1 n_A^{-a} v_L^0 && \text{(19c)} \\ r v_L^0 &= \pi - n_B^{1-a} \lambda_0 \left(v_L^0 - v_L^1\right) + \frac{d v_L^0}{dt} && \text{(19d)} \\ r v_L^1 &= \pi - n_A^{1-a} \lambda_1 v_L^1 + \frac{d v_L^1}{dt} && \text{(19e)} \end{aligned}$$

Equation (19a) is the zero profit condition of a free entrant basic R&D firm in an A_0 industry, equalizing the skilled wage to the probability $\lambda_0 n_{TA}^{-a}$ of inventing a half idea times the theoretical value v_{TA} of the resulting applied patent. Interestingly, v_{TA} is endogenously determined in general equilibrium. Hence possible positive innovative effects of Kremer's auctions are dampened, via lower v_{TA}, by higher expected obsolescence and by higher R&D input prices (higher skill premium w_s).

Equation (19b) states that financial arbitrage pins down the unique value of the theoretical value v_{TA} of the downstream applied firm that would maximize its profits, by optimally choosing skilled labour employment n_{TA}. The first order conditions yield the optimized value of applied R&D employment:

$$n_{TA}^* = \left[\frac{(1-a)\lambda_1 (v_L^0 - v_{TA})}{w_s} \right]^{\frac{1}{a}}. \tag{20}$$

Plugging this expression for n_{TA}^* into (19b) determines its stock market value. Expecting this value, the bidding firms willing to monopolize downstream research by appropriating the research tool would bid v_{TA}. This is the value that the government pays to the inventor of this research tool in exchange for appropriating the patent and putting it into the public domain.

Free access to the research tools triggers a patent race in each A_1 industry, thereby pinning down quantities, wage and prices so that the zero expected profit condition (19c) holds. Notice the difference between the theoretical applied R&D labour employment, n_{TA}^*, chosen by each would-be monopolistic applied researcher firm and the actual free entry equilibrium value, n_A, of applied R&D labour.

The final two equations determine the values of the monopolistic manufacturing producers in each A_0 and A_1 industry.

As in the previous sections, the industrial dynamics of this economy is described by the following first order ordinary differential equation:

$$\frac{dm(A_0)}{dt} = (1 - m(A_0))\, \lambda_1\, (n_A)^{1-a} - m(A_0)\, (n_B)^{1-a}\, \lambda_0. \tag{21}$$

The previous equations, supplemented by the skilled labour market equilibrium condition

$$x + m(A_0)n_B + (1 - m(A_0))\, n_A = L \tag{22}$$

and by eq. (9) for x determine the equilibrium trajectories.

The steady state is unique and determinate in all our numerical simulations.

After simulating this scenario, we plot our implied innovation rates in the following figure 6:

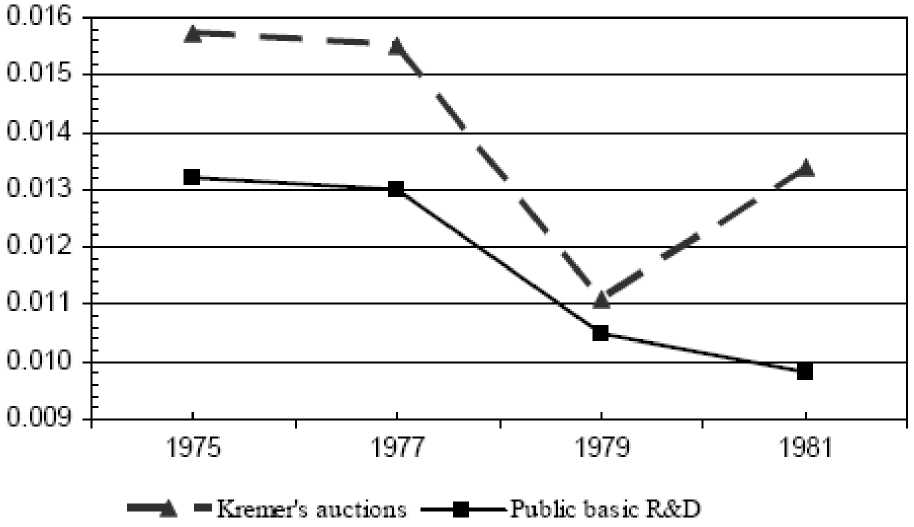

FIGURE 6: COMPARISON OF THE INNOVATIVE PERFORMANCES
Calibration on the US data from 1975 to 1981

(23)

As the reader can see, Kremer's (1998) mechanism is the only privatized scenario which dominates the public basic research case. In fact, the R&D

efficiency gains from giving upstream researchers the right targets are coupled with the freely accessible patent race to downstream R&D. Our results suggest that if policy makers had known this mechanism a couple of decades before Kremer's result they should have adopted it as a useful complement to the patentability of basic research[38].

9 Final Remarks

The debate on the effects of the patentability of research tools on the incentives to innovate is still very controversial, not only in the US but also in Europe and in other important areas of the world. This paper analyzed from a general equilibrium perspective the US policy shift towards the extension of patentability to research tools and basic scientific ideas that took place around 1980. These normative innovations have been modifying the industrial and academic lives in the last three decades, raising doubts on their desirability. The losses from the monopolization of applied research induced by intellectual property of research tools have been compared with the inefficacy of public research institutions to promptly react to downstream market opportunities.

Results are not a priory unambiguous, which forced us to use the available data to calibrate and simulate our model in order to check if the US did it right in changing their institutions around 1980. We found that maintaining free access to basic research findings would have been better for innovation despite the inefficiency of the public laboratories and universities.

We have extended the basic model to incorporate research exemptions and reach-through licensing, without modifying our main conclusions.

Interestingly, it turns out that private research would have been enhanced if the government bought out the research tool patents and rendered them publicly available to the private applied R&D firms, as suggested by Michael Kremer (1998). Notice that in such a framework basic research is indeed patentable, but the government intervention removes the restriction to the downstream patent races. This is consistent with a completely privatized

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[38] Adding R&D subsidies in Kremer's scenario would have make it overtake the actual public scenario as well. Of course the "public basic R&D scenario" of Figure 6 costs much less to the taxpayer than the actual public scenario.

research environment in which the government organizes societal knowledge procurement in a growth enhancing manner. Such third way eliminates public research inefficiency while guaranteeing perfect competition at all stages of research and development. In light of the current international negotiations on the application of TRIPs, our analysis might be helpful in providing insights from the experience of an important turning point in the US national system of innovation.

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Appendix 1

Model Details

This Appendix 1 puts our theory in the traditional quality ladder models. It may be skipped by most readers familiar with this literature or non-interested in this particular micro-foundation, who would only be interested in the results used in the text, namely eq.s (39), (41) and (43).

