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REGULAR ARTICLE

Thomas Vallée · Murat Yıldızoglu

Social and technological efficiency of patent systems

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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. The first results obtained in our article are rather consistent with the anti-patent arguments and do not favor the case for a stronger patent system: higher social welfare and technical progress are observed in our model in industries with milder patent systems (lower patent height and patent life).

Keywords Innovation · Technical progress · Patent system · Intellectual property rights (IPR) · Technology policy

JEL Classification O3 · O34 · L52

1 Introduction

The demand for a stronger patenting system has become in the recent period a major source of tension between the U.S. government and the E.U. (see the recent debate on software patents). The US demand is generally motivated by the conventional economic wisdom affirming that a strong patenting system yields convenient incentives for the 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

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T. Vallée
LEN, Université de Nantes, Chemin de la censive du Tetre,
44322 Nantes, France
E-mail: Thomas.Vallee@univ-nantes.fr

M. Yıldızoglu (✉)
E3i, IFReDE-GRES, Université Montesquieu Bordeaux IV,
Avenue Léon Duguit, 33608 Pessac, France
E-mail: yildi@u-bordeaux4.fr

on the neoclassical theory of technical progress that strongly focuses on the agents' incentives rather than on the dynamics of the existing technological systems.

1.1 What is a patent?

The US Patent and Trademarks Office (USPTO) gives the following definition on its web site:

> A patent for an invention is the grant of a *property right to the inventor*, issued by the United States Patent and Trademarks Office. Generally, *the term of a new patent is 20 years* from the date on which the application for the patent was filed in the United States or, in special cases, from the date an earlier related application was filed, subject to the *payment of maintenance fees*(...). The right conferred by the patent grant is, in the language of the statute and of the grant itself, "*the right to exclude others from making, using, offering for sale, or selling" the invention in the United States or "importing" the invention into the United States*. (...) Once a patent is issued, the patentee must enforce the patent without aid of the USPTO. [US Patent and Trademarks Office legal web site[1]]

This definition puts a particular stress on the role of a patent as a certificate of private ownership of an invention. This ownership gives to the inventor the right to exclude anyone from the provision of this invention in the US. From the point of view of the inventor, the benefits of this exclusivity (the monopoly rent) should be opposed to the costs of filing and maintaining a patent. These dimensions of the patent system directly follow from the theoretical arguments that have been used to defend the establishment of patent systems during the 19th century patent controversy.

1.2 Arguments for a patent system

Following the arguments that have been developed by the defendants of a patent system during the patent controversy of the 19th century (see van Dijk 1994), a patent is

- the natural property right in ideas;
- the just reward for the inventor;
- the best incentive to invent;
- the best incentive to disclose secret information.

These arguments are based on the assumption that the main motivation of an *intentional* innovation is the monopoly rent that can be obtained using a superior technology or product.

Modern theoretical arguments emphasize the particularities of new technical knowledge for justifying the necessity of protecting intellectual property rights.

[1] http://www.uspto.gov/

Following these arguments,

- knowledge has two important characteristics: nonrivalry and nonexcludability;
- technical knowledge is a source of externalities in R&D.

These two dimensions may induce an underprovision of this *public good*. As a consequence, the correct incentives must be established through a temporary monopoly position and the public disclosure of private information. These arguments have regularly been questioned by the opponents of a strong patent system. This is quite natural given that patent systems concern the reallocation of rents in society and possess, as such, a political dimension.

1.3 Some stylized facts about patenting

Following van Dijk (1994), Cohen et al. (2000), Gallini and Scotchmer (2002), Hall (2002), and Mansfield (1986), we can specify some stylized facts about patenting:

- most patentable innovations are patented (the exact proportion is industry-specific);
- inventing around a patent occurs (with an average cost advantage of 35%);
- most innovations combine elements from existing products;
- 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.

There are more than four million patents in force in the world today, and every year applications are filed for a further 700000 inventions. In 2002, the European Patent Office (EPO) received over 160000 patent applications. Figure 1 clearly shows the *explosion* of the number of patent applications and of effectively granted patents in Europe.

