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Reinforcing the patent system? Effects of patent fences and knowledge diffusion on the development of new industries, technical progress and social welfare

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Renforcer le système de brevet ? Effets des barrières de brevet et de la diffusion des connaissances sur le développement de nouvelles industries, progrès technique et bien-être social

Résumé

Cet article développe le modèle évolutionniste de dynamique industrielle de Vallée & Yildizoglu (2006) de manière à mener une analyse théorique plus riche des conséquences d'un système de brevet renforcé. Ce modèle prend explicitement en compte les effets potentiellement positifs des brevets : La publication des brevets participe à la construction d'un stock collectif de connaissances sur lequel les innovations peuvent s'appuyer et les brevets abandonnés peuvent fournir une nouvelle source de progrès techniques aux firmes retardataires. Ces dimensions positives sont mobilisées pour questionner les résultats négatifs de Vallée et Yildizoglu (2006). Les principaux résultats du nouveau modèle montrent que les effets positifs ne contrebalancent pas les conséquences négatives sur le progrès technique et le bien-être social d'un système de brevet plus fort, même si ce dernier est une source de meilleure protection et de profits plus élevés pour les firmes. Le modèle intègre aussi l'effet des brevets sur la survie et le développement des industries naissantes.

Mots-clés : Innovation, Progrès technique, Système de brevet, Droits de propriété intellectuelle (DPI), Politique technologique

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Keywords: Innovation, Technical progress, Patent system, Intellectual property rights (IPR), Technology policy.

JEL : O3, O34, L52

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Reinforcing the patent system? Effects of patent fences and knowledge diffusion on the development of new industries, technical progress and social welfare

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Abstract

This article extends the industry dynamics model of **?** in order to carry out a richer theoretical analysis of the consequences of a stronger patent system. This model explicitly takes into account the potentially positive effects of patents: publication of patents participates to the building of a collective knowledge stock on which new innovations can rely, and dropped patents can provide a source of technological progress for firms that are lagging behind the leaders of the industry. These dimensions of the patent system are used to question the negative results of **?**. The main results of the new model show that these positive effects do not counterbalance the negative effects of a stronger patent system on social welfare and global technological progress, even if it is a source of better protection and higher profits for the firms. The model also considers the effect of patents on the survival of the newly founded industries and on their development.
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1 Introduction

This article develops the analysis initiated in **?** on the social costs and benefits of a stronger patent system. The actual tendency of the Intellectual Property Rights (IPR) policies in United States and in Europe effectively correspond to the strengthening and to the extension of the patent system as a global incentive device for private (and even public - *see* the motivation of the Bayh-Dole Act on US university research) innovative efforts.

The actual tendency is generally motivated by the conventional economic wisdom affirming that a strong patenting system yields convenient incentives for private investment in Research and Development (R&D) and hence for technical progress in society. In the incentive based vision, the patent system solves two problems caused by the public good nature of technological innovation: the monopoly position granted by the patent corrects the insufficient incentives to invest in private R&D and the publication of the patent assures the diffusion of the invented knowledge. As a consequence, this vision establishes the patent system as a perfect source of social and technological efficiency in the long term: the innovation-driven growth is supposed to largely compensate the static dead–weight loss of the transitory monopoly position and the limited span of the property rights granted by the patent (the official maximal patent life) reinforces this positive dynamic effect by limiting the number of periods during which this dead-weight incurs.

The weaknesses of the patent system to fulfill such a role has been emphasized in the literature since Arrow's classic article (Arrow (1962)) that underlines that the patent system must be extremely complex and subtle in order to secure complete appropriation of the invention by the innovator. Moreover, this purely incentive based approach of technological dynamics and of the role of patenting largely underestimates the complexities of the dynamics of the existing technological systems. Hence, it is not surprising that this view is quite systematically challenged by empirical studies and, more specifically, by the recent results about the diversified role that the patents are called to play in different industries and other stylized facts about patenting by firms. Following van Dijk (1994), Cohen, Nelson & Walsh (2000), Gallini & Scotchmer (2002), Hall (2002) and Mansfield (1986), we can underline some interesting stylized facts about patenting:

- Most innovations combine elements from existing products;
- Inventing around a patent occurs (with an average cost advantage of 35%);
- The effective lifetime of a patent is generally shorter than the legal lifetime (less than 8 years for the 50% of the patents in the UK and France);
- Patents are useful to impede imitation (the supplementary imitation cost due to the existence of a patent is industry-specific, with weights from 7% to 30%);
- The propensity of patenting has heavily increased in the last decade. This propensity is industry-specific and it is higher for larger firms.

The last observation is in fact quite overwhelming. Since 1978, the European Patent Office (EPO) has studied more than two millions patent applications. It has received over 120 000 patent applications in 2004. Figure 1 clearly shows the *explosion* of the number of patent applications from 1990 and on (more than 76% of these two millions patents have been filed after 1990).

Another important observation that comes to dominate our empirical understanding of the patent system concerns the quite low esteem in which the firms consider patents in comparison with other tools that they commonly use (like secrecy, the lead time or having recourse to complementary services or manufacturing.The 1994 Carnegie Mellon Survey of the U.S. manufacturing sector (*see* Cohen et al. (2000)) clearly shows that the main motivation for patenting does not correspond to the theoretical argument used in defence of a stronger patent system (better incentives for R&D). This observation, combined with the recent surge in patenting gives rise to what is called today the

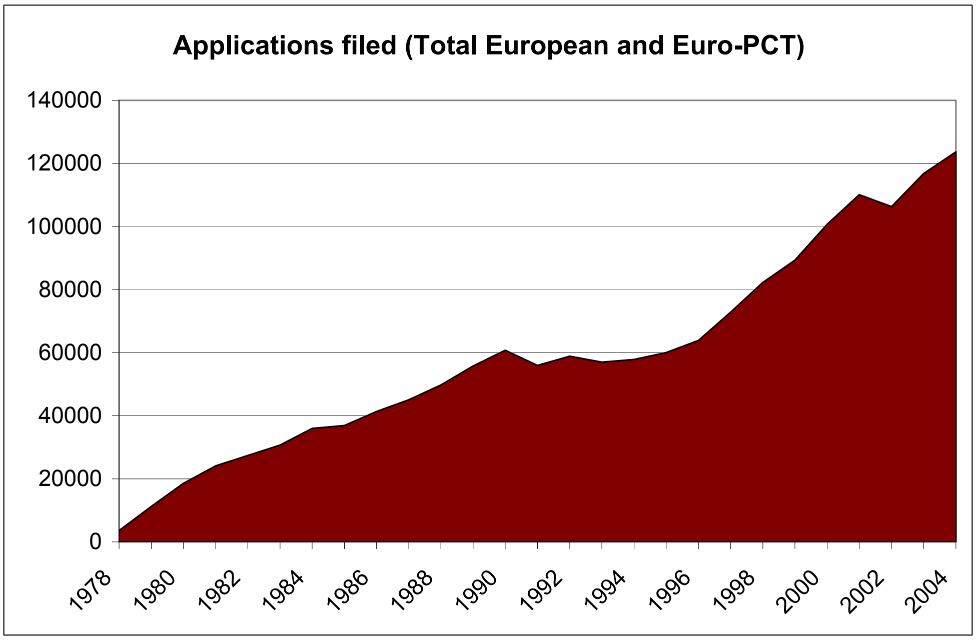

Figure 1: Applications to the European Patent Office (EPO)

patent paradox (low effectiveness but high patenting – *see* Hall & Ziedonis (2001) for electronics firms). As a consequence, it is quite difficult to ignore that patenting is very frequently used by firms for strategic reasons: **constructing patent fences** around discrete inventions; building negotiation power through a patent portfolio in complex industries, especially for cross-licensing issues, etc.

