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Private and social functions of patents: Innovation, markets, and new firms☆

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ABSTRACT

This article provides a review of the private and social functions of patents using data and evidence from the economic and management literature. While patents provide incentives to invent by providing private protection to appropriate the returns on inventions, they also have broader effects. For example, in this paper we focus on the fact that they provide signals about the value of new firms, disclose information about the invention, and encourage the exchange of inventions and ideas in markets for technology. In order to better understand the relative importance of the implications of patents, patent agencies and stakeholders should invest to a greater extent in data collections or in creating the conditions for research designs and experiments that nail down causal effects and mechanisms. Available data are not created with these identification strategies in mind, which limits the questions that scholars can ask. Systematic studies that identify different effects of patents can provide the basis for rigorous evidence-based management and policy about patents. This would imply a wider shift from a world in which managerial and policy analysis is distinct from practice, to a world in which analysis and implementation are increasingly co-produced, and there is greater integration between them.

1. Introduction

This article discusses some aspects of the impact and implications of patents for firms and society, drawing on data, evidence and insights from the economic and management literature. The article does not cover all relevant topics about patents. The subject of patents and the literature are so vast that it will be impossible to cover all these topics in the space of one article. The article is a selection of topics and problems that the author believes are worth the attention of readers, with no claim to exhaust all topics worthy of attention.

A focal theme of this article is the dual role of patents. By this we mean the distinction between the value of patents to the individual owners and the broader value of patents to society.

Patents are economic assets. Like other economic assets, the value for their owners is equal to the sum of the discounted stream of profits generated by the asset. At the same time, in this paper we focus on three broader values of patents in our societies: they can signal the quality of inventors or organizations, disclose information about inventions that generates spillovers or avoid duplications in research efforts, and encourage markets for technology disembodied from physical products.

The classical perspective on patents highlights that they privatize inventions. The broader perspective highlights that they also help the diffusion of knowledge and perform other valuable functions in our societies. This perspective raises natural points of discussion – how important are these different roles and functions of patents? How much do policies that target one goal also affect the others? To what extent can policies optimize trade-offs among these goals?

There have been quite a few surveys of patents. Many of them focus on coherent bodies of work such as the role of patents as indicators of economic activities (Griliches et al., 1987), the relations between the market value of firms and knowledge assets such as patents or R&D (Hall, 2000; see also Hall et al., 2005), the broad relations between patents and innovation, with a special focus on the role of patents in furthering economic development (Hall, 2022). Some reviews focus, among other things, on topics that we also deal with in this review, such as the disclosure function of patents, follow-on inventions, and more generally the dual function of patents (e.g. Mazzoleni and Nelson, 1998; Hall and Harhoff, 2012; Williams, 2017).

Some reviews tackle upfront the critical questions about patents – that is, whether they create incentives to innovate that we would not have without them, the extent to which the property rights implied by patents should be strengthened or weakened, the optimal degree of patent protection (e.g. in terms patent length or scope), and more generally whether the current patent system is a net gain or loss in our societies. Hall (2022) provides an excellent summary of these issues, including the natural differences in the answers to these questions

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depending on conditions and contexts such as different industries or technologies. Interestingly, both a 25-year-old review such as Mazzoleni and Nelson (1998) and the most recent survey by Hall (2022) draw similar conclusions suggesting that strong patent protection is more likely to undermine innovation by stifling many social functions of patents without making a big difference in terms of incentives to innovate.

This paper builds on these earlier reviews, shows recent data not published elsewhere, and discusses papers not discussed in these other reviews. It starts with Section 2 by providing an overview of survey data on patent values from the pioneering paper by Scherer and Harhoff (2000) to PatVal-EU (Giuri et al., 2007) and the recent InnoS&T survey (Torrisi et al., 2016), whose data on patent values have not been published anywhere. This overview shows that the three surveys produce remarkably similar distributions, as well as means, medians and modes. We then discuss recent papers that deal with patent values using extensive evidence (1926–2010) from the more classical stock market return approach (Kogan et al., 2017), as well as other recent papers on the patent premium (Arora et al., 2008), the value of patent portfolios (Gambardella et al., 2017), or the distribution of patent values (Kline et al., 2019).