1.4 Behind the incentives

Is patenting the only tool for protecting an innovation? The results of the 1994 Carnegie Mellon Survey of the U.S. manufacturing sector are summarized in Cohen et al. (2000). Following these results, firms declare that they have at their disposal a variety of tools, and they do not necessarily prefer patents to other means for protecting their innovations. In fact, firms' declarations imply the following ordering of these mechanisms with decreasing protective effectiveness:

1. Secrecy;
2. Lead time;
3. Complementary sales/services;
4. Complementary manufacturing;
5. Patenting

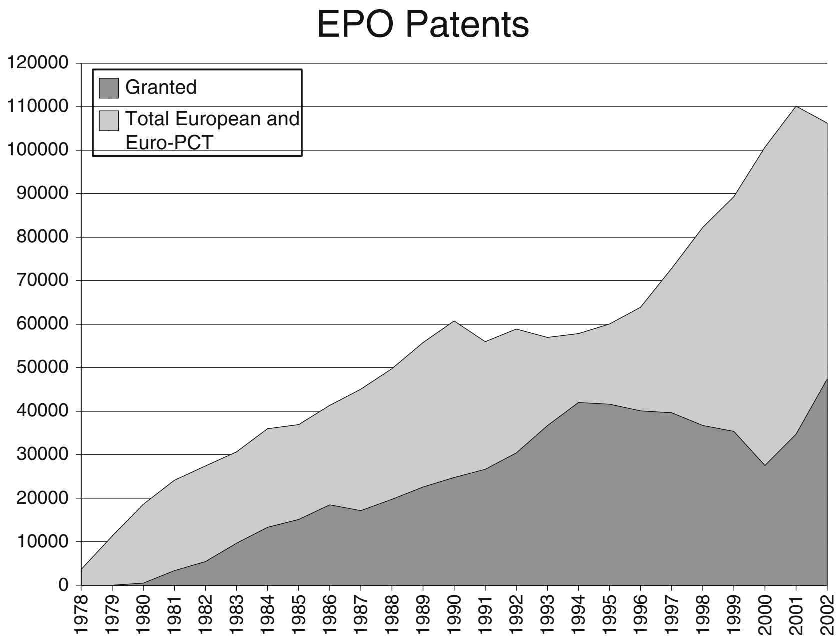

Fig. 1 Applications to the European Patent Office (EPO)

Secrecy is considered by the firms as the most effective mechanism for protecting process innovations, while lead time is considered to be slightly more effective for product innovations. 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 surge in patenting gives rise to what is called today the *patent paradox* (low effectiveness but high patenting).[2]

Patenting is mainly 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. Patent systems are promoted on the basis that they are the least expensive means to provide incentives for innovation. The anti-patent movement argues that patents are inefficient and expensive: the costs of bureaucracy (strongly increased during the recent patent surge– see Fig. 1), court personnel and lawyers make the patent system very costly and unattractive. These costs add to the welfare lost due to monopoly granted by the patent system. Even worse, building *patent fences* around discrete innovations can constitute *patent thickets* implying strong dynamical inefficiencies in innovation systems.

The social cost of defensive patenting (Cohen et al. 2000) follows from the fact that, in these cases, patenting does not foster inventions. Merges and Nelson (1990) and Mazzoleni and Nelson (1998) emphasize the complex nature of the dynamics of technology in many industries. Merges and Nelson (1990) show that a stronger

[2] See Hall and Ziedonis (2001) for electronics firms.

patent system can have very different effects on different industries. They distinguish four classes of technologies in which the role of patents can be strongly contrasted: *discrete inventions* (new pharmaceuticals), *cumulative technologies* (aircraft), *chemical technologies* and *science-based technologies* (biotechnology).

A "one size fits all" system of intellectual property rights seems quite illusionary and can sometimes generate strong social dynamic costs by blocking the development of complementary innovations or of better substitutes. The diversity-reduction effect of broad patents on prospect opening inventions can generate high social costs. As a consequence, models of innovation and of patenting must take into account the complexity of different technological regimes while evaluating the global impact of a stronger patent system and of its dimensions (mainly scope and length). An agent based approach to the industrial system, composed of boundedly rational firms, can help us to locate main issues in this debate. Moreover, at the more specific level of the patent race models, the main results are generally *too* strongly sensitive to the rational expectations (or perfect foresight) assumption and to the assumed homogeneity of the firms.[3] The main results of this literature should be tested against more realistic assumptions before using them in the analysis of intellectual property regimes. This article develops an evolutionary model of industry dynamics, aiming to enhance our theoretical understanding of the consequences of a stronger patent system. The next section will briefly present the main characteristics of our 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.