This strategic use of the patent system must be taken into account in the evaluation of its social costs and benefits using a dynamic setup that allows the analysis of potential intertemporal inefficiencies. Would a stronger patent system foster technological innovations if firms use it for impeding their competitors' progress? Is the knowledge diffusing effect sufficient to compensate the static inefficiencies due to the monopoly position? Does the publication of the patents assure efficient knowledge diffusion, enough to compensate the potentially negative effects of patent fencing and, finally yield a higher social welfare and technological pace? The model we develop in this article aims to tackle these questions. In order to focus on the role of patent fences in technology dynamics, we deliberately disregard some other important aspects of these questions like the potential ineffectiveness of the patents and the potentially positive effect of patents through licensing. Both issues are underlined in the literature (already in Arrow (1962); *see* also Bessen & Meurer (2008) for a more recent discussion). We disregard the possible ineffectiveness of patents in order to place the model in a framework favorable to patents. We exclude licensing issues from the model because their integration would necessitate a much more complex model, with many supplementary causal mechanisms and because the model would become much less tractable, even using Monte Carlo simulations.

This article proposes an extension of the evolutionary model of **?** in order to present a more balanced view of patents. Indeed, in the evaluation of the social costs and benefits of a stronger patent system, **?** exclusively focuses on the technology dynamics resulting from patenting motivated by the building of patent fences. Several potentially positive effects of patents are neglected in this first study. We now develop a richer model where these effects are taken into account: if a firm drops a patent, the latter can now contribute to the global technological progress by allowing retarded firms to adopt it. Also, the publication of patents contributes to the general knowledge level of the industry and to potential technological progress through innovation. The possibility of keeping secret the technological knowledge is also introduced as an alternative appropriation tool. We evaluate the global effects of these positive aspects of the patent system in interaction with effects of patent fences on technology dynamics. Moreover, we also analyze the role of the patent system in the birth and development of new industries. The main results of the article show that the potentially positive effects of the patent system are not sufficient for justifying a stronger patent system.

The next section will present the main characteristics of the model. The third section will be dedicated to the presentation of our simulation protocol and of the results of the model. We will provide results on the role of patents in the birth and death of industries; in the determination of social welfare and of technical progress. Our results show that a stronger patent system has negative effects on all these dimensions. A special attention will be given to the mechanisms that are behind these results. The last section will conclude the article. The appendix gives the initial values and the meaning of the parameters and the variables used in the model.

2 The Model

This model concerns an industry producing a homogenous good and facing a decreasing, constant elasticity market demand. It extends the initial model of **?**. This initial model was an extension of the industrial dynamics model of Nelson & Winter (1982). The actual model is also inspired by Winter (1993) that was the first model incorporating patents in the Nelson & Winter (1982) model.

As in the Nelson & Winter (1982) model, the only production factor is physical capital, and technology has constant returns to scale. In each period, each firm shares its gross profits between different investment outlets: R&D, physical capital, patent budget, and saving. R&D investment is necessary for the imitative and innovative activity of the firm. Technical progress comes from disembodied process innovations and corresponds to the increase of the productivity of the firm's capital stock.

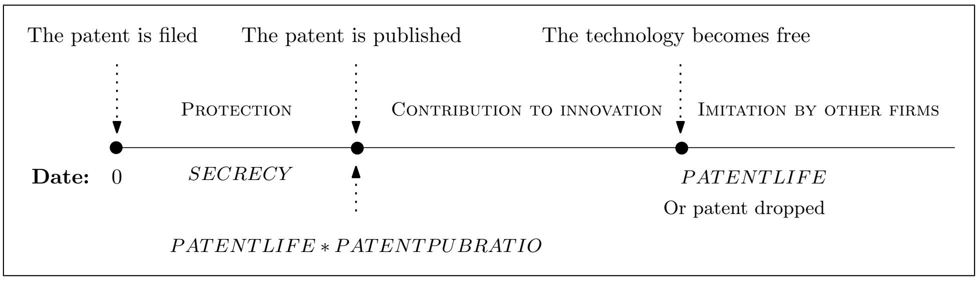

Figure 2: The Life of a patent...

The industry is initially populated by a unique firm with random characteristics (drawn following a normal distribution centered on common averages). This firm is the founder of the industry. Its technology is drawn from a log-normal distribution centered on the initial value of the latent productivity in this economy (see paragraph 2.2). The population of firms evolves as a consequence of the entry and exit processes (see paragraph 2.3). In each period, the short-period market equilibrium fixes the price at which the consumers buy this product, given their demand function. Market price determines the firm's gross profits, and these profits are used for investing in different assets (strategies): innovation and imitation follow from the R&D investment; physical capital increases as a consequence of the investment; the patent budget is used to finance new patents or to renew the patent portfolio of the firm; the saving can provide supplementary revenues for investing in future periods. These strategies evolve as a consequence of the social learning of firms (*see* paragraph 2.1).

In this model, we dedicate a particular attention to the patenting strategies of the firms and to different dimensions of the patent system. Patents can contribute to the aggregate technological advance at three levels: **(a)** a patented technology is protected from imitations and from innovations too similar to it (given the patent height corresponding to the patent system); **(b)** when a granted patent is published, it contributes to the collective knowledge stock of the industry on which the innovations are based (this effect is controlled by the ratio of the publication date to patent life – *see* Figure 2); **(c)** when a patent is dropped or when it arrives to the end of the patent life, the corresponding technology becomes available to all firms in the industry (the technology becomes *free*). The channels *(b)* and *(c)* constitute the contribution of this model in the construction of a fairer picture of the patent system's welfare effects. If an invented technology is not filed for a patent, it remains secret for the competitors of the innovator. In this case, the appropriability conditions of the industry are represented by the parameter $SECRECY$ that gives, in probabilistic terms, the effectiveness of secrecy (the higher the $SECRECY$, the lower the probability of being imitated). In accordance with the empirical results emphasized in the introduction, the patenting strategies of the firms are driven in this model by their desire to build patent fences in order to slow their competitors behind them.

In the rest of this section we will briefly present the main components of the model. The articulation of these components is depicted in the Figure 3 and the simplified pseudo code of the model is given in Figure 4.