Time $t \geq 0$ population $P(t)$ is assumed growing at rate $g \geq 0$ and its initial level is normalized to 1. The representative household's preferences are represented by the following intertemporally additive utility functional[39]:

$$U = \int_0^{\infty} e^{-rt} u\left(t\right) dt, \tag{24}$$

where $r > 0$ is the subjective rate of time preference. Per-family member instantaneous utility $u\left(t\right)$ is defined as:

$$u\left(t\right) = \int_0^1 \ln\left[\sum_j \gamma^j d_{jt}\left(\omega\right)\right] d\omega, \tag{25}$$

where $d_{jt}\left(\omega\right)$ is the individual consumption of a good of quality $j = 1, 2, ...$ (that is, a product that underwent j quality jumps) and produced in industry ω at time t. Parameter $\gamma > 1$ measures the size of the quality upgrades. This formulation, the same as Grossman and Helpman (1991) and Segerstrom (1998), assumes that each consumer prefers higher quality products.

The representative consumer is endowed with $L > 0$ units of skilled labor and $M > 0$ units of unskilled labor summing to 1. Since labour bears no disutility it will be inelastically supplied for any level of non negative wages. Since initial population is normalized to 1, L and M will also equal, in equilibrium, the percapita supply of skilled, respectively, unskilled labour. Unskilled labor can only be employed in the final goods production. Skilled labour is able to perform R&D activities.

In the first step of the consumer's dynamic maximization problem, she selects the set $J_t(\omega)$ of the existing quality levels with the lowest quality-adjusted prices. Then, at each instant, the households allocate their income to maximize the instantaneous utility (25) taking product prices as given in the following static (instantaneous) constraint equation:

$$E(t) = \int_0^1 \sum_{j \in J_t(\omega)} p_{jt}(\omega) d_{jt}\left(\omega\right) d\omega. \tag{26}$$

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[39] We skip starting with an expectational operator in order to save notation. As the experienced reader knows, a more general setting of the consumer problem would not change results, as in our framework, due to perfectly diversifiable risks, the consumer's asset evolves deterministically in equilibrium.

Here $E(t)$ denotes percapita consumption expenditure and $p_{jt}(\omega)$ is the price of a product of quality j produced in industry ω at time $t.$ Let us define $j_t^*(\omega) \equiv \max\{j : j \in J_t(\omega)\}$ Using the instantaneous optimization results, we can re-write (25) as

$$\begin{aligned} u\,(t) &= \int_0^1 \ln\left[\gamma^{j_t^*(\omega)} E(t)/p_{j_t^*(\omega)t}(\omega)\right] d\omega = && (27) \\ &= \ln[E(t)] + \ln(\gamma)\int_0^1 j_t^*(\omega) d\omega - \int_0^1 \ln[p_{j_t^*(\omega)t}(\omega)] d\omega && (28) \end{aligned}$$

The solution to this maximization problem yields the static demand function:

$$d_{jt}(\omega) = \begin{cases} E(t)/p_{jt}(\omega) \text{ for } j = j_t^*(\omega) \\ 0 \;\; \text{otherwise.} \end{cases} \qquad (29)$$

Only the good with the lowest quality-adjusted price is consumed, since there is no demand for any other good. We also assume, as usual, that if two products have the same quality-adjusted price, consumers will buy the higher quality product - although they are formally indifferent between the two products - because the quality leader can always slightly lower the price of its product and drive the rivals out of the market.

Therefore, given the independent and - in equilibrium and by the law of large number - deterministic evolution of the quality jumps and prices, the consumer will only choose the piecewise continuous expenditure trajectory, $E(\cdot)$, of each family member that maximizes:

$$U = \int_0^\infty e^{-rt} \ln[E(t)] dt. \qquad (30)$$

Assume that all consumers possess equal shares of all firms at time $t = 0$. Letting $A(0)$ denote the present value of human capital plus the present value of asset holdings at $t = 0$, each individual's intertemporal budget constraint is:

$$\int_0^\infty e^{-I(t)} e^{gt} E(t) dt \leqq A(0) \qquad (31)$$

where $I(t) = \int_0^t i(s) ds$ represents the equilibrium cumulative real interest rate up to time $t.$

Finally, the representative consumer chooses the time pattern of consumption expenditure to maximize (30) subject to the intertemporal budget constraint (31). The optimal expenditure trajectory satisfies the Euler equation:

$$\dot{E}(t)/E(t) = i(t) - (r+g) \tag{32}$$

where $i(t) = I(t)$ is the instantaneous market interest rate at time t.

Euler equation (32) implies that a constant (steady state) per-capita consumption expenditure is optimal when the instantaneous market interest rate equals the consumer's subjective discount rate r plus the population growth rate g. Since preferences are homothetic, in each industry aggregate demand is proportional to the representative consumer's one. E denotes the aggregate consumption spending and d denotes the aggregate demand.

As for the production side, we assume constant returns to scale technologies in the (differentiated) manufacturing sectors represented by the following production functions:

$$y(\omega) = X^{\alpha}(\omega)\, M^{1-\alpha}(\omega)\,, \text{ for all } \omega \in [0,1], \tag{33}$$

where $\alpha \in (0,1)$, $y(\omega)$ is the output flow per unit time, $X(\omega)$ and $M(\omega)$ are, respectively, the skilled and unskilled labour input flows in industry $\omega \in [0,1]$. Letting w_s and w_u denote the skilled and unskilled wage rates, in each industry the quality leader seeks to minimize its total cost flow $C = w_s X(\omega) + w_u M(\omega)$ subject to constraint (33). For $y(\omega) = 1$, the solution to this minimization problem yields the conditional unskilled (34) and skilled (35) labour demands (i.e. the per-unit labour requirements):

$$M(\omega) = \left(\frac{1-\alpha}{\alpha}\right)^{\alpha} \left(\frac{w_s}{w_u}\right)^{\alpha}, \tag{34}$$

$$X(\omega) = \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha} \left(\frac{w_u}{w_s}\right)^{1-\alpha}. \tag{35}$$

Thus the (minimum) cost function is:

$$C(w_s, w_u, y) = c(w_s, w_u)y \tag{36}$$

where $c(w_s, w_u)$ is the per-unit cost function:

$$c(w_s, w_u) = \left[\left(\tfrac{1-\alpha}{\alpha}\right)^{-(1-\alpha)} + \left(\tfrac{\alpha}{1-\alpha}\right)^{-\alpha}\right] w_s^{\alpha} w_u^{1-\alpha}. \tag{37}$$

Since unskilled labour is uniquely employed in the final good sectors and all price variables (including wages) are assumed to instantaneously adjust to their market clearing values, unskilled labour aggregate demand $\int_0^1 M(\omega)\, d\omega$ is equal to its aggregate supply, $MP(t)$, at any date. Since industries are symmetric and their number is normalized to 1, in equilibrium[40] $M(\omega) = MP(t)$.