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 Fig. 2). In this model, we dedicate particular attention to the patenting strategies of the firms.

[3] See Silverberg and Yildizoglu (2002) for a discussion of this problem in the context of the Aghion and Howitt (1992) model.

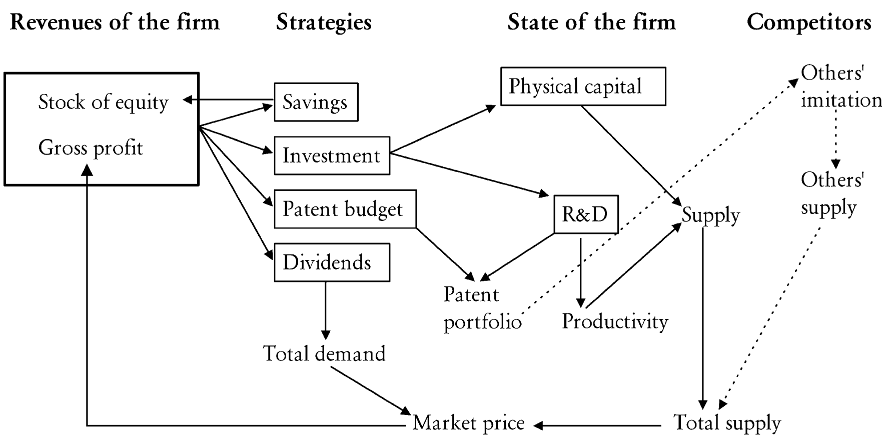

Fig. 2 The main connections in the model

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 Fig. 2):

Investment in physical capital The firms 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. The obsolescence cost of the R&D stock, for a given firm, depends on its relative productivity, compared to the maximum level of productivity in the industry. Hence, if a firm's productivity is low compared to the maximum level of productivity in the industry, its R&D stock will be subject to a high degree of obsolescence. As a consequence, the firm with the highest productivity in the industry faces no obsolescence cost. Thus, even without any new specific investment, a leading firm will be able to keep constant its R&D stock. *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, a company 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 a period necessitates the payment of *RENEWPATENCOST*. *PATENTRATE* is the initial average value of this investment rate around which the strategies of the firms are created.

Dividends Companies 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 Companies 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 company experiences negative profits and does not have any more saving, it quits the industry. *EQUITY RATE* 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 and 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 *PROBMIMITATE* and *PROBMUTATE*.

2.2 Technical progress and patenting

Technical progress is a result of the innovation or 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 technologies from imitation by competitors.

2.2.1 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.

It should be noted that a new technology may only be used and patented if it is not covered by an existing patent.

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.

2.2.2 Patenting

The management of the patent portfolio is very crucial in our model. In this version we do not allow any sleeping patents. 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 firms 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.

2.2.3 Management of the patent budget

In the beginning of each period, the firm will try 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 will result 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. Nevertheless, an upper bound is fixed, which is the initial size N.

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). If the number of active firms is lower than N at the beginning of a period, some new firms may enter the industry. For example, persistent high profits or increases of the level of profits in an industry may be an attractive signal for new entry. When entry occurs, the characteristics of the new firms are drawn from values around the industry-averages. If a potential new entrant is not profitable at the current market price, and/or if the technology found by it is patented, the potential firm will not be able to enter. The probability of entry is *ENTRY PROB*. The entry is also limited, in our model, by the inverse Herfindhal concentration index.