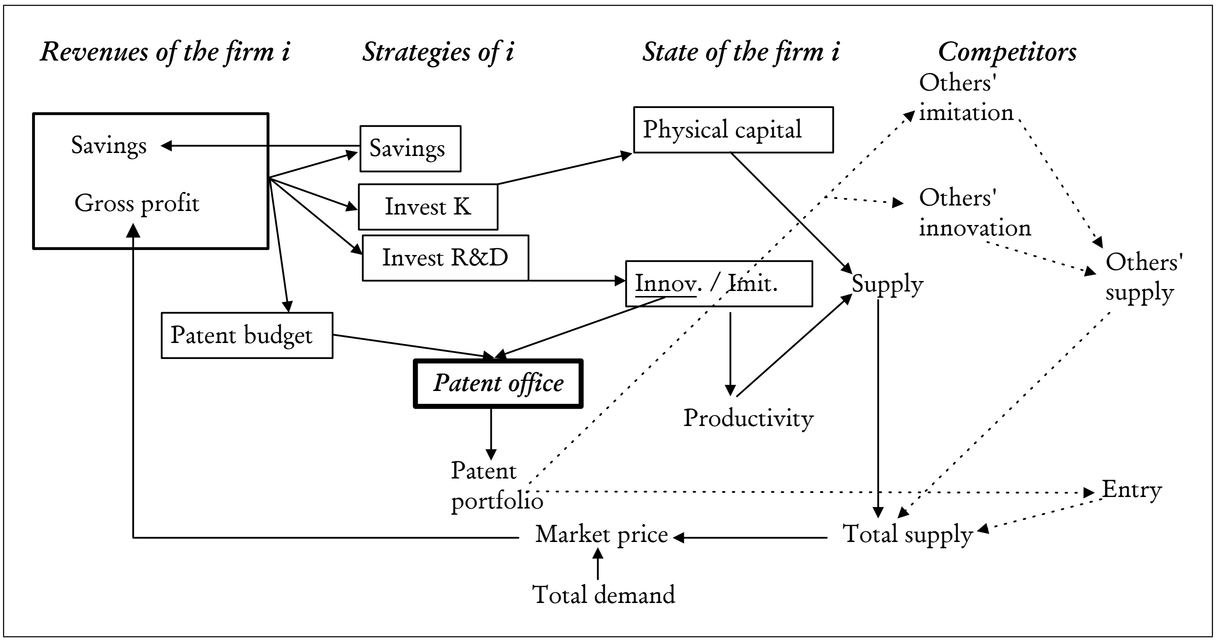

Figure 3: The main connections in the model

2.1 Strategies and learning processes of firms

At the beginning of each period, the firm must decide how to spend the gross profits and the savings from previous periods. In our model, these revenues can be allocated between four alternative assets (*see* Figure 3):

Investment in physical capital: The firm expands its capital stock in order to increase its market share. $IKRATE$ is the initial average value of this investment rate around which the strategies of the firms are created.

R&D investment: R&D allows the firm to create new technologies, or to imitate the technology of a successful competitor. $IRDRATE$ is the initial average value of this investment rate around which the strategies of the firms are created.

Patent budget: In order to prevent other firms from benefiting from its technological investments, the firm can decide to protect innovations. We assume that a technology may only be patented if it is sufficiently distinct from an already patented technology. The patent office can be more or less indulgent and this dimension of the patent system is represented in our model by the variable $PATENTHEIGHT$. A patented technology can be protected for a maximum of $PATENTLIFE$ periods. A new patent costs $NEWPATENTCOST$, and renewing a patent for one more period requires the payment of $RENEWPATENCOST$. $PATENTRATE$ is the initial average value of the investment rate around which the strategies of the firms are created.

Savings: Firms can save a part of their profits. Involuntary savings arise when one of the budget lines is not spent in its totality. Otherwise, the saving is precautionary, since it enables the firm to offset certain consequences of unforeseen events (e.g. negative profits). In our model, if a firm gets negative profits and it does not have any more saving, it quits the industry. $SAVINGRATE$ is the initial average value around which the strategies of the firms are created.

A strategy vector of a firm i at period t is therefore given by:

$$s_t^i = \left(\omega_{K,t}^i, \omega_{RD,t}^i, \omega_{P,t}^i, \omega_{S,t}^i,\right), \ \omega_{j,t}^i \in [0,1], \ \sum_j \omega_{j,t}^i = 1. \tag{1}$$

In each period, the learning of the firms is represented through an evolutionary algorithm: firms learn through imitation of the strategies of others and through random experimenting (mutations). In our model, the imitation is based on the market size of the opponents (rather than on their profits, as in Silverberg & Verspagen (1994)). As a consequence, a bigger competitor will have a higher probability of being imitated (the probability of being imitated is equal to the market share of each firm). When imitation occurs, the imitator adopts the strategy vector of the imitated firm. The strategy vector of each firm can also change in each period as a consequence of random experimenting. These two mechanisms are respectively commanded by the probabilities $PROBIMITATE$ and $PROBMUTATE$.

2.2 Technical progress and patenting

Technical progress is a potential result of the innovation and imitation processes of firms. The success of these processes is an increasing function of the R&D investment of the firms in the industry. Entering firms benefit from the advancement of the technological knowledge in Society and their innovations are driven by the evolution of the latent productivity (*see* section 2.3). Firms may file patents in order to protect new technologies from imitation by competitors.

Productivity gains: innovation and imitation

In our model, innovation is a two-stage stochastic process as in Nelson & Winter (1982). A first draw determines if the firm has been successful to innovate. The probability of this success increases with the R&D investment. A second draw then gives the effective new productivity that results from the innovation. This Gaussian draw is centered on a mean that corresponds to the average of the actual technology of the firm and the best published technology of the period (the weight of this factor is controlled with the parameter $WEIGHTPUB$):

$$\begin{gathered} \mu_t^i = A_t^i + WEIGHTPUB \cdot max\left\{0, A_t^f - A_t^i\right\} \\ \tilde{A}_t^i \rightsquigarrow \aleph\left(\mu_{i,t}, \sigma_{in}\right) \end{gathered} \tag{2}$$

where A_t^i is the actual productivity of the firm, A_t^f the highest free productivity and $\tilde{A}_t^i$ the result of the innovation. As a consequence, if a firm is behind the published knowledge, it can benefit from it for accelerating its technical progress. It should be noted that a new technology may only be used and patented if it is not protected by an existing patent (given the $PATENTHEIGHT$).

A firm can also benefit from imitating a successful competitor's technology. Imitation is rather rare and the probability of success again increases with the R&D investment of the firm. Only unpatented technologies can be imitated. When the imitation happens, each competitor has a probability of being imitated that increases with its market share.

The last possibility for technological progress is the adoption by the firm of a technology that has been patented in the past, but that is not anymore protected by a patent (the original firm has stopped renewing the patent or the patent has become older than the $PATENTLIFE$).

Patenting

The management of the patent portfolio is very crucial in our model. When a new technology is found, the inventor can choose to protect it by filing a patent. A filed patent is supposed to be automatically validated by the Patent Office if it is not infringing on an existing patent. We do not consider in this model the important complexities that arise from the uncertainties of the verification period by the patent office. We deliberately adopt here a vision quite favorable to patents. If the firm does not protect it, the technology may be imitated (given the level of $SECRECY$ representing the appropriability regime in this industry) or invented around by the competitors.

