Reinforcing the patent system? Patent fencing, knowledge diffusion and welfare

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Abstract

This article develops an evolutionary model of industry dynamics 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 the patents: 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 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 Vallée & Yildizoglu (2006). 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.
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JEL Classification: O3, O34, L52

1 Introduction

This article develops the analysis initiated in Vallée & Yildizoglu (2006) 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 the extension of the patent system as a global incentive device for private (and even public - see the impact 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. This rather mechanistic approach of technological dynamics and of the role of the patenting is mainly based on the neoclassical theory of technical progress that strongly focuses on the agents' incentives rather than on the dynamics of the existing technological systems. It also does not correspond to the recent empirical findings about the diversified role that the patents are called to play in different industries and other stylized facts about patenting by firms.

In the incentive based vision, the patent system solves both 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.

This rather optimistic approach of technological dynamics and of the role of the patenting does not really correspond to the recent empirical findings 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, which comes to dominate our empirical understanding of the patent system, concerns the quite low esteem in which the firms consider the patent in comparison with other tools that they commonly use (like secrecy, the lead time or to have recourse to complementary services or manufacturing – see, for example, the 1994 Carnegie Mellon Survey of the U.S. manufacturing sector are summarized in Cohen et al. (2000)). This survey clearly shows that the main motivation for patenting does not correspond to the theoretical argument used in defense of a stronger patenting policy (better incentives for R&D). This observation, combined with the recent

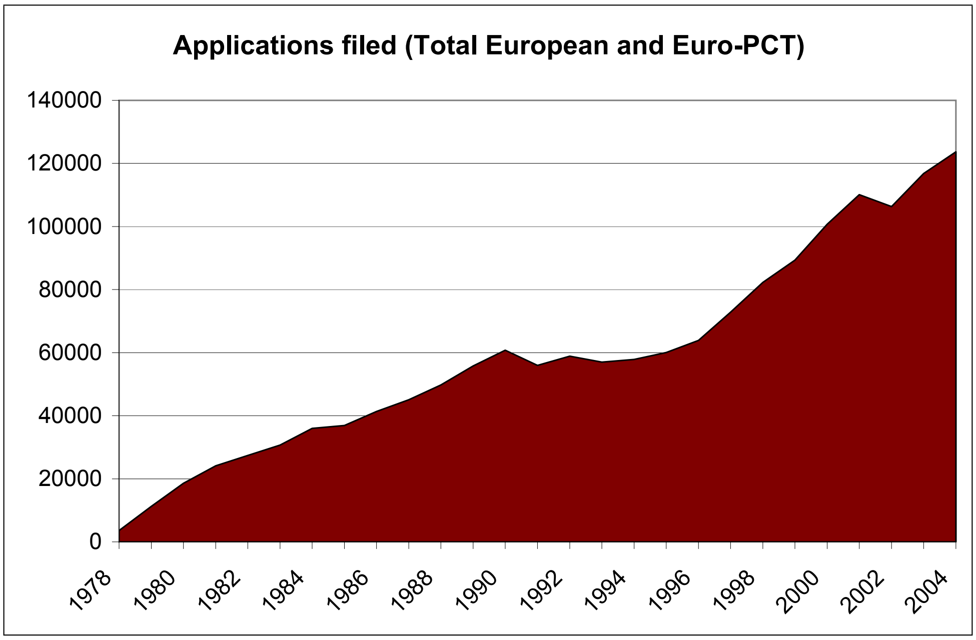

Figure 1: Applications to the European Patent Office (EPO)

surge in patenting gives rise to what is called today the *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.

The 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 inefficacies. Does a stronger patent system really foster technological innovations? Is this effect enough to compensate the static inefficiencies due to the monopoly position? Does the publication of the patents assure an efficient knowledge diffusion, compensate the potentially negative effects of patent fencing and finally yield a higher technological pace?

This article develops the evolutionary model of Vallée & Yildizoglu (2006) in order to try to give a more balanced answer to these questions. Vallée & Yildizoglu (2006) has focused on the technology dynamics resulting from patent thickets in the evaluation of the social costs and benefits of a stronger patent system. Several potentially positive effects of patents were neglected in this study. We now develop a richer model where these effects are clearly 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 contribute to the general knowledge level of the industry and to potential technological progress through innovation. We evaluate the global effect of these positive aspects of the patent system in interaction with patent fencing effects on the technology dynamics. The main results of the article show that these positive effects are not enough for advocating for a stronger patent system.

The next section will briefly present the main characteristics of the model. The third section will be dedicated to the presentation of our simulation protocol and of the first results of the basic model. The last section will conclude the presentation.

2 The Model

This model concerns an industry producing a homogenous good and facing a decreasing market demand. The only production factor is physical capital, and technology has constant returns to scale (it is linear). In each period, each firm shares its gross profits between different investment outlets: R&D, physical capital, patent budget, saving (equity) and distribution of dividends. R&D investment is necessary for the imitative and innovative activity of the firm, and these are the only sources of productivity gains in the model. Technical progress is disembodied and corresponds to the increase of the productivity of the firm's capital stock.