Section 3 shifts to the broader function of patents. It discusses recent papers on patents as signals, disclosure, and markets for technology. The peculiarity of these papers is that they provide initial but systematic evidence about these functions, and quite a few of them provide clear identification strategies to pin down the hypothesized effects. These papers are good examples of causal evidence that can provide the basis for evidence-based policy-making or firm strategies.

Section 4 picks on this point to highlight the main conclusion of this paper, and this is that we need more studies such as the ones in the previous section that provide robust empirical understanding of the many functions of patents. However, the problem is that, while there is wide availability of data about patents, they are not created with the goal of providing causal understanding of phenomena, particularly the implications of the many functions of patents. This calls for the collaboration of patent agencies, firms and other institutions or stakeholders. They can both raise relevant questions from the practice, and help to coordinate, facilitate and encourage data collections, research designs, and experiments that generate identification strategies to answer these relevant questions by nailing down causal effects and mechanisms. This will provide the basis for rigorous evidence-based management and policies about patents. This section also provides examples of these analyses.

Section 5 provides a brief conclusion.

2. Private value and uses of patents

2.1. *Distribution of patent values*

Following the work by Pakes and Griliches (1980, 1984) on the relationships between patents and R&D, Pakes (1985) first provided a framework and an estimation of patent values using news from the stock market. Similarly, Pakes (1986) and Schankerman and Pakes (1986) pioneered the use of patent renewal fees. Renewal fees, which only existed in Europe at that time, estimate a lower bound of the value of patent right below which patent owners do not find it profitable to renew the patent. This limited the growth of this line of research. In contrast, studies on the use of stock market return have since then represented the major attempt to estimate patent values (e.g. Hall et al., 2005; Kogan et al., 2017; Kline et al., 2019).

These studies have been reviewed extensively – e.g. in Griliches et al. (1987), and more recently by studies that build on this approach to provide original contributions (Hall et al., 2005; Kogan et al., 2017, and Kline et al., 2019). Thus, here we focus on an alternative approach based on survey measures that we compare with the most recent estimates based on news in the financial market by Kogan et al. (2017).

Scherer and Harhoff (2000) pioneered this approach by asking company respondents to estimate values of a sample of 772 German patents filed in the 1977 and sufficiently valuable that the patent owners renewed their patent fees till expiration in 1995. The estimation was based on the following question:

> If in 1980 you knew what you now know about the profit history of the invention abstracted here, what is the smallest amount for which you would have been willing to sell this patent to an independent third party, assuming that you had a bona fide offer to purchase and that the buyer would subsequently exercise its full patent rights? (p.560)

Respondents were asked to estimate patent values in German Marks by placing each patent in one of these five intervals: 0.04–0.1; 0.1–0.4; 0.4–1; 1–5; 5–50; above 50. The logic of this question is that respondents provide an estimate of the discounted sum of future profits foregone by the owner. Scherer and Harhoff (2000) note that if owners want to use the invention, this requires that they pay the rights to use the invention to the new owner. As a result, they state that their measure reflects the value of the invention and of the patent right, that is the right to exploit the invention under monopolistic conditions. Therefore, it is higher than valuation made using renewal fees that only capture the value of patent rights (Pakes, 1986; Schankerman and Pakes, 1986).

Scherer and Harhoff (2000) find that the distribution of patent values is skewed, with 5 patents in the "above 50" class accounting for 54 % of the total value of the patents in the sample. Simple calculations at the mid-point of the values of the intervals in their Fig. 1 (using 75 m for the above-50 class) yields an average value of 4.4 million German Marks, which is approximately 2.3 million euros.

Gambardella et al. (2008) scale up this approach by using patent data from the PatVal-EU survey (Giuri et al., 2007). This survey collects data on 9107 patents granted by the European Patent Office, with priority dates 1993–1997, whose inventors are located in France, Germany, Italy, Netherlands, Spain, and the UK. The project collected the data by surveying the patent inventors. It selected a representative sample of the patents granted by the EPO to inventors in these six countries, with a slight overrepresentation of patents with a larger number of citations. Giuri et al. (2007) provides details about the data collection and the sample.