A firm will only patent a technology if *(a)* the technology is seen as sufficiently interesting to patent (effective in slowing the competitors, in accordance with the strategy of patenting studied in this article), and *(b)* if the firm owns a sufficient patenting budget. More specifically, the probability of adopting (or keeping) a particular patent is given by a normal distribution that depends on the relative efficiency of the technology. Efficiency of a given technology is measured by the number of firms that have a productivity lower than the productivity of this technology: the higher the number of such firms, the more efficient the patent in slowing the competitors. We also assume that firms cannot perfectly observe the efficiency of their innovation and they are prone to errors. This efficiency criterion represents the patent fencing strategies of firms. The probability of patenting a new innovation is therefore given by:

$$P[patent] = \frac{nbLaggingFirms}{nbActiveFirms} + \varepsilon,\ \varepsilon \rightsquigarrow N(0, \sigma) \tag{3}$$

The same criterion is used for renewing existing patents. The firm considers the possibility of renewing patents by beginning with patents corresponding to the highest productivity.

In the beginning of each period, the firm tries to reserve a budget for patenting. This budget should cover two kinds of expenses: *(a)* the cost of maintaining previously filed patents, *(b)* the possible cost of filing a patent for a new innovation. This budget results from the investment strategy of the firm on patenting.

2.3 Entry and exit

In this model, the size of the industry, in terms of active firms, is allowed to change at each period. In each period, there are $ENTRYRATE$ attempts to entry in the industry. This variable represents the easiness to entry to this industry (the height of the barriers to entry, when these barriers correspond to other dimensions of the industrial regime, like the institutional ones). The corresponding number of potential entrants attempt to enter into the market in each period, with randomly drawn characteristics, but only candidates with technologies that are not impeded by an existing patent can effectively enter. Firms rely on global technological knowledge for developing the technology with which they enter the industry. Hence, technologies of all entering firms are driven by the latent productivity in the economy that results from the advancement of the scientific knowledge (as in Winter (1993)). The productivity of each new firm is drawn from the log-Normal distribution centered on the latent productivity of the period

$$\begin{gathered}\lambda(t) = L_0 + \gamma t \\ \log\left(A_t^e\right) \rightsquigarrow \aleph\left(\lambda(t), \sigma_{in}\right)\end{gathered} \tag{4}$$

where A_t^e is the productivity of the potential entrant. If the corresponding productivity is already protected by a patent, the entry can not take place. Other dimensions of the entrants are normally drawn around actual industry averages. We also assume that only the entrants who expect a positive profit, given the actual level of the market price, would enter. Once in the industry, each firm relies on internal R&D and published patents to innovate (following 2).

Even with negative profits, a firm may stay in the industry as long as it holds some positive savings that offset the loss. When this is no longer the case, the firm exits the industry (bankruptcy).

For each period t, until $t = T$:

1. Populating the industry:
   - if $t = 1$: creation of an industry composed of 1 firm (the founder)
   - if $t > 1$: entry of new firms ($ENTRYRATE$) and exit
2. Computation of the production levels: Q_t^i and the total supply Q_t
3. Computation of the intra-period price (as a function of the inverse demand function): p_t
4. Computation of the gross profits and social surplus
5. Saving results at the industry level
6. Compute imitable productivities
7. Randomize the order of play of firms in the current period t
8. Setting of the different budget levels for R&D, investment, patenting, savings and dividends
9. Investment of firms in capital
10. Innovation of firms
11. Effective imitation of technologies (using the list established in step 6)
12. Management of the patent portfolio and patenting
13. Technical progress through the adoption of free technologies
14. Computation of the list of the productivities of the active firms
15. Computation of the lists of all patented, published and free productivities in the industry
16. Diffusion of the best strategies in the industry (depends on the market shares of firms) and mutation of strategies

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Figure 4: The pseudo code of the model

3 Simulation protocol and results

3.1 Simulation protocol

Given the complexity of the interactions that we model, we adopt a methodology that allows quite a systematic exploration of the parameter space of the model. This methodology is close to the Monte-Carlo method. We execute 20000 runs of 100 periods each, where the results from each period have a probability of 10% of being saved. We also systematically save the first and the last periods. The first period data is only used for checking the initial configurations. So, for each run we obtain an average number of 12 observations for all variables. 9320 runs correspond to industries that are able to survive 100 periods. We mainly use these runs in the results we discuss in this article. The paragraph 3.3 will summarize the results of the econometric analysis of the determinants of the probability of dying for an industry.

All runs are initialized with a unique initial firm (the founder of the industry) with randomly drawn characteristics (the capital stock of the firm and its strategies). The means around which these characteristics are randomly drawn are given in the Appendix A. This appendix also contains the means around which other parameters of the model are uniformly drawn for each run, in accordance with the Monte Carlo methodology, and the meaning of the parameters and the variables used in this article. The productivity of the initial firm is drawn around $\lambda(1)$. We do not necessarily discuss in the text all the parameters that appear in this appendix, but only the most significant ones. As a result, we obtain a set of 175 303 observations covering quite a diversified subset of the parameter space. We analyze the observations sampled from the last half of each run (letting time to the learning process of the firms), corresponding to dates higher than the second quartile of the saved dates $\left(t \geq Q_2^t = 39\right)$. This sample contains 53 901 observations. We use for this analysis box plots (giving the four quartiles of the distributions of the variables), non-parametric Wilcoxon rank sum tests (**WRS tests**) between subsets, linear and probit regressions and, regression trees. The statistical analysis is conducted using $\mathsf{R-project}$ (see R Development Core Team (2003))[1]. In the boxplots, the box gives the central 50% of the sample centered on the median: the box hence gives the first, second and third quartiles (Q_1, Q_2, Q_3) of the distribution. The whiskers give the significant minimum and the significant maximum of the distribution.

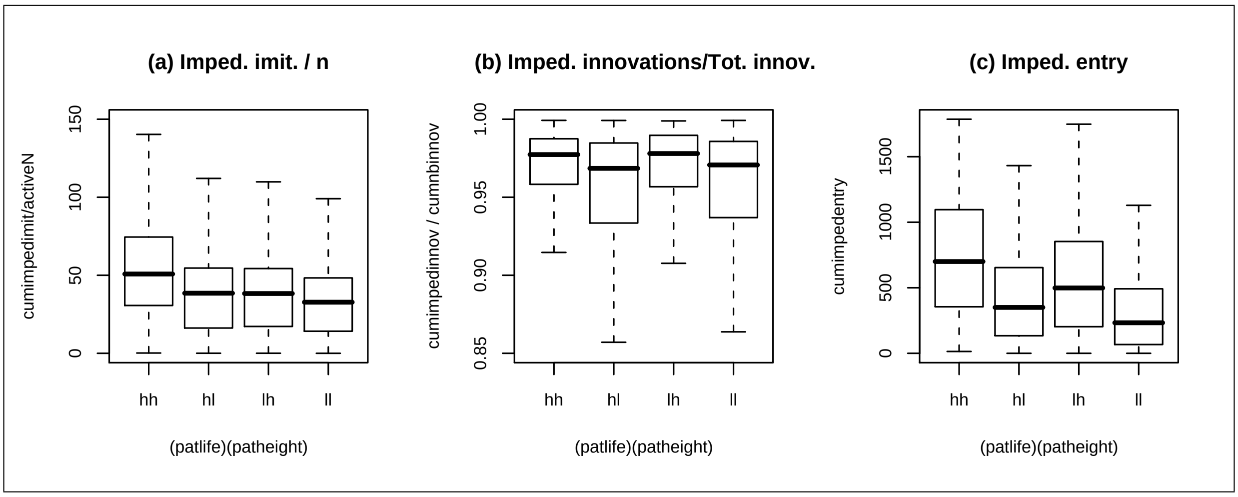

Figure 5: Effectiveness of the patent system. Boxplots with values cumulated over T periods

3.2 Effectiveness of the patent system

We first check that the possibility of patenting is effectively used by the firms in the economy and that these patents are effective in protecting their holders' technology. Before establishing this property, we introduce a coding scheme for the main dimensions of the patent system that we use in the rest of the article.