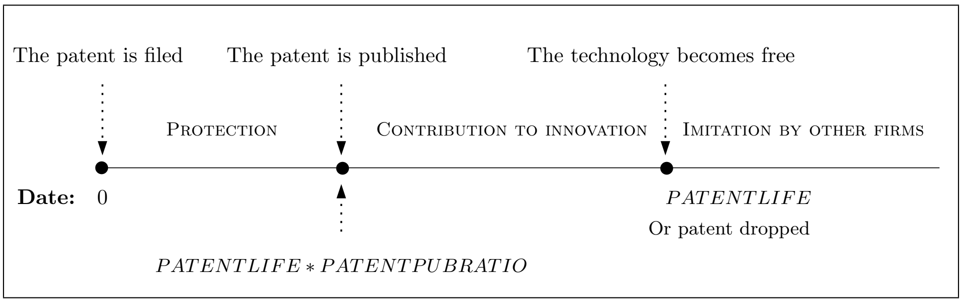

Figure 2: The Life of a patent...

The industry is initially populated by firms with random characteristics (drawn following a normal distribution centered around common averages). The short-period market equilibrium fixes the price at which the consumers agree to buy this product, given their demand in each period. 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; dividends are distributed to the consumers and they can increase demand; the equity is used as saving and can provide supplementary revenues for investing in future periods (see below). In this model, we dedicate a particular attention to the patenting strategies of the firms. 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 used in 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); **(c)** when a patent is dropped or when it arrives to the end of the patent life (*see* Figure 2), 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 is represented by a parameter $SECRECY$ that gives, in probabilistic terms, the effectiveness of secrecy (the higher the $SECRECY$, the lower the probability of being imitated for inventions kept secret).

In the rest of this section we will briefly present the main components of 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 the previous periods. In our model, these revenues can be allocated between five alternative assets (*see* Figure 3):

Investment in physical capital: The firms expands its capital stock in order to increase its market

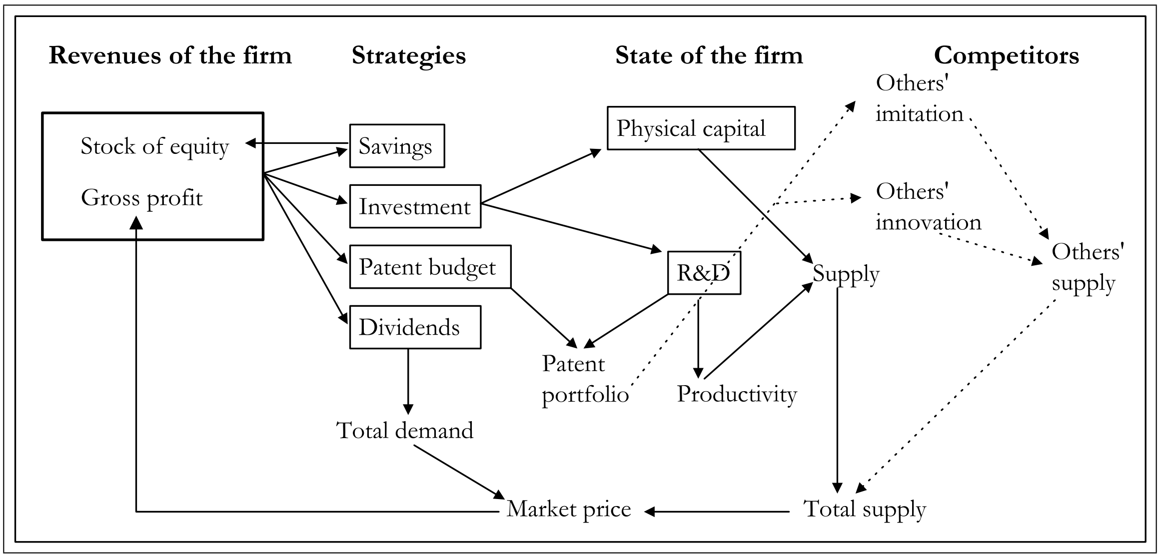

Figure 3: The main connections in the model

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 own technological investments, the firm can decide to protect an innovation. 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 measured 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 this investment rate around which the strategies of the firms are created.

Dividends: Firms can redistribute a part of their profits to shareholders and thus to households. In this simplified model, this is the only way by which the total demand increases. The coefficient that transforms the distributed dividends into demand increases is γ. $DIVIDENDRATE$ is the initial average value of this investment rate around which the strategies of the firms are created.

Savings: Firms can save voluntarily and/or involuntary, part of their profits. Involuntary savings arise when one of the budget lines is not spent in its totality. This saving is precautionary, since it enables a company 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. $EQUITYRATE$ is the initial average value of this investment rate around which the strategies of the firms are created.