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 algorithm of the model runs the following steps in each period t:

1. Populating the industry:

   – if t=1: creation of an industry composed of N firms
   – if t>1: death and birth process

2. For each period t, until t=T:

   (a) Computation of the production levels: Q_t^i and the total supply Q_t
   (b) if t>1 evolution of the demand D_t (depends on past dividend strategies)
   (c) Computation of the intra-period price (as a function of the inverse demand function): p_t
   (d) Randomize the order of play of firms in the current period t
   (e) Computation of the gross profits
   (f) Definition of the different budget levels for R&D, investment, patenting, savings and dividends
   (g) Computation of the list of all patented productivities in the industry
   (h) Imitation of technologies
   (i) Innovation of firms
   (j) Management of the patent portfolio and patenting
   (k) Diffusion of the best strategies in the industry (depends on the market shares of the firms)
   (l) Mutation of strategies: possible change of the individual set of strategy rates

3 Simulation protocol and first 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 1,000 series of 500 periods[4] each, where the results from each period have a probability of 2% of being saved. So, for each run we obtain an average number of ten 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 10000 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 ($t \geq Q_2^t = 254$). We use for this analysis box plots (giving the four quartiles of the distributions of the variables), Wilcoxon–Mann–Whitney

[4] Running 1,000 simulations is sufficiently robust and secure in our case since $\sigma^2/\bar{x}$ becomes stable after 500 runs for any variable x in our model.

tests between subsets, and regression trees. The statistical analysis is conducted using R (see R Development Core Team 2003).

3.2 First results on patents and social welfare

Table 1 shows the influence of the dimensions of the patent system on some of our aggregate indicators (market price, productivities, number of firms...). We only present here the influences that are statistically significant at a unilateral test level higher than 5% in linear regressions computed between each of the dependent variables and the indicated four dimensions of the patent system.

Table 1 indicates that a stronger patent system (with a longer PATENTLIFE, and a more indulgent patent office corresponding to a stronger PATENTHEIGHT) would imply higher concentration, market prices and profits. These benefits for the firms in the economy would also have a social cost in terms of technical progress, since the average and maximal productivity would be lower under such a system. This phenomenon would also be concomitant with longer effective patent lives and fewer innovations. The influence of the cost dimensions is rather obvious and marginal.

Would these influences necessarily yield a lower social welfare? Answering this question using only the market price is not very straightforward in our model since, when distributed as dividends, the profits increase the revenues of the consumers and yield a higher consumers' surplus. As a consequence, a higher price does not automatically imply in our model a lower consumer' surplus. This is even more likely given the increasing relationship between the PATENTLIFE and the

Table 1 The role of characteristics of the patent system ($t \geq Q_2^t = 254$)

Variable	PL	PH	NPC	RNPC
price	+	+		
maxprod	−	−		+
averprod	−	−		+
activeN	−	−		−
invCI	−	−		
log (averprofit)	+	+		
nbinnov	−	−		
nbpat	+	−		−
cumnbpat	+	−		−
maxpatage	+	+	+	−
nbpatfirms	+	−	+	−
Behaviors				
avpatrate	+		−	−
avirdrate	−	−	+	+
avikrate			+	−
avequitrate		−	+	−
avdivrate	+		−	

PL PATENTLIFE; *PN* PATENTHEIGTH; *NPC* NEWPATENTCOST;
RNPC RENEWPATENTCOST

average dividend rate of the firms (see the last line of Table 1). So, we must take a better look at the social welfare for judging its evolution under a stronger patent system.

Figure 3 gives the distribution of the social welfare (consumers' surplus and total social surplus[5]) for different patent systems: for each of the dimensions (PATENTLIFE and PATENTHEIGHT) we call *low* the value of this dimension if it is lower than the second quantile of this variable and we call it *high* otherwise. The configuration *hl* corresponds, for example, to a situation where the *PATENTLIFE* is *high* and the *PATENTHEIGHT* is *low*. As is shown by the boxplot,[6] the highest social surplus is observed when both dimensions are low and, hence, the patent system is mild. Non-parametric Wilcoxon–Mann–Whitney tests[7] confirm this graphical result. As a consequence, the positive impact of a stronger patent system on the profits of the firms does not finally outweigh the negative impact on consumer welfare. This result casts a shadow on the admitted social efficiency of strong intellectual property rights. Moreover, the similarity between the configurations *hh* and *lh*, on the one hand, and between *hl* and *ll* on the other, indicates that PATENTHEIGHT dominates the impact of the patent system on social surplus. This point calls for a more detailed analysis of the determinants of social welfare in our model.