Figure 5 introduces the role of the two main dimensions of the patent system: patent life and patent height, which also covers patent breath in this model. We use the following categorical coding of these variables.

Notation 1 *Classifying values of the variables $PATENTHEIGHT$ and $PATENTLIFE$:*

[1]A detailed statistical appendix can be found at the following addres:
`http://beagle.u-bordeaux4.fr/yildi/files/patents2-statisticalappendix.pdf`

- *We use the value l (*low*) for a variable x when x is inferior to the second quartile of its distribution: $l \Leftrightarrow x \leq Q_2^x$ and*
- *the value h (*high*) in the complementary case: $h \Leftrightarrow x > Q_2^x$.*

For example, the configuration hl corresponds to $(patentlife = high, patentheight = low)$: a patent system where the patent office grants relatively long-lived and narrow patents. The configuration hh would correspond to what we call a "strong" patent system that gives a high protective capacity to new patents. In comparison, the configuration hl corresponds to a system where granted patents have long maximal life but a narrow scope (their $PATENTHEIGHT$ is low (l)).

In our model, patents can be used to:

- allow the patenting firm to protect its innovation from imitations;
- allow the patenting firm to prevent the competitors who have invented an already protected technology from using it;
- allow the patenting firm to impede entry by firms with similar technologies.

Figure 5 shows that patents do effectively impede imitations, innovations and new entry in this economy. These boxplots show that higher patent height is the main source of effectiveness in impeding imitations, innovations and entry. A longer patent life has a complementary efffect. We also remark that short and narrow patents are favorable to imitations and entry. Boxplot (b) shows that a very significant proportion of the potential innovations are blocked by the existing patents and this effect is maximal when the patent life is relatively high and the patents are broad. These global results are also confirmed using linear regression for the last period variables (*cf.* online statistical appendix, and also Table 1[2]).

Proposition 1 *The protective role of patents is effective in our model: patents impede imitations and innovations by the competitors and the entry of new competitors. A patent regime with short and narrow patents is the most favorable one to entry and imitations.*

Given that the patent system is effective in this economy, we can now study the impact of a stronger patent system on social welfare in order to verify if a reinforcement of the patent system is socially desirable. Before getting to this point of the analysis, we shortly discuss the factors that cause the death of industries.

3.3 Why do industries die?

Only 46.6% of the created industries are able to survive 100 periods in this model. The section E of the online statistical appendix gives probit regression results on the determinants of the probability to dying before period 100. Several factors play a significant role:

Market conditions and costs: The probability of dying increases with the elasticity of the demand (ETA) , entry attempts ($ENTRYRATE$), fixed costs (FC) and unit capital cost ($cost$) and decreases with the size of the demand (DEM). These results are not surprising, except maybe the one concerning the role of the easiness of entry: it seems that entry can play a destabilizing role.

[2]The Table 1 gives the sign of the coefficients with a statistical significance of at least 5% (detailed results are available in the section *B.* of the online statistical appendix). Only the main dimensions of the patent system and the technology regime are used as independent variables. Only relationships that are significant over all configurations figure in this table.

Learning of firms: The probability of dying decreases with the probability of imitation of the strategies and the probability of mutation. Higher learning rates are hence favorable to the survival of the industry.

Patent system and technology regime: The probability of dying increases with the patent height and patent life, as well as with the publication date of the patents and the weight of the published patents in the innovation process. Secrecy also is unfavorable to the survival of the industry but, in accordance with the first elements, the patent costs decrease the probability of dying. A stronger patent system and weak diffusion of the technologies are consequently unfavorable to the survival of the industry.

Proposition 2 *New industries have more difficulty to survive when the patent regime is stronger.*

The rest of our analysis is focused on industries that have been able to survive 100 periods.

	Variables	PL	PH	PPDR	NPC	RNPC	SEC	WP
1	SS	−	−		−		+	+
2	CS	−	−	− (∗)	−			+
3	$averprofit$	+	+	−	−		+ (∗)	+
4	$activeN$	−	−	+		−		
5	$invCI$	−	−	+	+		+	
6	$averprod$	−	−					
7	$nbentry$	−	−				+	
8	$maxprod$	−	−					
9	$nbpat$	+	−	+	+			
10	$cumnbpat$	+	−					
11	$maxpatage$	+	−					−
12	$cumnbinnov$	−	−	−				
13	$nbpatfirms$	+	−	+	+			
14	$cumimpedentry$	+	+					−
15	$cumimpedinnovrel$		+	−				
16	$cumimpedimit$	−	−					+
17	$cuminnovfree$	−	−				+ (∗)	

(∗) : Significant only at 10%.

Patent system:
PL: PATENTLIFE **PN:** PATENTHEIGTH **PPDR:** PATENTPUBDATERATIO
NPC: NEWPATENTCOST **RNPC:** RENEWPATENTCOST
Technological regime: **WP:** WEIGHTPUB **SEC:** SECRECY

Table 1: The global role of patent system's dimensions. Linear regresion results for $t \geq Q_2^t$. Sign of the coefficients significant for $\alpha = 5\%$.

3.4 Patent system and social welfare

We begin the analysis by our central question about the patent system: is a stronger patent system desirable from the social point of view. In order to obtain a first indication on the effects of the main two dimensions of the patent system on social welfare, we compute the median values of consumers' surplus, average profits and social surplus in 10 equally sized intervals of values of these dimensions of the patent system ($PATENTLIFE$ and $PATENHEIGHT$).[3].

Profits. The second column in Figure 6 indicates how the median of average profit evolves when the values of these dimensions increase. Graphs *(a2,b2)* indicate that the average profits of the firms are respectively higher in patent systems with longer $PATENTLIFE$ and higher $PATENTHEIGHT$ (broader patents). Non-parametric (WRS) test results given in Table 2 and the linear regression

[3] $PATENTHEIGHT$ is a continuos variable and $PATENTLIFE$ is discrete. We call the `cut` function of R-project in order to divide the random values of these variables in 10 equally sized intervals.