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, 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. 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. Firms may file patents in order to protect their new technologies from imitation by competitors.

Productivity gains: innovation and imitation

In our model, innovation is a two-stage stochastic process. 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 taken around a mean that correspond 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 $WEIGHTPUB$).

It should be noted that a new technology may only be used and patented if it is not covered 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 advance 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. Hence, when a new technology is found, the inventor can choose to protect it by filing a patent. If the firm does not protect it, the technology may be imitated or invented around by the competitors. A firm will only desire to patent a technology if *(a)* the technology is seen as sufficiently interesting to patent, and *(b)* the firm has a sufficient 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 with a productivity lower than the productivity of this technology: the higher the number of such firms, the more efficient the patenting. We assume that firms cannot perfectly observe the efficiency of their innovation and they are prone to errors. This efficiency criteria represents the patent fencing strategies of the firms.

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 can be a potential of ($ENTRYRATE * n$) new entries in the industry (n is the number of active firm in the period). The corresponding number of potential entrants are presented to the market, drawing randomly their characteristics but only candidates with technologies that are not impeded by an existing patent can effectively enter. We also assume that only the entrants who expect a positive profit, given the actual level of the market price, would enter.

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 exists the industry (the case of bankruptcy).

2.4 The pseudo-code of the model

We start with a population of N firms in the industry. We assume that each firm is initialized with random strategies that are drawn from the same normal distributions. The pseudocode of the model is given in Figure 4.

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

1. Populating the industry:
   - if $t = 1$: creation of an industry composed of N firms
   - if $t > 1$: entry of new firms
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 productivities of
15. active firms
16. Computation of the lists of all patented, published and free productivities in the industry
17. Diffusion of the best strategies in the industry (depends on the market shares of firms) and mutation of strategies
18. If $t > 1$ evolution of the demand D_t (depends on past dividend strategies)

Figure 4: The pseudocode 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 run 10000 series of 500 periods each, where the results from each period have a probability of 0.5% of being saved. We also systematically save the first and the last periods. So, for each run we obtain an average number of 5 randomly chosen observations for all the measured variables. The simulations are initialized with a randomly drawn vector of values for the main parameters of the model. As a result, we obtain a set of 44 968 observations covering quite a diversified subset of the parameter space. The values from which different parameters are drawn can be read in Appendix A. We do not necessarily discuss in the text all the parameters that appear in this appendix, but only the most significant ones. We analyze the observations sampled from the last half of each run, for dates higher than the second quartile of the saved periods $\left(t \geq Q_2^t = 249\right)$. This sample contains 22 454 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 regressions and regression trees. The statistical analysis is conducted using R (see R Development Core Team (2003))[1]. In the boxplots, the box gives the central 50% of the sample centered around 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.

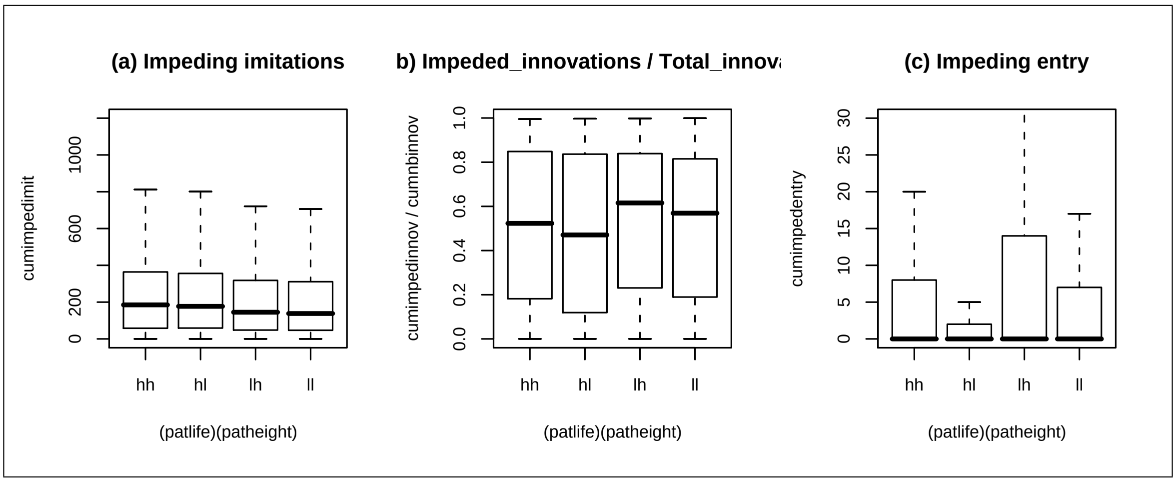

Figure 5: Effectiveness of the patent system. Numbers cumulated over 500 periods

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 $PATENTLIFE$:*

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

[1] A detailed statistical appendix can be downloaded from the following addres: `http://beagle.u-bordeaux4.fr/yildi/files/patents2_StatisticalAppendix.zip`

For example, the configuration hh corresponds to ($patentlife = high, patentheight = high$): a patent system where the patent office grants rather long-lived and broad patents. This 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)).