The choice of unskilled labour as numeraire imposes $w_u = 1$, from equations (34) and (35) we get the firm's skilled labour demand negatively depending on skilled (/unskilled) wage (ratio):

$$X(\omega) = \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right) MP(t) \tag{38}$$

In percapita terms,

$$x(\omega) \equiv \frac{X(\omega)}{P(t)} = \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right) M. \tag{39}$$

In each industry, at each instant, firms compete in prices. Given demand function (29), within each industry product innovation is non-drastic[41], hence the quality leader will fix its (limit) price by charging a mark-up γ over the unit cost (remember that parameter γ measures the size of product quality jumps).

$$p = \gamma c(w_s, 1) \Rightarrow d = \frac{E}{\gamma c(w_s, 1)}. \tag{40}$$

Hence each monopolist earns a flow of profit, in percapita terms, equal to

$$\begin{aligned} \pi &= \frac{\gamma - 1}{\gamma} E = (\gamma - 1)\frac{w_s x}{\alpha} \\ \pi &= (\gamma - 1)\frac{1}{1-\alpha} M. \end{aligned} \tag{41}$$

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[40] More generally, with mass $N > 0$ of final good industries, in equilibrium $M(\omega) = \frac{MP(t)}{N}$.

[41] We are following Aghion and Howitt's (1992) and (1998) definition of drastic innovation as generating a sufficiently large quality jump to allow the new monopolist to maximize profits without risking the re-entry of the previous monopoly. Given the unit elastic demand, here the unconstrained profit maximizing price would be infinitely high: that would induce the previous incumbent to re-enter.

From eq.s (41) follows:

$$\frac{\gamma-1}{\gamma}E=(\gamma-1)\,\frac{1}{1-\alpha}M\Rightarrow E=\frac{\gamma}{1-\alpha}M. \tag{42}$$

Interestingly, eq. (42) implies that in equilibrium total expenditure is always constant. Therefore, eq. (32) implies a constant real interest rate:

$$i(t)=r+g. \tag{43}$$

Appendix 2

1 Introduction

This appendix describes the detail of the calibration procedure adopted in sections 6-8 of the main text. In doing this it might be useful first to present the main data series we used in the paper. This is done in the next Section 2 of this Appendix. Section 3 explains the procedure and the algorithms adopted in the numerical analysis. In doing this, we strictly follow the structure of the paper. We present the details of the computations for each scenario in the same order as it is presented there and for each scenario an example - the 1975 - is developed. Yet the reader should keep in mind that, for the sake of conciseness, a full explanation of the models here presented is provided only in the main part of the paper.

1.1 Description of the Procedure

Our calibration procedure consists of the following four steps.

1. *FIRST STEP makes inference on the equilibrium values of the unobservable variables* λ_0 *and* λ_1 *during rhe 1975-1981 U.S. period.*
2. *SECOND STEP uses the estimated values* $\hat{\lambda}_0$ *and* $\hat{\lambda}_1$*as exogenous variables into the system of equations characterizing the steady-state equilibrium of the hypotetical scenario with patentable basic research.*
3. *THIRD STEP evaluate the innovative performances of the two basic research policy scenarios.*
4. *FOURTH STEP evaluates the impact of reach-through claims/research exemption in terms of innovation rate.*
5. *FIFTH STEP asseses the innovative performance of a perfect competitive basic research sector with Kremer's governmental patents buy-outs.*

2 The Data

Table 1 presents the data we used to perform the numerical simulation:

γ is the mark-up as estimated by Roeger (1995)[1] and Martins et al. (1996)[2];

L is the percentage of people 25 years or more who have completed at least 4 years of college, U.S. Census, Current Population Survey, Historical Tables

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[1] Roeger, W. (1995). "Can Imperfect Competition Explain the Difference between Primal and Dual Productivity Measures? Estimates for US Manu-facturing", *Journal of Political Economy 103, 2, 316-330*

[2] Martins, J. Scarpetta, S. and D. Pilat, (1996),. "Markup Pricing, Market Structure and the Business Cycle", *OECD Economic Studies 27, 71-105*

available at ://www.census.gov/population/socdemo/education/tabA-2.xls on the 01/04/08;

a is the intra-sectoral congestion parameter (as in Jones and Williams's - 1998[3] and 2000[4] - specification of the R&D technology);

$0 < \alpha < 1$ is the skilled labour manufacturing production elasticity;

$\bar{L}_G$ is the share of S&E doctorate holders in research universities and other academic institutions[5] over the U.S. total employment[6] from 1975 to 1981;

finally g (according to our model, the measure of the actual U.S innovation rate) is the number of patents granted to U.S. residents per million inhabitants[7].

We tried to make our relevant real interest rate, r, series follow a path similar to the true real interest rates through the Seventies[8]. Several different data sets are known on the real interest rates in the US in the years 1975-1981, all heterogeneous but all significantly different from the usual constant 5% benchmark level we had started our simulations with. Some estimated real interest rates were even negative in that period[9].

Table 1

	γ	L	M	a	α	r	$\bar{L}_G$	g
1975	1.68	0.139	0.861	0.3	0.1	0.035	0.00156	0.0046
1977	1.68	0.154	0.846	0.3	0.1	0.025	0.00158	0.0041
1979	1.68	0.164	0.836	0.3	0.1	0.016	0.00157	0.0031
1981	1.68	0.171	0.829	0.3	0.1	0.018	0.00166	0.0039

3 Numerical Analysis

3.1 First Step: Estimate the Unobservable

Consistently with the framework of our model, in order to estimate the unobservable during the 1975-1981 period we take the Unpatentable Research Tools as a benchmark since it was the scenario effective in the U.S. at that time.

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[3] Jones, C. and J.Williams (1998), "Measuring the Social Return to R&D", *Quarterly Journal of Economics, November 1998, Vol. 113*, pp. 1119-1135.

[4] Jones, C. and J. Williams (2000), "Too Much of a Good Thing? The Economics of Investment in R&D", *Journal of Economic Growth, March 2000, Vol. 5, No. 1,* pp. 65-85.

[5] National Science Foundation, Division of Science Resources Statistics,Science and Engineering Indicators 2006, Appendix table 5-22, available at www.nsf.gov/statistics/seind06/append/c5/at05-22.pdf on the 18/04/2008.

[6] OECD (2002) OECD Statistical Compendium, 2002#2 CD-ROM edition.