We analyze the role of different parameters of the model using regression trees. A regression tree 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 value in terms of their contribution to the overall fit and of their predictions for the dependent variables (all parameters that are modified by the Monte Carlo procedure are included as explanatory variables in each of the following regressions). This value is validated

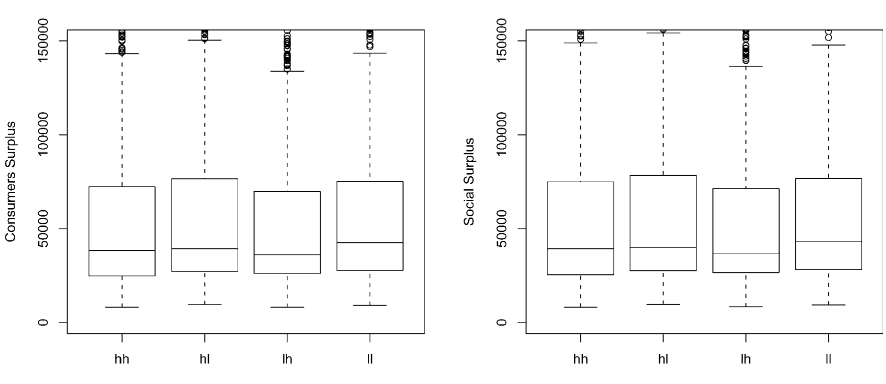

Fig. 3 Patent strength and social welfare

[5] Social suplus=consumers' surplus+total profits of the firms.

[6] These boxplots show four quartiles of the distributions of our indicators: the statistically significant minimum and the maximum correspond to the extreme end of the whiskers, while Q_1 and Q_3 correspond to the edges of the central box and the median corresponds to the horizontal line inside the box.

[7] The statistical appendix may be obtained from the following address: http://beagle.u-bordeaux4.fr/yildi/files/tvmy1appendix.pdf.

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 Fig. 4.

Figure 4 shows that the main determinant of the social welfare in this model is the demand effect of the distributed dividends. γ is the coefficient through which dividends are transformed into supplementary demand by the consumers. The top first branching of Fig. 4 shows that the social surplus is the lowest (log(*SS*)= 10.47)⇒*SS*=35242.22) when this coefficient is very small (the left branch: $\gamma<$ 0.008993). In our model, 2703 observations correspond to this case. When γ is higher, the second component of this demand effect enters onto the scene: the initial average dividend rate (*DIVIDENDRATE*) around which the firms are initialized during the creation of the industry. The highest social welfare is obtained in the model when this value is very high (*DIVIDENDRATE*≥0.8674 – the highest result corresponding to log(*SS*)=19.06 can only be obtained in the right branch of this test). If the dividend rate is more reasonable (*DIVIDENDRATE*<0.8674 – the right branch), distinguishes again two sets of cases: on the left, we have the cases where $\gamma<0.01686$ and, on the right the ones with $\gamma\geq0.01686$. The first set of cases confirms again the preponderant role played by the demand effect in our model.

We should also note an interesting result that concerns the role played by the cost of new patents: the highest welfare in this case is obtained when firms distribute large dividends and when the *NEWPATENTCOST* is higher (so that they issue fewer patents given the lower resources dedicated to patenting and the higher cost of each patent). The second set of cases (corresponding to $\gamma\geq0.01686$ and *DIVIDENDRATE*<0.8674) is more interesting. Here the highest social welfare (log (*SS*)=17.31)⇒*SS*=32933469) is observed when *(i)* initially firms invest sufficiently in physical capital (*IKRATE*≥0.21), *(ii)* the height of the granted patents is not too high or too low (*PATENTHEIGHT*∈[1.138, 2.124]) and *(iii)* the depreciation of technological knowledge is not *too* strong (α<0.1207). When