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

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 $t \geq Q_2^t = 249$

In our model, patents can be used to:

- allow the patenting firm to protect its innovation from imitations;
- allow the patenting firm to impede entry by firms with similar technologies;
- allow the industry to benefit from technologies that become public when the patent is dropped or expired.

Figure 5 shows that patents do effectively impede imitations, innovations and new entry in this economy. The boxplot (a) shows that longer patent life is the source of the effectiveness in impeding imitations, while we observe in Boxplot (c) that broader patents are more effective in impeding new entry. We also remark that this phenomenon is rarer: in 50% of the cases no entry is blockaded by existing patents. Boxplot (b) shows that significant proportions of the potential innovations are blocked by the existing patents and this effect is maximal when the patent life is relatively short but the patents are broad. Paradoxically enough, at a very global level, a higher proportion of innovations is blocked when the patent life is shorter (this global result is obtained using a linear regression (*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.*

[2]The Table 1 gives the sign of the coefficients with a statistical significance of at least 10% (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 can figure in this table.

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.

3.3 Patent system and social welfare

We begin the analysis by our central question about 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 dimensions of the patent system on social welfare, we compute the median values of average profits and social surplus in different intervals of values of these three dimensions of the patent system[3].

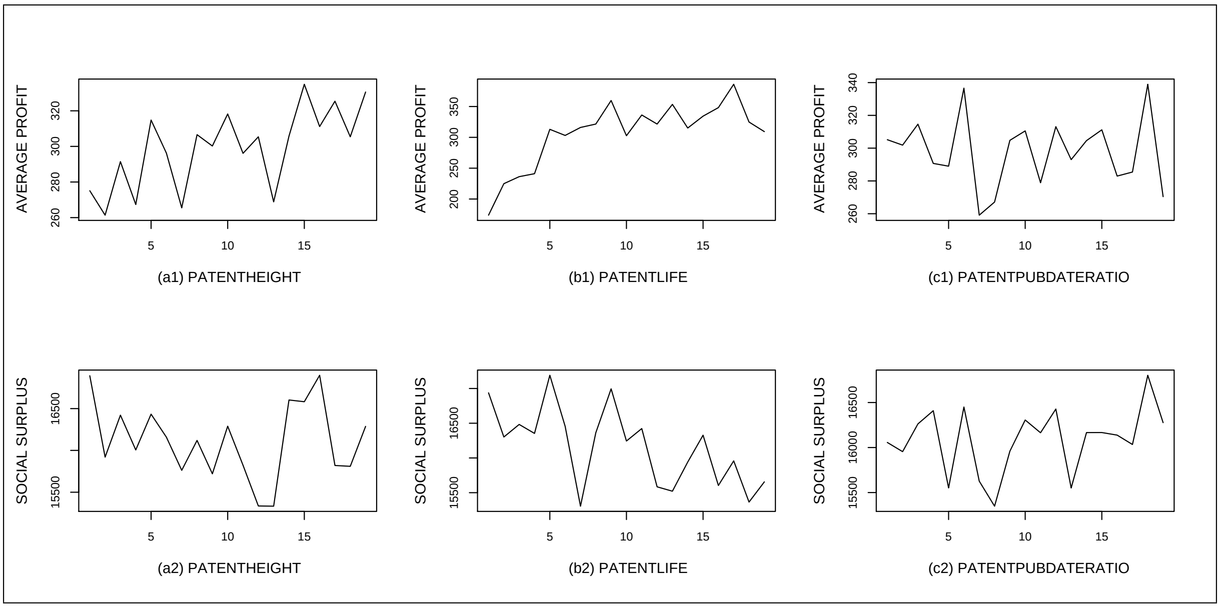

Figure 6: Patent system and welfare ($t > Q_2^t$)

Profits. The top row in Figure 6 indicates how the median of average profit evolves when the values of these dimensions increase. Graph *(a1)* indicates that the average profits of the firms are higher in patent systems with higher $PATENTHEIGHT$ and hence broader patents. Graph *(b1)* indicates a similar impact of official patent life on profits and the last graph ($c1$) exhibits an ambiguous relationship between the publication date of patents and profits (this ambiguity is confirmed by the WRS tests given in the section $A.6$ of the online appendix). These results indicate that a stronger patent system would be beneficial to firms and they are also confirmed, at a very global level, by the results of Table 1, line 3). Does this mean that we should adopt 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 bottom row of Figure 6 exhibits the evolution of social welfare. Graphs ($a2$-$b2$) indicate that a stronger patent system is harmful on social welfare: the effect of these dimensions on consumers surplus clearly overweights the supplementary profits of the firms. The WRS test results given in the statistical Appendices $A.2$ confirm this result because they imply the following ordering of our patent system configurations: $ll = lh > hl = hh$ (see Table 2). As a consequence, short-lived patents are more beneficial to social welfare (but the patent height does not play a significant role). Test results of the section $A.1$ of the appendix exhibit similar results for the consumers welfare. This confirms Graph ($b2$). Graph ($a2$) weakly indicates that social surplus