[7] WIPO, 100 Years Protection of Intellectual Property Statistics, available on http://www.wipo.int/ipstats/en/statistics/patents/, this source was also adopted by Segerstrom, P.S. (1991), "Innovation, Imitation and Economic Growth", *Journal of Political Economy, pp. 807-827.*

[8] To obtain as fine estimates of our productivity parameters as possible, we constructed ranges from different available real interest rate series consistent with their observed dynamics, but - as done by Jones and Williams (1998) and (2000) - shifted up towards the stock market average returns, which was 0.03 in the 1969-1978 decade

[9] See the estimated real interest rate (of three-month treasury bill) series constructed by Mishkin (2006, p. 88-89), based on Mishkin's (1981) method of using the after tax nominal interest rate minus expected inflation.

In order to depict a pre-1980 US normative environment, consider the economy depicted at pages 11-14 (section 3) of the main text.

In equilibrium the following equations will hold at any date:

$$
\begin{aligned}
w_s &= \lambda_1 n_A^{-a} v_L^0 && \text{(1a)}\\
rv_L^0 &= (\gamma-1)\tfrac{1}{1-\alpha}M - \bar{L}_G^{1-a}\lambda_0\left(v_L^0 - v_L^1\right) && \text{(1b)}\\
rv_L^1 &= (\gamma-1)\tfrac{1}{1-\alpha}M - n_A^{1-a}\lambda_1 v_L^1 && \text{(1c)}\\
g &= \lambda_1\left(1-m(A_0)\right)n_A^{1-a} && \text{(1d)}\\
\left(1-m(A_0)\right)n_A^{1-a}\lambda_1 &= m(A_0)\bar{L}_G^{1-a}\lambda_0 && \text{(1e)}\\
x + \bar{L}_G + (1-m(A_0))n_A &= L && \text{(1f)}\\
x &= \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right)M && \text{(1g)}\\
n_A^* &= \frac{L - \frac{1}{w_s}\left(\frac{\alpha}{1-\alpha}\right)M - \bar{L}_G}{(1-m(A_0))}. && \text{(1h)}
\end{aligned}
$$

In this first step, merely for computational purposes, the endogenous variables w_s and g (the innovation rate) together with the exogenous variables α, a, γ, $\bar{L}_G$, r, M and L, are considered parameters and given the values reported in the previous table 1.

In particular w_s is the skilled premium estimated by Krusell, Ohanian, Rios-Rull and Violante (2000)[2]; L is the skilled labour equilibrium employment in manufacturing; M is the share of the unskilled labour input in manufacturing computed as $M = 1 - L$.

This procedure - by returning a snapshot of the U.S. 1973-1981 period - allow us to punctually estimate the equilibrium values of the unobservable variable λ_0 and λ_1. The solution of the system of equations (1a)-(1h) are the steady-state values of λ_0, λ_1, $m(A_0)$, n_A^*, x, v_L^0 and v_L^1.

3.1.1 Example 1975

Consider for instance the computation of the steady-state values of λ_0 and $\lambda_1$for the year 1975. Substitute for the parameters reported in table 1 into system (1a)-(1h).

The previous system (1a)-(1h) becomes:

---

[2] Krusell, P., L. Ohanian, J.V. Rios-Rull and G. Violante (2000): "Capital-Skill Complementarity and Inequality", *Econometrica*, *68:5*, 1029-1054.

$$
\begin{aligned}
1.2946 &= \lambda_1 n_A^{-3} v_L^0 && \text{(2a)}\\
0.035 v_L^0 &= 0.6505 - 0.0108\lambda_0 \left(v_L^0 - v_L^1\right) && \text{(2b)}\\
0.035 v_L^1 &= 0.6505 - n_A^{0.7}\lambda_1 v_L^1 && \text{(2c)}\\
0.0047 &= \lambda_1 \left(1 - m(A_0)\right) n_A^{0.7} && \text{(2d)}\\
\left(1 - m(A_0)\right) n_A^{0.7}\lambda_1 &= m(A_0) 0.0108\lambda_0 && \text{(2e)}\\
x + 0.00156 + (1 - m(A_0)) n_A &= 0.139 && \text{(2f)}\\
x &= \frac{0.0957}{w_s} && \text{(2g)}\\
n_A^* &= \frac{0.0087}{(1 - m(A_0))}. && \text{(2h)}
\end{aligned}
$$

where $w_s = 1.2946$ is the skilled premium estimated by Krusell et al. (2000); L is the skilled labour equilibrium employment in manufacturing in 1975; M is the share of the unskilled labour input in manufacturing computed as $M = 1 - L$.

By solving the previous system we get the 1975's equilibrium values of the endogenous variables. In particular, the punctual estimation, according our model, of the research productivities parameters for 1973 is $\hat{\lambda}_0 = 0.5973$ and $\hat{\lambda}_1 = 0.1004$. By repeating this procedure for years 1977, 1979 and 1981 we get the series of $\hat{\lambda}_0$ and $\hat{\lambda}_1$ reported in the following figures 1 and 2 - figure 2 and figure 3 in the main text.

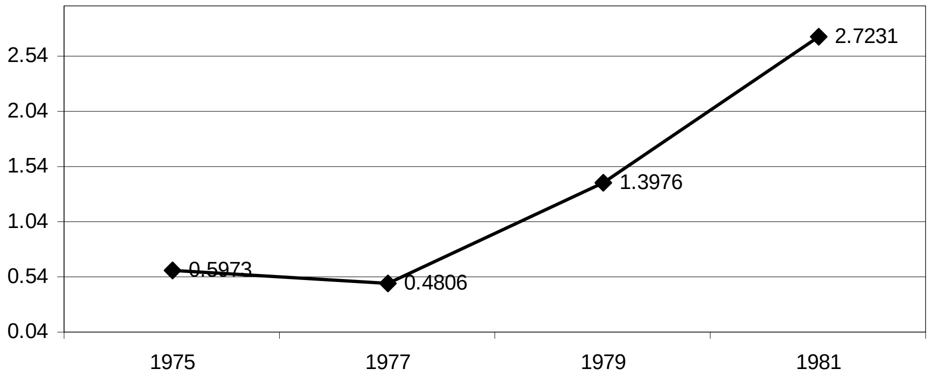

FIGURE 1: BASIC RESEARCH PRODUCTIVITY

Calibration for the US data from 1975 to 1981

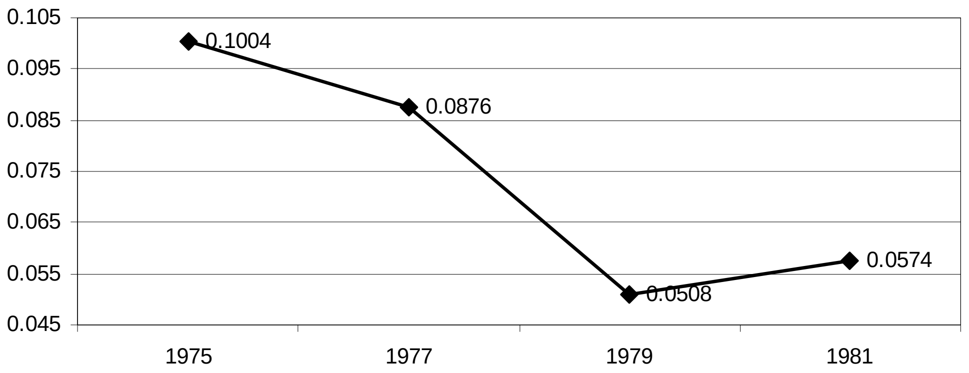

FIGURE 2: APPLIED RESEARCH PRODUCTIVITY
Calibration for the US data from 1975 to 1981