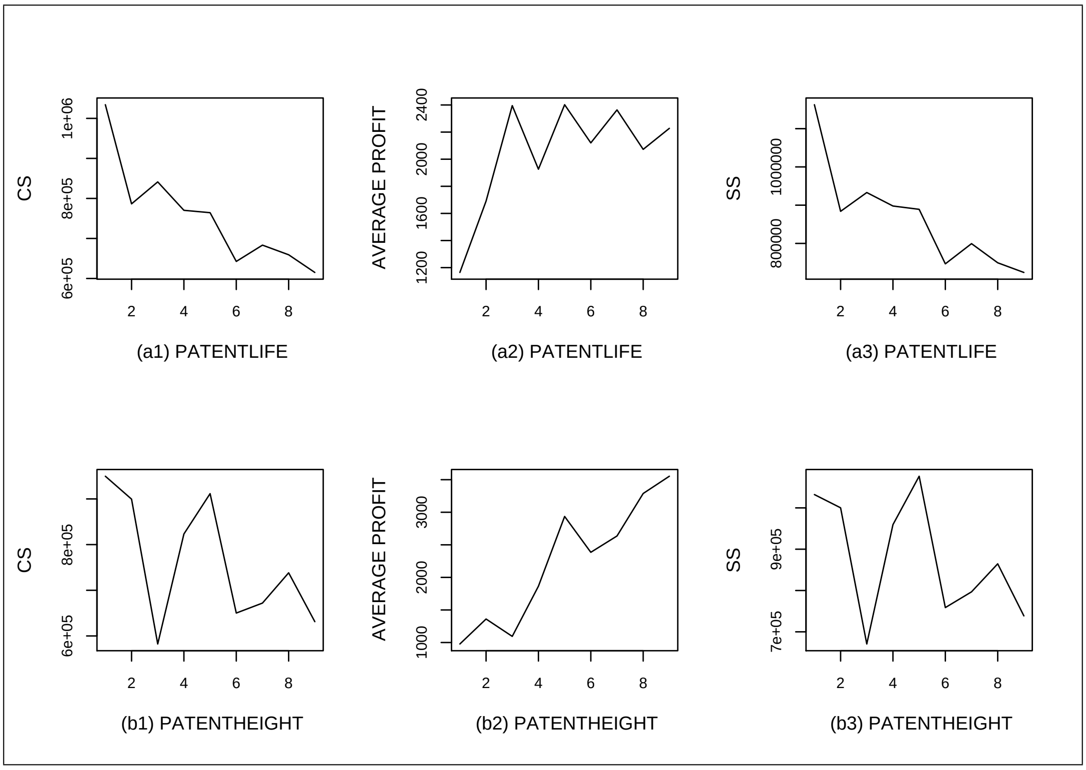

Figure 6: Patent system and welfare ($t \geq Q_2^t$). Medians computed in 10 equally spaced intervals of PATENTLIFE and PATENTHEIGHT values.

Variable	Ordering
Consumer surplus	$ll > lh > hl > hh$
Average profits	$ll < hl < lh < hh$
Social surplus	$ll > lh > hl > hh$
Average productivity	$ll > hl > lh > hh$
Maximal productivity	$ll > hl > lh > hh$

Table 2: Patents and social welfare. Summary of the results of WRS tests ($\alpha = 1\%$) given in the online appendix D (for values from periods $t \geq Q_2^t$).

results of Table 1, line 3 confirm these results. WRS test results show that the main determinant dimension is the height of the patents (broad patents give higher profits even if the patent life is short). Firms clearly benefit from a stronger patent system in our model. Does this mean that we should favor such a system? In order to answer this question, we must take into account the global effect of such a system, including the consumers' welfare.

Consumers' surplus and social welfare. The last column of Figure 6 exhibits the evolution of social welfare. Graphs (*a3-b3*) indicate that a stronger patent system is harmful on social welfare: the negative effects of these dimensions on consumers' surplus (given in the first column of the figure) clearly overweigh the supplementary profits of the firms. The WRS test results again confirm these results, as well as the regression results. As a consequence, short-lived and narrow patents are more beneficial to social welfare (but the patent life is the most determinant dimension here).

The results concerning the social welfare are summarized in the following proposition (they are also confirmed by the results of Table 1).

Proposition 3 (Results on social welfare)

- *It is socially preferable to have short-lived narrow patents instead of long-lived broad ones (to* answer the central question posed by O'Donoghue, Scotchmer & Thisse (1998)).*

- *The Pareto-dominant patent system configuration is the mildest one* (ll) *and it grants short-lived and narrow patents. Even if the profits of the firms are the lowest in this case, the consumer's surplus is the highest and this effect dominates the social surplus in our dynamic framework.*
- *The worst situation from the point of view of social welfare corresponds to the strongest patent system with longest and broadest patents* (hh).

The technical progress is another (and even more) relevant criteria for comparing patent regimes from the efficiency point of view. As a matter of fact, establishing a more efficient innovation system is the declared objective of the defendants of a stronger patent system. The rest of the article will focus on the connection between the dimensions of the patent system and technical progress.

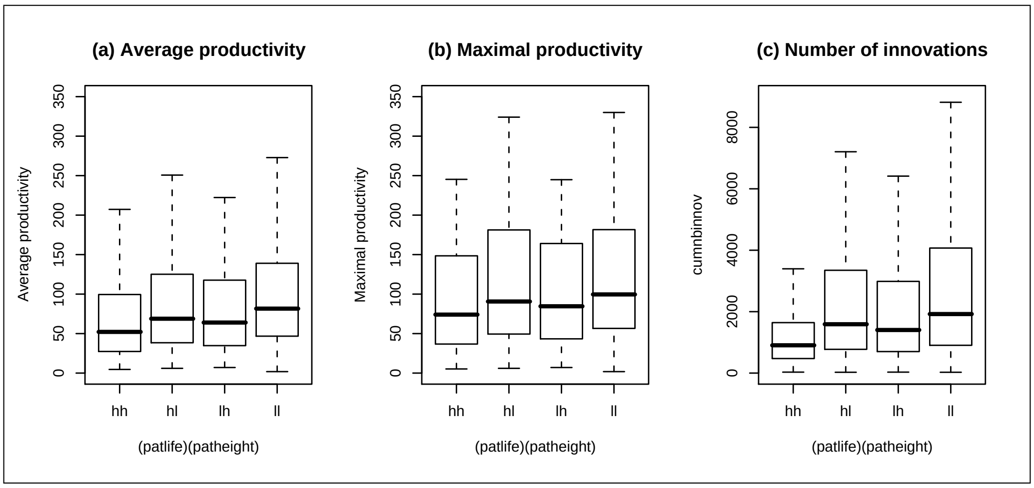

Figure 7: Technical progress is decreasing with PATENTHEIGHT ($t \geq Q_2^t$)

3.5 Patent regimes and technical progress

Is a stronger patent system favorable to technical progress? We have already observed that patents are effective in impeding innovations of the competitors and imitation. But, they can nevertheless be favorable to technical progress by protecting leaders in the industry. We now consider the final effects of a stronger patent system on global technical progress.

The Figures 7–(a,b) give the distributions of the average and maximal productivities and they clearly show that the most strong technical progress is observed in the mildest patent system where the patent life is the shortest and the patents are the narrowest (the configuration ll). We have also the highest number of innovations in this case (Figure 7(c)). Again, the strongest patent system (hh) corresponds to the weakest performance. These figures give the same answer to the main question of O'Donoghue et al. (1998): from the technological point of view also, it is preferable to have short-lived and narrow patents. These results are confirmed by the WRS tests (*see* Table 2), since these tests induce the following ordering for the average productivity and maximal productivity between configurations: $ll > hl > lh > hh$. As a consequence, a lower patent height is favorable to technical progress. If patents are broad, shorter patents are preferable. In even a more global level, lines 6 and 8 in Table 1 show that technical progress is slower when the patent system is stronger. As a consequence, the negative result on the social utility of a stronger patent protection is very systematic in this model.