[3] $PATENTHEIGHT$ and $PATENTPUBDATERATIO$ are continuos and $PATENTLIFE$ is discrete. We call the `cut` function of R in order to divide the rando values of these variables in 20 intervals.

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

Table 2: Patents and social welfare. Results of WRS tests

is decreasing with the patent height, at least for non extreme values. Moreover our WRS tests of the section *A.6* of the online appendix indicate that early publication of the patents has a puzzling negative impact on consumers surplus in this economy.

The results concerning the social welfare are summarized in the following proposition.

Proposition 2 (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 (taking into account the potential dynamic efficiency of a higher patent protection).*
- *The worst situation from the point of view of social welfare corresponds to the strongest patent system with longest patent lives and broadest patents (hh).*

In this model, the possibility of a complementarity between profits and consumer surplus exists. In fact, firms can choose to distribute dividends in order to sustain the growth of their industry. In this case, a higher price can coexist with a higher consumers surplus because of the demand increase that results from the distributed dividends.

As a consequence, rather than the consumers surplus, the technical progress is the 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.

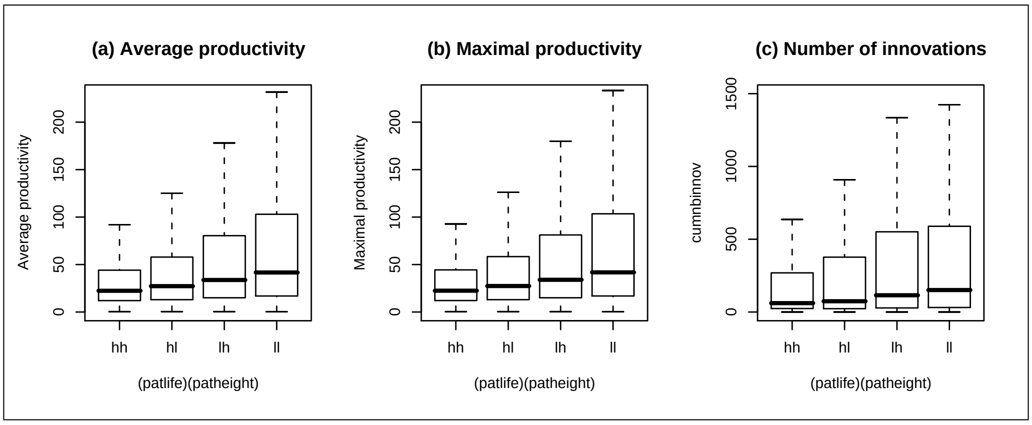

Figure 7: Technical progress is decreasing with PATENTLIFE ($t > Q_2^t$)

3.4 Patent regimes and technical progress

Is a stronger patent system favorable to technical progress? The Figures 7(a-b) give the distributions of the average and maximal productivities and they clearly show that the technical progress is the strongest in the mildest patent system where the patent life is low 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 (*cf.* section *A.4* of the on line statistical appendix), since they induce the following ordering for the average productivity between configurations: $ll > lh > hl > hh$. As a consequence, a shorter patent life is favorable to technical progress. If the patent life is long, a narrower patent is then preferable (this is also true with short-lived patents). In even a more global level, lines 6 and 7 in Table 1 show that technical progress is slower when the patent system is stronger (broader patents with longer life) and the publication is later. As a consequence, the negative result on the social utility of stronger patents is very robust in this model.