3.2 Second Step: Running the Patentable Research Tools Scenario

Consider the R&D sector described by the model explained in section 4, pags.14-18 of the paper. The following arbitrage equations must hold in equilibrium:

$$\begin{aligned}
w_s &= \hat{\lambda}_0 n_B^{-a} v_A && \text{(3a)}\\
r v_A &= \left(n_A^*\right)^{1-a} \hat{\lambda}_1 (v_L^0 - v_A) - w_s n_A^* + \frac{dv_A}{dt} && \text{(3b)}\\
r v_L^0 &= \pi - \left(n_B\right)^{1-a} \hat{\lambda}_0 \left(v_L^0 - v_L^1\right) + \frac{dv_L^0}{dt} && \text{(3c)}\\
r v_L^1 &= \pi - \left(n_A^*\right)^{1-a} \hat{\lambda}_1 v_L^1 + \frac{dv_L^1}{dt} && \text{(3d)}\\
g &= m(A_0) \left(n_B\right)^{1-a} \hat{\lambda}_0 && \text{(3e)}\\
\frac{dm(A_0)}{dt} &= \left(1 - m(A_0)\right) \hat{\lambda}_1 \left(n_A^*\right)^{1-a} - m(A_0) \left(n_B\right)^{1-a} \hat{\lambda}_0 && \text{(3f)}\\
L &= x + m(A_0) n_B + \left(1 - m(A_0)\right) n_A^* && \text{(3g)}\\
n_B &= \frac{L - x - (1 - m(A_0)) n_A^*}{m(A_0)} && \text{(3h)}\\
n_A^* &= \left[\frac{(1-a)\hat{\lambda}_1 (v_L^0 - v_A)}{w_s}\right]^{\frac{1}{a}} && \text{(3i)}\\
x &= \frac{1}{w_s} \left(\frac{\alpha}{1-\alpha}\right) M && \text{(3j)}
\end{aligned}$$

where the capped variables $\hat{\lambda}_0$ and $\hat{\lambda}_1$ denote research productivity parameters estimated in the previous section 2.

In this second step the exogenous variables α, a, γ, r, M and L are considered parameters and reported in table 1.

System (3a)-(3j) is a system of four first order ordinary differential equations, whose solution describes the dynamics of this economy for any admissible initial value of the unknown functions of time v_L^0, v_L^1,v_A, and $m(A_0)$. In a steady state, $\frac{dv_L^1}{dt} = \frac{dv_L^0}{dt} = \frac{dv_A}{dt} = \frac{dm(A_0)}{dt} = 0$.

The files .mod used to simulate the model in Dynare are available from the authors on request. In all numerical simulations the steady state exists, it is unique and it is saddle point stable for a large set of parameter values. Therefore, given an initial condition for $m(A_0)$, there is (locally) only one initial condition for v_L^0, v_L^1, and v_A such that the generated trajectory tends to the steady state vector: the equilibrium is therefore determined.

3.3 Third Step: Comparing the Main Innovative Performances

In order to make comparisons in terms of innovation in the two scenarios, we controlled for the number of researchers employed - in steady-state - in the fully-privatized basic R&D scenario; operatively:

1. after estimated the R&D productivities $\hat{\lambda}_0$ and $\hat{\lambda}_1$(*FIRST STEP*), run the system (3a)-(3j) in Dynare (*SECOND STEP*);
2. now, substitute the steady-state equilibrium employment in basic R&D according to this simulation - $n_B m(A_0)$- into the exogenously given $\bar{L}_G$ into system (1a)-(1h);
3. run the system (1a)-(1h);
4. compare the values of the innovation rates - g -.
5. The previous points 2, 3 and 4 are illustrated in detail by the following example.

3.3.1 Example 1975

After substituting for $\hat{\lambda}_0 = 0.5973$ and $\hat{\lambda}_1 = 0.1004$ and the relevant data for 1975, in the steady state, system (3a)-(3j) becomes:

$$w_s = 0.5973 n_B^{-0.3} v_A \tag{4a}$$

$$0.035 v_A = \left(n_A^*\right)^{1-a} 0.1004 (v_L^0 - v_A) - w_s n_A^* \tag{4b}$$

$$0.035 v_L^0 = 0.6505 - \left(n_B\right)^{0.7} 0.5973 \left(v_L^0 - v_L^1\right) \tag{4c}$$

$$0.035 v_L^1 = 0.6505 - \left(n_A^*\right)^{0.7} 0.1004 v_L^1 \tag{4d}$$

$$g = m(A_0) \left(n_B\right)^{0.7} 0.5973 \tag{4e}$$

$$m(A_0) \left(n_B\right)^{0.7} 0.5973 = \left(1 - m(A_0)\right) 0.1004 \left(n_A^*\right)^{0.7} \tag{4f}$$

$$0.139 = x + m(A_0) n_B + \left(1 - m(A_0)\right) n_A^* \tag{4g}$$

$$n_B = \frac{0.139 - x - (1 - m(A_0)) n_A^*}{m(A_0)} \tag{4h}$$

$$n_A^* = \left[\frac{0.0703(v_L^0 - v_A)}{w_s}\right]^{\frac{1}{a}} \tag{4i}$$

$$x = \frac{0.1052}{w_s} \tag{4j}$$

where v_A, v_L^0, v_L^1, $m(A_0)$, n_B, w_S, g, n_A^* and x are the variables endogenously determined.

Again, $\alpha = 0.1$ is the (Cobb-Douglas) production function esponent for population shares of the skilled labour input in manufacturing; $\gamma = 1.68$ is the mark-up as estimated by Roeger (1995) and Martins et al. (1996); $a = 0.3$ is the intra-sectoral congestion parameter (as in Jones and Williams's - 1998 and 2000 - specification of the R&D technology); $r = 0.035$ is the relevant interest rate; $L = 0.139$ is the skilled labour equilibrium employment in manufacturing; $M = 0.861$ is the share of the unskilled labour input in manufacturing.

The solution of the previous system is: $m(A_0)$=0.0939, n_A^* =0.0783, n_B =0.1562, v_A =1.7205, v_L^0 =13.6076, v_L^1 =12.5377, w =1.7935, x =0.0533, g =0.0153.