Proposition 4 (Technical progress 1) *A stronger patent system implies a weaker technical progress. The highest average and maximal productivities are observed in economies where the patent office grants short-lived and narrow patents.*

We can establish these results in a more detailed way by using regression trees. The regression tree of Figure 8 gives the dimensions of the patent system that most significantly determinate the technical progress measured by the average productivity.

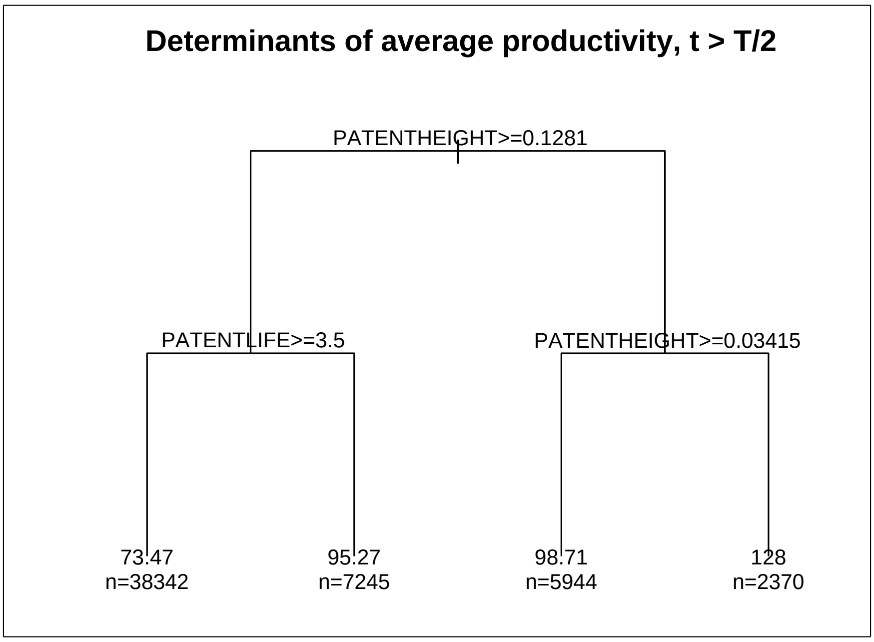

Figure 8: Patent dimensions and average productivity ($t \geq Q_2^t$). Very low patent heights are the key to maximal productivity.

A regression tree (Venables & Ripley (1999), chapter 10) establishes a hierarchy between independent variables using their contributions to the overall fit $\left(R^2\right)$ of the regression. More exactly, it partitions the set of observations in sub-classes characterized by their values in terms of their contribution to the overall fit and of their predictions for the dependent variables (all dimensions of the patent system that are modified by the Monte Carlo procedure are included as explanatory variables in the regressions). This value is validated against a fraction (10%) of the sample that is not used during the estimation. Regression trees are very flexible and powerful in the clarification of the structure of the observations. The tree gives a hierarchical sequence of conditions on the variables of the model: the higher the role of a condition in the classification of the observed cases, the higher its status on the tree. For each condition, the left branch gives the cases for which the condition is true and the right branch gives the cases that are compatible with the complementary condition. At each end of the tree, we have cases that verify the intersection of several conditions and the tree indicates the expected value of the independent variable in the corresponding configuration and the number of cases that verify all these conditions.

The tree 8 is constructed by using all dimensions of the patent system as potential explanatory variables. The top branch show that the height of the patents is the main determinant and, following the right branch of the tree, we observe that the highest productivity is observed when $PATENTHEIGHT$ is inferior to 3.4%. That corresponds to very narrow patents in this model. Following the left branch, we observe that for heights superior to 12.8%, the highest productivity is observed when $PATENTLIFE$ is inferior to 3 periods. This again corresponds to very short patents in this model. Other dimensions of the patent system play a much less significant role and they do not appear in this tree. These results confirm the proposition 4.

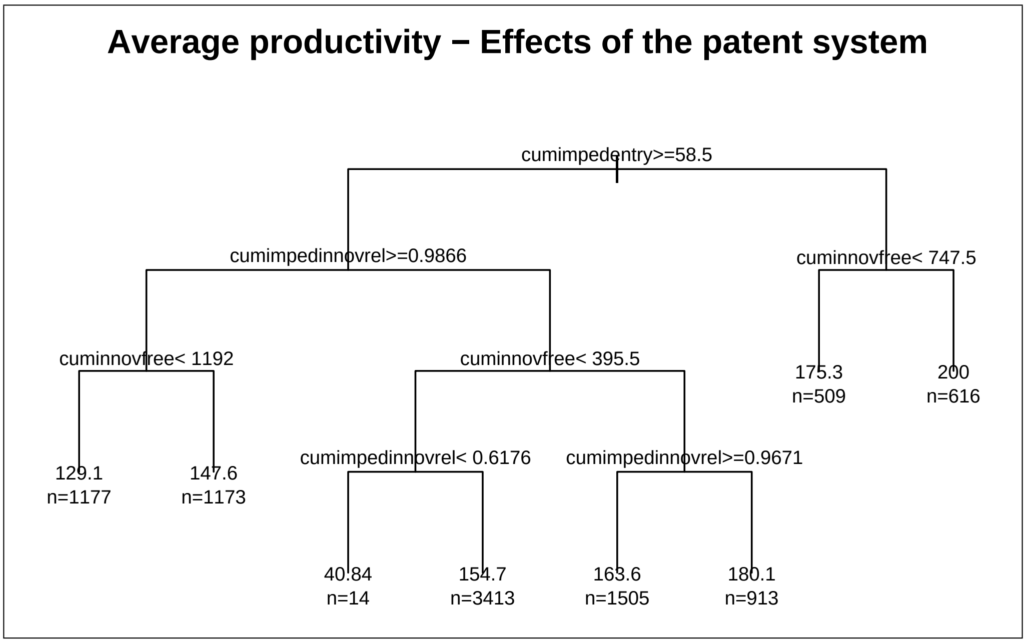

Figure 9: Effects of patents and average productivity ($t = T$). The dominant role of impeded entry and free technologies.

The question of the mechanisms through which patents determine the technical progress then arises. We know that these mechanisms must correspond to the following effects of patents: impeding entry, impeding imitations, impeding innovations and allowing firms to catch up using technologies that become free after the abandoning of the corresponding patents.

We study the role of these effects in the tree of Figure 9. Initially, all these effects are included as potential explanatory variables (*cumimpedentry*, *cumimpedimit*, *cumbimpedinnovrel* and $cuminnovfree$ that give the cumulative numbers on these effects).

These results clearly show that the main impeding effect that plays against the average productivity is the impeding of new entry. On the most right branch, we observe that the highest expected average productivity is attained when the number of impeded entries is lower that 58 and when the firms strongly benefit from free technologies. The potential role of the patents in the diffusing of knowledge effectively helps the industry in technical progress. On the most left branch, we see, on the contrary, that lower expected average productivities are observed when entry is frequently impeded.