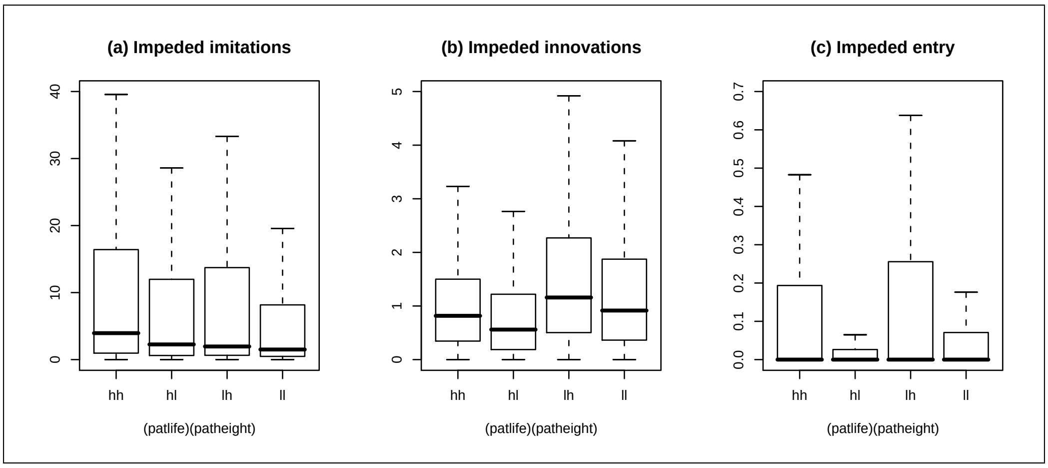

Figure 8: Relative efficiency of patents ($t = T$)

Proposition 3 (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 gives short-lived and narrow patents and where the granted patent is published quite early in the process.*

Which mechanisms are behind these results? Figure 5 already shows that patents are effective in impeding innovations and imitations. We give another picture of this effectiveness in Figure 8 where the number of impeded elements are cumulated until period 500 and divided by the cumulated number of patents, in order to represent the *productivity* of patenting in different regimes. These figures show that the negative impact of *hh* is mainly due to the capacity of impeding imitations (Graph-*(a)*) and new entry (Graph-*(c)*) in this regime, rather than to the capacity to impede innovations (Graph-*(b)*). Moreover, the impeding of imitations comes from longer life of patents in this regime, while the impeding of the entry results from their broader scope. The figure also shows that the configuration that is the most entry and innovation friendly is *hl* corresponding to long-lived but narrow patents.

The regression trees of Figure 9 give some complementary insights on the impact of patents' consequences on productivity. A regression tree (Venables & Ripley (1999), chapter 10) establishes a hierarchy between independent variables using their contributions to the overall fit (R^2) of the regression. More exactly, it splits the set of observations in sub-classes characterized by their values

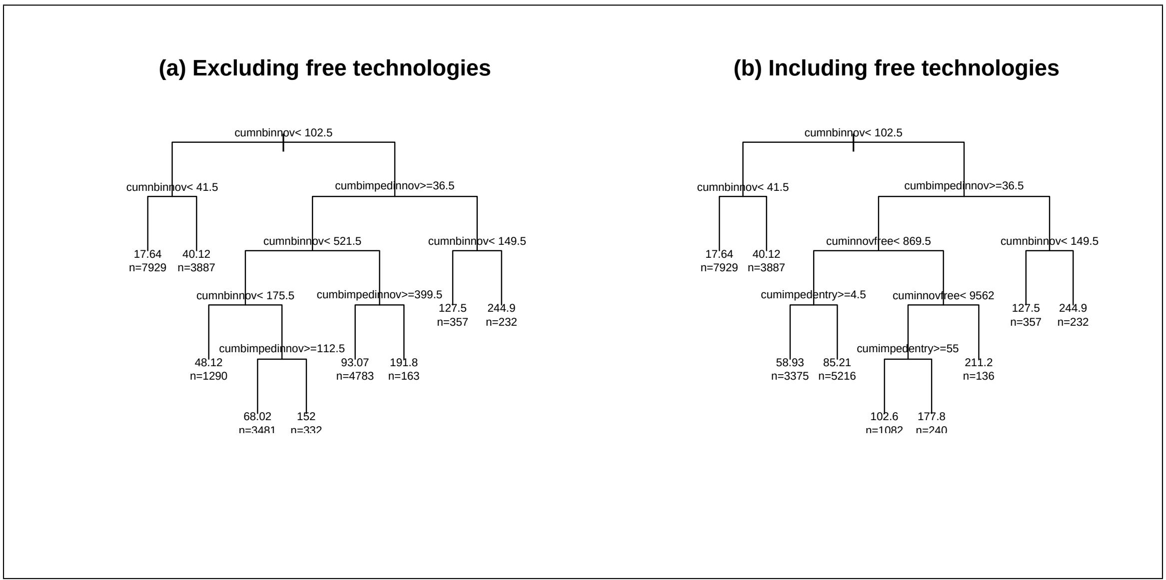

Figure 9: Effects of patents and average productivity ($t > Q_2^t$)

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. We give now a step-by-step interpretation of the main elements of the regression tree exposed in Figure 9.