Let us define the steady-state number of researchers employed into basic R&D as $\bar{B}_P \equiv n_B m(A_0) = 0.0147$.

Now, consider the economy characterized by the system (1a)-(1h). In order to compare its 1975's innovative performance respect to the privatized scenario, let us control for the number of researchers employed in equilibrium into basic R&D by substituting $\bar{B}_P = 0.0147$ for $\bar{L}_G$ into system (1a)-(1h):

$$\begin{aligned} w_s &= 0.1004 n_A^{-0.3} v_L^0 && \text{(5a)} \\ 0.035 v_L^0 &= 0.6505 - 0.0311 \left(v_L^0 - v_L^1 \right) && \text{(5b)} \\ 0.035 v_L^1 &= 0.6505 - n_A^{0.7} 0.1004 v_L^1 && \text{(5c)} \\ g &= 0.1004 \left(1 - m(A_0) \right) n_A^{0.7} && \text{(5d)} \\ m(A_0) 0.0311 &= \left(1 - m(A_0) \right) n_A^{0.7} 0.1004 && \text{(5e)} \\ x + (1 - m(A_0)) n_A &= 0.1243 && \text{(5f)} \\ x &= \frac{0.0957}{w_s} && \text{(5g)} \\ n_A^* &= \frac{0.1243 - \frac{0.0957}{w_s}}{(1 - m(A_0))}. && \text{(5h)} \end{aligned}$$

By solving the previous system we get the steady-state 1975's values of the endogenous variables: $m(A_0) = 0.5563$, $n_A^* = 0.259$, $v_L^0 = 67.5018$, $v_L^1 = 42.4572$, $w_s = 10.1643$, $x = 0.0094$, $g = 0.0173$.

Now we are able to compare the values assumed by the endogenous innovation rate - g -according the two scenarios, after controlling for the basic R&D employment endogenously generated within the patentable basic R&D assumption.

Thanks to this procedure we are also able to track the path of the calibrated innovations rates from 1975 to 1981. In fact, by iterating steps 1-3 for the years 1977, 1979 and 1981, we get the numerical results discussed in Section.6 of the article. These results are here summarized by the following figure 3:

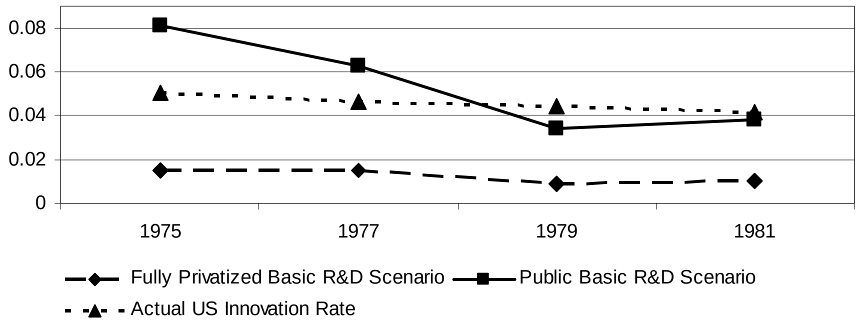

FIGURE 3: COMPARISON BETWEEN THE INNOVATIVE PERFORMANCES

Calibration on the US data from 1975 to 1981

(6)

3.3.2 Fourth Step: Assessing Research Exemption

Consider the basic R&D normative environment depicted by the model in Section 7, pag.24-26 of the main text. In equilibrium, the costless arbitrage between risk free activities and firms' equities imply that at each instant the following equations shall hold:

$$w_s = \lambda_0 n_B^{-a} v_B \tag{7a}$$

$$rv_B = \lambda_1 n_A^{1-a}\left(\beta v_L^0 - v_B\right) + \frac{dv_B}{dt} \tag{7b}$$

$$w_s = \lambda_1 n_A^{-a}\left(1-\beta\right) v_L^0 \tag{7c}$$

$$rv_L^0 = \pi - n_B^{1-a}\lambda_0\left(v_L^0 - v_L^1\right) + \frac{dv_L^0}{dt} \tag{7d}$$

$$rv_L^1 = \pi - n_A^{1-a}\lambda_1 v_L^1 + \frac{dv_L^1}{dt} \tag{7e}$$

$$\frac{dm(A_0)}{dt} = \left(1 - m(A_0)\right)\lambda_1\left(n_A\right)^{1-a} - m(A_0)\left(n_B\right)^{1-a}\lambda_0 \tag{7f}$$

$$L = x + m(A_0)n_B + \left(1 - m(A_0)\right)n_A \tag{7g}$$

$$g = \left(1 - m(A_0)\right)\lambda_1\left(n_A\right)^{1-a} \tag{7h}$$

System (7a)-(7h) is a system of four first order ordinary differential equations, whose solution describes the dynamics of this economy for any admissible initial value of the unknown functions of time v_L^0, v_L^1,v_{TA}, and $m(A_0)$[10]. In a steady state, $\frac{dv_L^1}{dt} = \frac{dv_L^0}{dt} = \frac{dv_B}{dt} = \frac{dm(A_0)}{dt} = 0$.

In order to make comparisons in terms of innovation of the two scenarios - the public basic R&D scenario and the Kremer's one -, we controlled for number of researchers employed in steady-state according to the reach-throgh claims on basic R&D scenario. Operatively:

1. after estimating the R&D productivities $\hat{\lambda}_0$ and $\hat{\lambda}_1$(*FIRST STEP*), run the system (7a)-(7h) in Dynare (*FOURTH STEP*);
2. substitute the steady-state equilibrium employment in basic R&D determined within this simulation - $n_B m(A_0)$- into the exogenously given $\bar{L}_G$ into the system (1a)-(1h);
3. solve system (1a)-(1h);
4. compare the values of the innovation rates - g -.
5. The previous points 2,3 and 4 are described in detail by the following 1975's example.

---

[10] The files .mod used to simulate the model in Dynare are available from the authors on request. In all numerical simulations, the steady state exists, it is unique and it is saddle point stable for a large set of parameter values. Therefore, given an initial condition for $m(A_0)$, there is (locally) only one initial condition for the unknown functions of time such that the generated trajectory tends to the steady state vector, the Blanchard-Kahn conditions conditions are verified and the equilibrium is therefore determined.