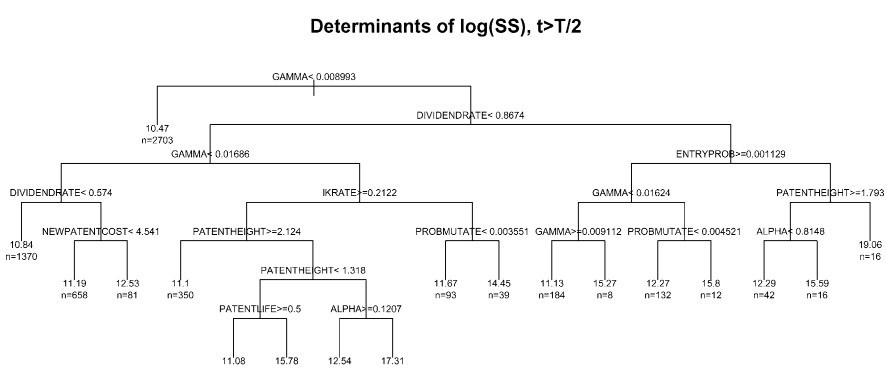

Fig. 4 Determinants of social surplus

PATENTHEIGHT<1.318, the highest welfare is obtained when the official patent life is nil and thus patents do not play any positive role in the profits of the firms (*PATENTLIFE*<0.5⇔*PATENTLIFE*=0). These results show that, under each set of conditions concerning other variables, welfare is higher when the patent system is milder.

We summarize in the following proposition our main conclusions concerning the welfare effects of a stronger patent system.

Proposition 1 (Welfare effects) *A stronger patent system implies a lower social welfare even if it implies higher profits for the firms. The indulgence of the patent office on the height of the accepted patents is the main determinant of this negative social effect. As a consequence, a more demanding and restrictive patent office that attributes very tightly defined protection with each patent would be beneficial to social welfare.*

What about the technological effects of the patent system? Figure 5 shows the distribution of the average productivity and of the maximal productivity, both conditioned by the dimensions of the patent system: the officially allowed patent life (*patlife*) and the patent height (*patheight*) that also corresponds to the patent breadth in our one-dimensional technological system. As before, the qualifications high (h) and low (l) result from the comparison with the second quantile (Q_2) of each variable. We again observe here the predominant role played by the *PATENTHEIGHT*: the technical progress is stronger when this dimension of the patent system is lower and hence, when the protection accorded to each patent is narrower in the technology space. The weakest technical progress is observed when both dimensions are high, and hence the patent system is strong. *A contrario*, a weak patent system yields the strongest technical progress.

We use a regression tree for a more detailed analysis of these results. Figure 7 exposes the determinants of technical progress measured by the average productivity in the industry during the second half of its life. This figure first shows that technical progress is the lowest when the *PATENTHEIGHT* is very high (>2.734),

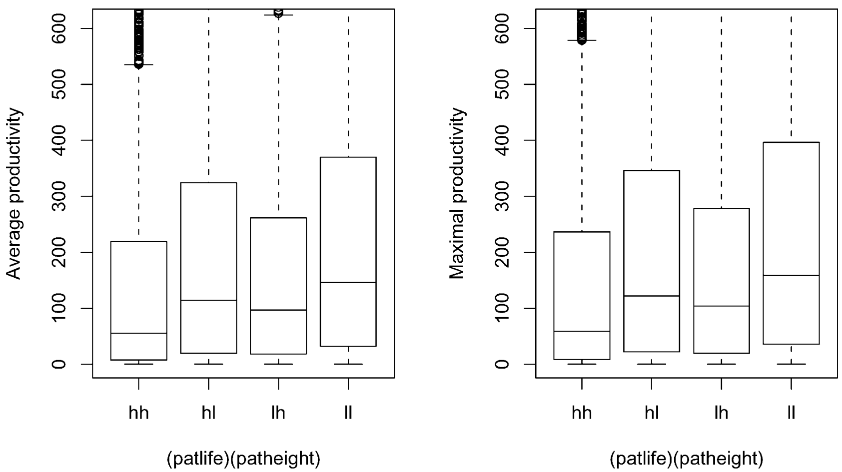

Fig. 5 Patent strength and technical progress

and hence the patent office is very indulgent. The predominant role played by this dimension of the patent system confirms the result of Fig. 3.