The tree *(a)* includes all cumulative variables (*cumnbpat*, *cumbimpedinnov*, *cumimpedimit*, *cumimpedentry*, *cumnbinnov*) but the diffusion of free technologies ($cuminnovfree$) as possible explanatory factors of average productivity. The most right branch corresponds to the highest expected average productivity (244.9) and this high value results from a significant number of innovations ($> 149.5 \approx 150$) with only a very small subset of them impeded by patents ($cumimpedinnov < 36.5 \approx 37$). If more innovations are impeded ($cumimpedinnov \geq 36.5$), the economy needs a much higher innovative capacity ($cumnbinnov \geq 521.5 \approx 522$) in order to attain the second best expected productivity level (191.8). The tree *(b)* includes in the set of explanatory factors the number of technologies that become free when their patent is dropped ($cuminnovfree$). We observe that this positive dimension of patents only plays a role when enough innovations take place and a significant number of them are impeded ($cumimpedinnov \geq 36.5 \approx 37$). In this case, the second best can only be attained if patenting gives back enough free technologies to the industry ($cuminnovfree \geq 869.5 \approx 870$) . These results clearly show that the main impeding effect of patents that play against productivity is the impeding of new innovations. Of course this is only a partial story since all these factors are endogenous and they depend on the dimensions of patent system.

What is the role of other dimensions of the patent system that we take into account in this article? The Figure 10 shows that the main determinant of the average productivity is the technology regime represented by the values of $WEIGHTPUB$: the necessity to rely on public knowledge to innovate. On the left, we have all observations for which $WEIGHTPUB \geq 0.08456 \approx 8.5\%$. On the right branch, we have all observations for which $WEIGHTPUB < 8.5\%$. If we follow this branch, we observe that values of $WEIGHTPUB$ again play an important role: the highest expected value of the

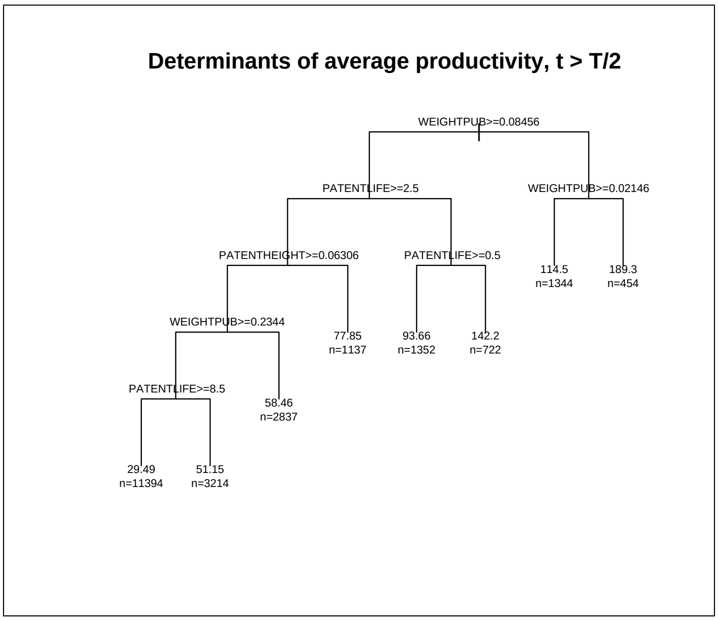

Figure 10: Patent dimensions and average productivity... ($t > Q_2^t$)

average productivity (189.3) can only be attained in regimes where $WEIGHTPUB < 0.02146 \simeq 2\%$. Hence when $WEIGHTPUB \in [2\%, 8.5\%[$, the expected value of the average productivity is 114.5 and we have $n = 1344$ observations corresponding to this case. As a consequence, we observe that the social dimension of the innovation process slows technical progress in this model instead of reinforcing it. If the social dimension is important ($WEIGHTPUB \geq 8.5\%$), other dimensions of the patent system condition the average productivity. As a consequence, the second best expected productivity (142.2) is observed when $PATENTLIFE$ is zero (< 0.5). Consequently, we can conclude that if the social dimension is unavoidable, a patentless system is the best from the point of view of technical progress. This is again quite a strong negative result against a stronger patent system, or even against the necessity of a patent system at all. The lowest productivity levels are observed when the social dimension is quite strong ($WEIGHTPUB \geq 23\%$) and the patent system is also strong ($PATENTHEIGHT \geq 6\%$ and $PATENTLIFE \geq 9$ periods). This result again confirms our general results (Proposition 3).

Proposition 4 (Technical progress 2) *The social dimension of the innovation process has a retarding effect on technical progress in this economy. When this dimension is not negligible, the highest productivity is obtained in a patentless system. The worst situation emerges when the social dimension of innovation is strong, corresponding to a strong reliance on published knowledge, and the patents are relatively long-lived and broad.*

Does the publication date play a significant role? Appendix *A.5* gives WRS tests results that clearly show that early publication yields higher average and maximal productivities in the economy. Early publication allows a more rapid increase of the collective knowledge on which are based innovations in the economy, and this clearly corresponds to higher productivities.

Does the strength of the social dimension imply significantly different roles for the dimensions of the patent system? We compare in Figure 11 two regimes: one where the social dimension of innovation is relatively high $\left(WEIGHTPUB > Q_2^{WEIGHTPUB}\right)$ and another where it is low. Graphs *(a)* and *(b)* show that patent life and patent height do not really play a differentiated role between these two regimes. Graph *(c)* shows that late publication is detrimental to productivity when the social dimension is high, while it does not make a significant difference when innovators do not much rely on published patents (this result is not really surprising, of course).