3.3.3 Example 1975

After substituting for $\hat{\lambda}_0 = 0.5973$ and $\hat{\lambda}_1 = 0.1004$ and the relevant data for 1975, in the steady-state, system (7a)-(7h) becomes:

$$
\begin{aligned}
w_s &= 0.5973 n_B^{-0.3} v_B && \text{(8a)}\\
0.035 v_B &= 0.1004 n_A^{0.7} \left(\beta v_L^0 - v_B\right) && \text{(8b)}\\
w_s &= 0.1004 n_A^{-0.3} \left(1-\beta\right) v_L^0 && \text{(8c)}\\
0.035 v_L^0 &= 0.6505 - n_B^{0.7} 0.5973 \left(v_L^0 - v_L^1\right) && \text{(8d)}\\
0.035 v_L^1 &= 0.6505 - n_A^{0.7} 0.1004 v_L^1 && \text{(8e)}\\
m(A_0) \left(n_B\right)^{0.7} 0.5973 &= \left(1 - m(A_0)\right) 0.1004 \left(n_A\right)^{0.7} && \text{(8f)}\\
0.139 &= x + m(A_0) n_B + \left(1 - m(A_0)\right) n_A && \text{(8g)}\\
g &= \left(1 - m(A_0)\right) 0.1004 \left(n_A\right)^{0.7} && \text{(8h)}
\end{aligned}
$$

where $\beta = 0.5$ represents the blocking patent holder's relative bargaining power.

The steady-state solution of the previous system is: $v_L^0 = 13.6769$, $v_L^1 = 13.1346$, $v_B = 2.0059$, $m(A_0) = 0.0438$, $n_B = 0.4043$, $w_s = 1.5721$, $n_A = 0.0632$, $x = 0.0608$, $n_{TA}^* = 0.0397$, $g = 0.0139$.

Let us define the steady-state number of researchers employed into basic R&D as $\bar{B}_R \equiv n_B m(A_0) = 0.0177$.

Now consider the economy characterized by the system (1a)-(1h). In order to compare its innovative performance respect to this kind of privatized scenario in 1975, let us control for the number of researchers employed into basic R&D by substituting $\bar{B}_R = 0.0177$ to $\bar{L}_G$ into system (1a)-(1h):

$$
\begin{aligned}
w_s &= 0.1004 n_A^{-0.3} v_L^0 && \text{(9a)}\\
0.035 v_L^0 &= 0.6505 - 0.0354 \left(v_L^0 - v_L^1\right) && \text{(9b)}\\
0.035 v_L^1 &= 0.6505 - n_A^{0.7} 0.1004 v_L^1 && \text{(9c)}\\
g &= 0.1004 \left(1 - m(A_0)\right) n_A^{0.7} && \text{(9d)}\\
\left(1 - m(A_0)\right) n_A^{0.7} 0.1004 &= m(A_0) 0.0354 && \text{(9e)}\\
x + (1 - m(A_0)) n_A &= 0.1213 && \text{(9f)}\\
x &= \frac{0.0957}{w_s} && \text{(9g)}\\
n_A^* &= \frac{0.1213 - \frac{0.0957}{w_s}}{\left(1 - m(A_0)\right)}. && \text{(9h)}
\end{aligned}
$$

By solving the previous system we get the steady-state 1975's values of the endogenous variables: $m(A_0) = 0.4976$, $n_A^* = 0.2234$, $v_L^0 = 67.1099$, $v_L^1 = 44.7769$, $w_s = 10.5635$, $g = 0.01766$.

Now we are able to compare the values assumed by the endogenous innovation rate - g -according the two scenarios, after controlling for the basic R&D

employment endogenously generated within the privatized regime with reach through patents and research exemption.

Thanks to this procedure we are also able to track the path of the calibrated innovations rates from 1975 to 1981. In fact, by iterating steps 1and 4 for the years 1977, 1979 and 1981, we get the numerical results discussed in Section.7 of the article. These results are here summarized by the following figure 4:

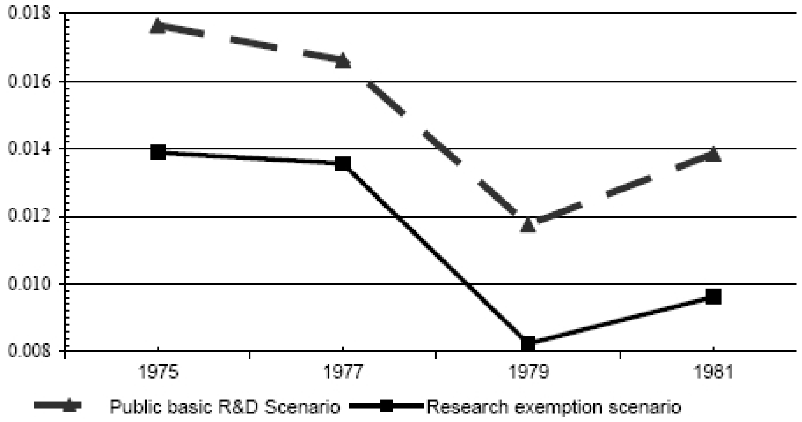

FIGURE 4: COMPARISON OF THE INNOVATIVE PERFORMANCES
Calibration on the US data from 1975 to 1981

(10)

3.3.4 Fifth Step: Assessing Kremer's Patent Buy-outs

Consider the R&D sector described by the model explained in Section 8 of the main text fo the paper. The following equations will hold in a steady-state

Kremer equilibrium:

$$w_s = \lambda_0 n_B^{-a} v_{TA} \tag{11a}$$

$$r v_{TA} = \lambda_1 \left(n^*_{TA}\right)^{1-a} \left(v_L^0 - v_{TA}\right) - w_s n^*_{TA} + \frac{dv_{TA}}{dt} \tag{11b}$$

$$w_s = \lambda_1 n_A^{-a} v_L^0 \tag{11c}$$

$$r v_L^0 = (\gamma - 1)\frac{1}{1-\alpha} M - n_B^{1-a} \lambda_0 \left(v_L^0 - v_L^1\right) + \frac{dv_L^0}{dt} \tag{11d}$$

$$r v_L^1 = (\gamma - 1)\frac{1}{1-\alpha} M - n_A^{1-a} \lambda_1 v_L^1 + \frac{dv_L^1}{dt} \tag{11e}$$

$$g = \left(1 - m(A_0)\right) \lambda_1 \left(n_A\right)^{1-a} \tag{11f}$$

$$n^*_{TA} = \left[\frac{(1-a)\lambda_1 (v_L^0 - v_{TA})}{w_s}\right]^{\frac{1}{a}} \tag{11g}$$

$$\frac{dm(A_0)}{dt} = \left(1 - m(A_0)\right) \lambda_1 \left(n_A\right)^{1-a} - m(A_0) \left(n_B\right)^{1-a} \lambda_0 \tag{11h}$$

$$L = x + m(A_0) n_B + \left(1 - m(A_0)\right) n_A \tag{11i}$$

System (11a)-(11i) is a system of four first order ordinary differential equations, whose solution describes the dynamics of this economy for any admissible initial value of the unknown functions of time v_L^0, v_L^1,v_{TA}, and $m(A_0)$[11]. In a steady state, $\frac{dv_L^1}{dt} = \frac{dv_L^0}{dt} = \frac{dv_{TA}}{dt} = \frac{dm(A_0)}{dt} = 0$.