For lower heights, the role played by the *PATENTLIFE* variable is more ambiguous: its value (PATENTLIFE$\gtreqless$1.5) does not really have a consequence on technical progress itself but on the nature of the model, since two different dimensions of learning play an important and distinct role in each of these two sets of cases. When the patent life is very low, random exploration of strategies represented by the mutation operator must remain very weak (*PROBMUMATE*< 0.0285%) in order for the industry to attain the highest productivities. When the allowed maximal life of the patents is longer, some significant entry (*ENTRY PROB*>0.726%) and learning through imitation (*PROBIMITATE*≥0.45%) are necessary for transforming lower investments rates on physical capital (*IKRATE*< 0.1568) to the highest productivities for the industry. Moreover, Fig. 6 shows that the firms rarely maintain their patents during the full legal patent life, and thus confirms the stylized fact that we have underlined in the introduction. As a consequence, the variable *PATENTLIFE* only plays a role when its value is very low. A *contrario*, when the patent life allows a significant role for the patents, the learning of strategies, and the budget constraint that binds together all strategies, become crucial for technical progress.

We can also check that these results comply with the main result of the Fig. 3, that is, the highest average productivity (2877) is compatible with the configuration (*hl*) (high *PATENTLIFE* and low *PATENTHEIGHT*). Figure 3 shows that this configuration provides a higher consumer surplus than configuration (*ll*): the higher the average productivity, the lower the price, and, the higher the consumer surplus.

Figure 7 also demonstrates the role of learning and diversity in technical progress: in both cases (with low or high *PATENTLIFE*), a lower *ENTRY PROB*

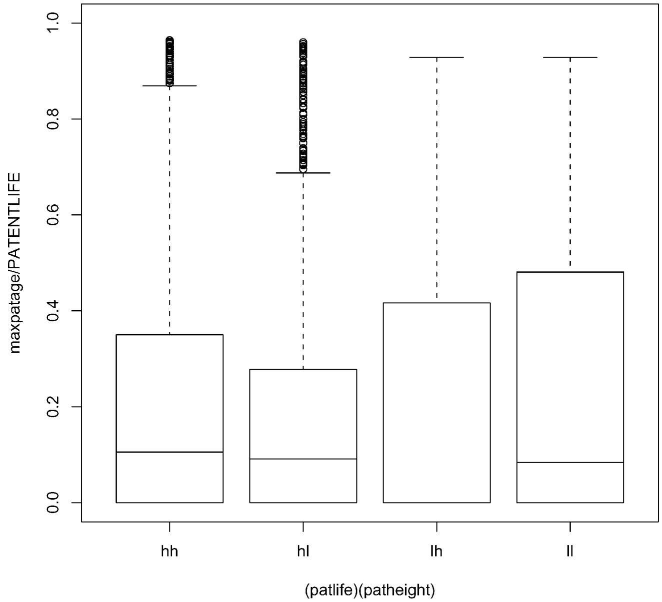

Fig. 6 Patent strength and effective patent life

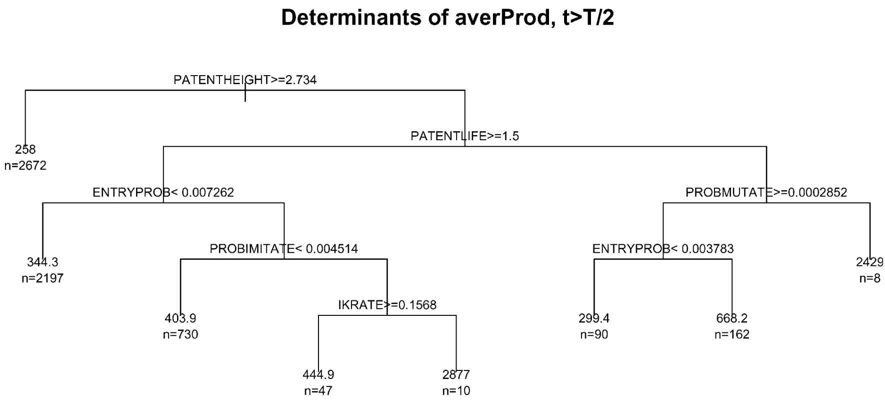

Fig. 7 Determinants of average productivity

decreases the average productivity. This result is quite normal, since a lower value of this variable implies a lower degree of diversity of the strategies and the technologies of the firms and, hence, a possibly higher degree of market concentration. The latter can, of course, lead to fewer innovations and, consequently, to a lower average productivity in the industry.