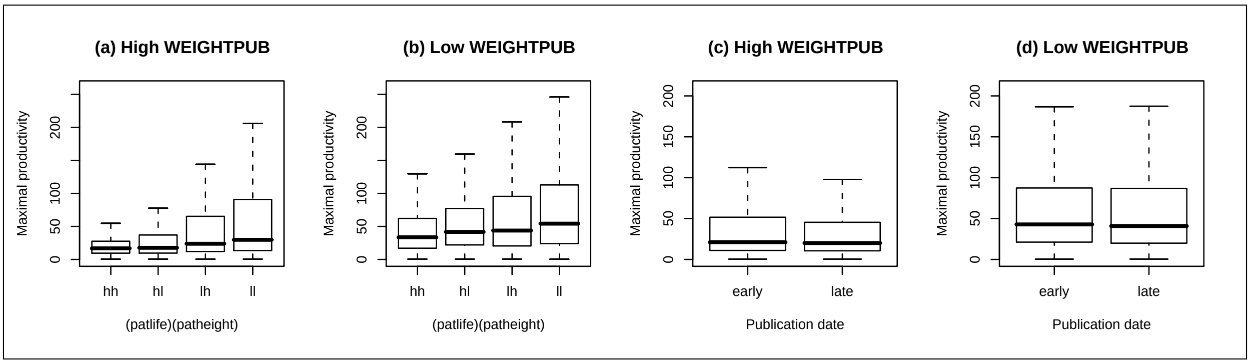

Figure 11: Different roles in different regimes? ($t > Q_2^t$)

Proposition 5 (Technical progress 3) *If patents are present, their early publication is beneficial to technical progress.*

4 Conclusion

I question in this model the negative results of Vallée & Yildizoglu (2006) in a context where the 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 technological 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 global technological progress, even if it is a source of better protection and higher profits for the firms.

Our model also contains a modest development in the direction indicated by Merges & Nelson (1990): patents could play a differentiated role in different technological regimes. First results of the model show that this is only true in our case for the publication date, but the negative effects of a stronger patent system can be observed in all regimes that are integrated in our analysis. As a consequence they constitute quite a robust argument against the reinforcement of patent system. Even if our approach do not yet include institutional dimensions of the patent system, our results yield a more radical conclusion than 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)).

These results definitely need to be refined, 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 as neutral as possible 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.

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A Initialization of the main parameters of the model

Exogenous variables

$N = 40$: Initial number of firms

$T = 500$: 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

$DIVIDENDRATE \in [0, 1]$: Initial average share of the distributed dividends in the gross profits

$PATENTRATE \in [0, 1]$: Initial average share of the patent budget in the gross profits

$EQUITYRATE \in [0, 1]$: 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

$ENTRYRATE \in [0, 0.05]$: Probability of new entry

$ALPHA \in [0, 1]$: Depreciation rate of the technological knowledge of the firm

$GAMMA \in [0, 0.01]$: Transformation rate of dividends into supplementary demand

$NEWPATENTCOST \in [0, 5]$: 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 $[A_0(1 - PATENTHEIGHT), A_0(1 + PATENTHEIGHT)]$ 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

$PROD \in [0.2, 1.2]$: Initial average productivity of the firms

$COST \in [0, 1]$: Initial average unit using cost of the capital

$DEM \in [200, 500]$: Initial demand coefficient

$ETA = 0.9$: Elasticity of demand

Endogenous variables

$price$: Market price

n : Number of active firms

$maxprod$: Maximal productivity of the period

$averprod$: Average productivity of the period

$activeN$: Number of active firms in the industry

$cumnbinnov$: Cumulated number of innovations (including the innovations that can not be implementing because of existing patents, *see* $cumimpedinnov$)

$cumimpedentry$: Cumulated number of entry trials impeded by the existing patents

$cumimpedinnov$: Cumulated number of innovations impeded by the existing patents

$cumimpedimit$: Cumulated number of imitation trials impeded by the existing patents

$cuminnovfree$: Cumulated number of technical progress steps obtained thanks to free technologies

$invCI$: Inverse Herfindall index of the period

$averprofit$: Average profits

$nbinnov$: Number of innovations in the period

$nbpat$: Total number of active patents in the period

$cumbpat$: Cumulated number of the patents in the industry history

$maxpatage$: Age of the oldest active patent
$nbpatfirms$: Number of patenting firms in the period
$avpatrate$: Average percentage of the patent budget in the gross profits
$avirdrate$: Average percentage of the R&D budget in the gross profits
$avikrate$: Average percentage of the capital investment budget in the gross profits
$avequitrate$: Average percentage of the savings in the gross profits
$avdivrate$: Average percentage of the distributed dividends in the gross profits.