In order to make comparisons in terms of innovation of the two scenarios - the public basic R&D scenario and the Kremer's one -, we controlled for number of researchers employed in steady-state according to the Kremer's scenario. Operatively:

1. after estimating the R&D productivities $\hat{\lambda}_0$ and $\hat{\lambda}_1$(*FIRST STEP*), run the system (11a)-(11i) in Dynare (*FIFTH STEP*);
2. substitute the steady-state equilibrium employment in basic R&D determined within this simulation - $n_B m(A_0)$- into the exogenously given $\bar{L}_G$ into the system (1a)-(1h);
3. solve system (1a)-(1h);
4. compare the values of the innovation rates - g -.

The previous points 2,3 and 4 are described in detail by the following 1975's example.

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[11] The files .mod used to simulate the model in Dynare are available from the authors on request. In all numerical simulations, the steady state exists, it is unique and it is saddle point stable for a large set of parameter values. Therefore, given an initial condition for $m(A_0)$, there is (locally) only one initial condition for the unknown functions of time such that the generated trajectory tends to the steady state vector, the Blanchard-Kahn conditions conditions are verified and the equilibrium is therefore determined.

3.3.5 Example 1975

After substituting for $\hat{\lambda}_0 = 0.5973$ and $\hat{\lambda}_1 = 0.1004$ and the relevant data for 1975, in the steady-state, system (11a)-(11i) becomes:

$$\begin{aligned}
w_s &= 0.5973 n_B^{-0.3} v_{TA} && \text{(12a)}\\
0.035 v_{TA} &= 0.1004 \left(n_{TA}^*\right)^{0.7} \left(v_L^0 - v_{TA}\right) - w_s n_{TA}^* && \text{(12b)}\\
w_s &= 0.1004 n_A^{-0.3} v_L^0 && \text{(12c)}\\
0.035 v_L^0 &= 0.6505 - n_B^{0.7} 0.5973 \left(v_L^0 - v_L^1\right) && \text{(12d)}\\
0.035 v_L^1 &= 0.6505 - n_A^{0.7} 0.1004 v_L^1 && \text{(12e)}\\
g &= \left(1 - m(A_0)\right) 0.1004 \left(n_A\right)^{0.7} && \text{(12f)}\\
n_{TA}^* &= \left[\frac{0.0703(v_L^0 - v_{TA})}{w_s}\right]^{\frac{1}{0.3}} && \text{(12g)}\\
\left(1 - m(A_0)\right) 0.1004 \left(n_A\right)^{0.7} &= m(A_0) \left(n_B\right)^{0.7} 0.5973 && \text{(12h)}\\
0.139 &= \frac{0.0957}{w_s} + m(A_0) n_B + \left(1 - m(A_0)\right) n_A && \text{(12i)}
\end{aligned}$$

The solution of the previous system is: $v_A = 1.1917$, $v_L^0 = 14.4350$, $v_L^1 = 10.0852$, $m(A_0) = 0.4690$, $n_B = 0.0163$, $w_s = 2.4496$, $n_A = 0.1739$, $x = 0.0391$, $n_{TA}^* = 0.0397$, $g = 0.0157$.

Let us define the steady-state number of researchers employed into basic R&D as $\bar{B}_K \equiv n_B m(A_0) = 0.0076$.

Now consider the economy characterized by the system (1a)-(1h). In order to compare its innovative performance respect to the privatized scenario in 1975, let us control for the number of researchers employed into basic R&D by substituting $\bar{B}_K = 0.0076$ to $\bar{L}_G$ into system (1a)-(1h):

$$\begin{aligned}
w_s &= 0.1004 n_A^{-0.3} v_L^0 && \text{(13a)}\\
0.035 v_L^0 &= 0.6505 - 0.0196 \left(v_L^0 - v_L^1\right) && \text{(13b)}\\
0.035 v_L^1 &= 0.6505 - n_A^{0.7} 0.1004 v_L^1 && \text{(13c)}\\
g &= 0.1004 \left(1 - m(A_0)\right) n_A^{0.7} && \text{(13d)}\\
\left(1 - m(A_0)\right) n_A^{0.7} 0.1004 &= m(A_0) 0.0196 && \text{(13e)}\\
0.1314 &= \frac{0.0957}{w_s} + (1 - m(A_0)) n_A && \text{(13f)}\\
x &= \frac{0.0957}{w_s} && \text{(13g)}\\
n_A^* &= \frac{0.1314 - \frac{0.0957}{w_s}}{(1 - m(A_0))}. && \text{(13h)}
\end{aligned}$$

By solving the previous system we get the steady-state 1975's values of the endogenous variables: $m(A_0) = 0.6715$, $n_A^* = 0.2697$, $v_L^0 = 15.0206$, $v_L^1 = 8.6601$, $w_s = 2.2344$, $g = 0.0132$.

Now we are able to compare the values assumed by the endogenous innovation rate - g -according the two scenarios, after controlling for the basic R&D employment endogenously generated within the Kremer's mechanism assumption.

Thanks to this procedure we are also able to track the path of the calibrated innovations rates from 1975 to 1981. In fact, by iterating steps 1 and 5 for the years 1977, 1979 and 1981, we get the numerical results discussed in Section.8 of the article. These results are here summarized by the following figure 5:

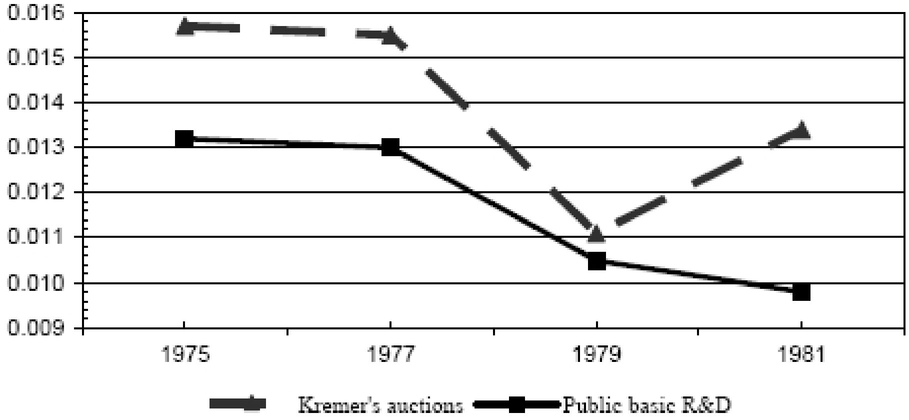

FIGURE 5: COMPARISON OF THE INNOVATIVE PERFORMANCES
Calibration on the US data from 1975 to 1981

(14)