Proposition 2 (Technical progress) *A stronger patent system implies weaker technical progress even if the firms do not fully exploit the officially permitted patent life. The height/breadth of the granted patents play a major role in this result and the weakest technical progress is observed when this height is very strong. When the allowed maximal life of the patents is longer, some significant entry and some intraindustry communications that allow learning through imitation are necessary for transforming lower investments rates on physical capital to the highest productivities for the industry.*

4 Conclusion

> "If we did not have a patent system, it would be irresponsible, on the basis of our present knowledge of its economic consequences, to recommend instituting one. But since we have had a patent system for a long time, it would be irresponsible, on the basis of our present knowledge, to recommend abolishing it." (Machlup 1958 – cited by Hall 2002).

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. Even if we agree with Machlup that the question of abandoning the existing patent system cannot be easily posed, the necessity for a stronger patent system, as it is defended by the North-American authorities, must be questioned. The first results obtained in our article are rather consistent with the anti-patent arguments and they do not favor the case for a stronger patent system: higher social welfare and technical progress are observed in our model in industries with milder patent systems (lower patent height and patent life). Even if the firms' profits are higher with a stronger patent system, the global effects are negative, since they correspond to lower social welfare and weaker technical progress. If the actual patent system is to be reformed, the system should be limited in scope instead of strengthened as demanded by American authorities. We do not have any evidence in this model for advising the generalization of patent systems to areas where innovations are not actually protected through this type of IPR.

But we must now refine and improve this analysis in two directions. First, we must carry out a more detailed analysis of individual results in order to understand the mechanisms that are behind our results. Second, we must develop a richer technology space in order to include in the analysis different technological regimes as stressed by Merges and Nelson (1990). Moreover, by adopting a multidimensional technology space, we can distinguish the length and the breadth of the patents and have a more subtle and more realistic apprehension of the consequences of a stronger patent system. On a complementary level, we should also study the possible role of more forward-looking behavior on behalf of the firms.[8]

Appendix

1. Initialisation of the main parameters of the model

1.1 Exogenous variables

N=50: Number of firms
T=500: Number of periods
PROBIMITATE ∈ [10, 0.005]: Probability of imitation
PROBMUTATE ∈ [0, 0.005]: Probability of mutation
SIGMA_IN ∈ [0.1, 5]: Standard deviation of the innovative draws
DIVIDENDRATE ∈ [0, 1]: Initial average share of the distributed dividends in the gross profits
PATENTRATE ∈ [0, 1]: Initial average share of the patent budget in the gross profits
EQUITY RATE ∈ [0, 1]: Initial average share of the savings in the gross profits
IKRATE ∈ [0, 1]: Initial average share of the investment in physical capital in the gross profits
IRDRATE ∈ [0, 1]: Initial average share of the R&D budget in the gross profits
ENTRY PROB ∈ [0, 0.01]: Probability of new entry
ALPHA ∈ [0, 1]: Depreciation rate of the technological knowledge of the firm
GAMMA ∈ [0, 0.02]: Transformation rate of dividends into supplementary demand
NEWPATENTCOST ∈ [0, 5]: Cost of filing a new patent
RENEWPATENTCOST ∈ [0, 1]: Cost of renewing an existing patent
PATENTHEIGHT ∈ [0, 5]: The height of the granted patents. If the patent correspond to the productivity A_0, all productivities in [A_0−*PATENTHEIGHT*, A_0+*PATENTHEIGHT*] are protected from the competitors.
PATENTLIFE ∈ [0, 30]: Legal maximal life of patents

[8] See Yildizoglu (2001) for a possible modelling strategy.

EQUITY ∈ [10, 50]: Initial equity of the firms
CF ∈ [0, 2]: Fixed costs of the firms
K ∈ [10, 50]: Initial average capital stock of the firms
PROD ∈ [0.2, 1.2]: Initial average productivity of the firms
COST ∈ [0, 1]: Initial average unit using cost of the capital
DEM ∈ [300, 1000]: Initial demand coefficient
ETA ∈ 0.9: Elasticity of demand

1.2 Endogenous variables

price: Market price
max prod: Maximal productivity of the period
averprod: Average productivity of the period
activeN: Number of active firms in the industry
invCI: Inverse Herfindal 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
max patage: 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

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