Proposition 5 (Technical progress 2) *The negative impact of patents on technical progress mainly arises from their role in impeding entry. Patents effectively contribute to technical progress in the industry by allowing the public use of abandoned technologies but this effect is not sufficient to compensate their negative effects.*

3.6 The role of other dimensions of the patent system

The preceding analysis shows that the life and height of patents play the main role in the influence of patent system on welfare and technical progress. The Table 1 shows that other dimensions also play secondary and more partial roles.

Does the publication date play a significant role? Early publication of patents (lower *PATENTPUBDATERATIO*) has a positive effect on the consumers' surplus and the average profits of the firms. It decreases the patenting activity of the firms and, even if its increases the concentration of the industry, earlier publication increases the number of innovations.

Proposition 6 (Technical progress 3) *If patents are present, their early publication is beneficial to technical progress and to consumers' welfare.*

The filing cost of new patents ($NEWPATENTCOST$) has a negative impact on social welfare since it decreases the surplus of the consumers and the profits of the firms. The renewal cost does not play a globally significant role.

We also observe that the effect of the published patents is positive on social welfare (through $WEIGHTPUB$) since all components of this welfare increase in industries where this effect is stronger.

4 Conclusion

This article checks the validity of the negative results of **?** on patent fences, in a context where the potentially positive effects of the patents are explicitly taken into account: publication of patents participates to the building of a collective knowledge stock, on which the innovations can rely, and dropped patents can provide a source of technical progress for firms that are lagging behind the leaders of the industry. The main results of the model show that these effects do not counterbalance the negative effects of a stronger patent system on social welfare and on the global technological progress, even if stronger patents are sources of better protection and higher profits for the firms: we observe that industries have difficulty to survive with stronger patent systems and, that such systems yield lower social welfare and technical progress. The negative impact of patents on technical progress mainly arises from their role in impeding entry. Patents effectively contribute to technical progress in the industry by allowing the public use of abandoned technologies but this effect is not sufficient to compensate their negative effects through the impeding of the introduction of innovations by the competitors (patent fencing). Consequently, the results of the model do not advocate the establishment of a stronger patent system.

Our model is simple and has several shortcomings. We do not explicitly address the differentiated roles that patents can play in different technological regimes Merges & Nelson (1990)). In order to keep the model simple, we also disregard the positive effects that can result from licensing. The inclusion of licensing would necessitate a much more complex representation of the strategies of the firms, with necessarily many supplementary assumptions. We do not address either the potential inefficiency of patents to protect from imitation, but this is deliberately chosen in order to consider the most favorable case to patents. Since our results are negative, the inclusion of this possibility would even more strengthen these results. Our approach do not include institutional dimensions of the patent system either, and their role has been emphasized in recent studies that criticize the *de facto* reinforcement of the U.S. patent system in the 80s, as a consequence of important institutional reforms (like the establishment of the Court of Appeals for Federal Circuit, *cf.* Jaffe & Lerner (2004)). Even with these shortcomings, we nevertheless consider that our model teaches us interesting insights about the potentially harmful effects of a patent system when firms chose to twist it to build patent fences and block the advancement of their competitors and hence, of the industry.

These results definitely need to be qualified, mainly in two directions. In the first place, a better and more realistic representation of the cumulative nature of the technology space must be developed. One strategy could consist in the construction of a more complex technology space with an explicitly modeled dependence structure between early technologies and later ones. This strategy can only be convincing if we can find a simple and neutral way of representing this dependence. A more immediate refinement is the introduction of a multi-dimensional technology space in order to distinguish the height and the breadth of the patents. It would also be very interesting at this stage to distinguish the lagging breadth of patents from their leading breadth. Last but not least, a model of product innovations would definitely complete our analysis by more directly introducing the role of the demand in industry dynamics and the corresponding effects of a stronger patent system.

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A Initialization of the main parameters of the model

Exogenous variables

$N = 1$: Initial number of firms
$T = 100$: Number of periods
$PROBIMITATE \in [0, 0.005]$: Probability of imitation
$PROBMUTATE \in [0, 0.005]$: Probability of mutation
$SIGMA\_IN \in [0.1, 4.1]$: Standard deviation of the innovative draws
$PATENTRATE \in [0, 1]$: Initial average share of the patent budget in the gross profits
$SAVINGRATE \in [0, 1]$: Initial average share of the savings in the gross profits
$IKRATE \in [0, 1]$: Initial average share of the investment in physical capital in the gross profits
$IRDRATE \in [0, 1]$: Initial average share of the R&D budget in the gross profits
$ENTRYRATE \in [1, 20]$: Number of entry attempts in each period
$\lambda_0 = 0.5$: Initial level of the latent productivity
$\gamma = 0.05$: Slope of the latent productivity
With these values, the productivity of the entrants is drawn around $exp(5.5) = 244.7$ at $t = 100$.
$NEWPATENTCOST \in [0, 5]$: Cost of filing a new patent
$RENEWPATENTCOST \in [0, 1]$: Cost of renewing an existing patent
$PATENTHEIGHT \in [0, 1]$: The height of the granted patents. If the patent correspond to the productivity A_0, all productivities in $[A_0 \cdot (1 - PATENTHEIGHT), A_0 \cdot (1 + PATENTHEIGHT)]$ are protected from the competitors.
$PATENTLIFE \in [0, 30]$: Legal maximal life of patents
$PATENTPUBDATERATIO \in [0, 1]$: The ratio of the publication date to the official patent life ($PATENTLIFE$)
$EQUITY \in [10, 60]$: Initial average equity of the firms
$WEIGHTPUB \in [0, 1]$: The weight of the maximal published productivity in the innovation process of the firms
$SECRECY \in [0, 1]$: The effectiveness of the secrecy to protect new inventions from imitation
$CF \in [0, 12]$: Fixed costs of the firms
$K \in [10, 60]$: Initial average capital stock of the firms
$COST \in [0, 1]$: Initial average unit using cost of the capital
$DEM \in [500, 1000]$: Demand coefficient
$ETA \in [0.5, 0.9]$: Elasticity of demand
$p = DEM/Q^{ETA}$

Endogenous variables

$price$: Market price
n : Number of active firms
$averprofit$: Average profits
CS : Consumers' surplus
SS : Social surplus
$maxprod$: Maximal productivity of the period
$averprod$: Average productivity of the period
$activeN$: Number of active firms in the industry
$invCI$: Inverse Herfindall index of the period
$nbinnov$: Number of innovations in the period
$nbpat$: Total number of active patents in the period
$maxpatage$: Age of the oldest active patent
$nbpatfirms$: Number of patenting firms in the period
$cumbpat$: Cumulated number of the patents in the industry history
$cumnbinnov$: Cumulated number of innovations
$cumimpedentry$: Cumulated number of entry trials impeded by the existing patents

$cumimpedinnov$: Cumulated number of innovations impeded by the existing patents
$cumbimpedinnovrel$: $cumimpedinnov/cumnbinnov$: proportion of innovations impeded by patents.
$cumimpedimit$: Cumulated number of imitation trials impeded by the existing patents
$cuminnovfree$: Cumulated number of technical progress steps obtained thanks to free technologies

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