Gambardella et al. (2008) employ data on the 8217 PatVal patents whose inventors answered the following question: if the owner of this patent sold it on the day of grant, what would be the minimum price at

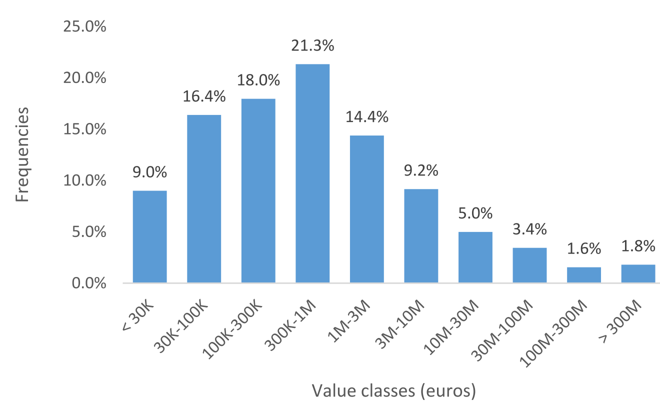

Fig. 1. Value of patents.
Based on 15,311 EU patent applications from the InnoS&T survey with available answers on the following question: "if the owner of this patent sold it on the day of grant, what would be the minimum price at which they will sell all technically related patents for this innovation?" Inventors indicates one of the 10 value classes. InnoS&T patents have priority dates 2003–2005, and inventors are located in 20 European countries, Israel, Japan and the US. See Torrisi et al. (2016) for details about the survey.

which they will sell the patent to a close competitor? Implicit in this question is the assumption that if the owners want to use the invention, they will have to pay back the patent rights. Thus, like in Scherer and Harhoff (2000), this question reflects a discounted sum of future profits that encompasses both the value of the invention and the patent right.

The inventors could pick one of the following 10 intervals from <30 thousand (30*K*) euros to >300 million (300 M) euros: < 30 K; 30 K–100 K; 100 K–300 K; 300 K-1 M; 1 M–3 M; 3 M–10 M; 10 M–30 M; 30 M–100 M; 100 M–300 M; > 300 M. Since we expect patent values to be skewed, these classes mirror a logarithmic distribution because the ratio, instead of the difference, of the two boundaries is roughly the same. As a robustness check, the paper uses a subsample of patents to compare the responses of inventors with the managers responsible for development of the invention who ought to be less emotionally attached to it. The estimates of inventors and managers are not very different.

Gambardella et al. (2008) find results in line with Scherer and Harhoff (2000). They find a skewed distribution of patent values, and an estimated mean of about 3 million euros. They find a median of about 400 thousand euros, and a mode of about 6 thousand euros (Gambardella et al., 2008, Table 8). The paper also shows that these estimates are correlated with several indirect indicators commonly used as proxies for patent value, such as forward and backward citations, number of claims, and other such measures.

The InnoS&T survey is a follow-up of PatVal-EU. It covers 23,044 representative EU patent applications with priority dates 2003–2005 by inventors located in 20 European countries, Israel, Japan, and the US. InnoS&T also surveyed the inventors and tried to make the final sample as representative as possible of the universe of EU patents in these countries. Torrisi et al. (2016) provides a comprehensive description of InnoS&T and its data.

InnoS&T asked the same question about the value of patents as Gambardella et al. (2008) using the same 10 classes of PatVal-EU, with one difference. InnoS&T recognizes that patents can be technically connected, and more patents can cover different inventions that are part of the same broad invention. Therefore, for each patent InnoS&T asks how many patents are technically connected to it. This is not the patent family, which is the term normally used to mean the number of jurisdictions that granted protection to a given invention. It is a genuine measure of the number of technically connected patents as perceived by the respondent.

To our knowledge this is the first time in which researchers use a measure of technical connection of patents different from the patent family. This is important in that technical connection, unlike the replication of the same patents in different countries, denotes different patents that are not independent from the point of view of the technological, as opposed to legal, family. As we will see below, this enables us to understand whether this technical connection has an effect on patent values because of technical complementarities across patented inventions, or because technical interdependence reinforces protection.

The survey finds that nearly 60 % of patents are stand-alone and the rest is technically connected to one or more patents. The InnoS&T question asks for the value of the whole set of connected patents. This is a more precise representation of value of inventions because it measures the value of the entire set of patents that cover a core invention.

Fig. 1 reports the distribution of these values using the 15,311 patents for which the project obtained answers to the question about value. This distribution is skewed and very similar to the distribution in Gambardella et al. (2008). Using the InnoS&T data, we estimated the mean, median and mode of the distribution, following the same procedure employed in Gambardella et al. (2008). We report these estimates in Table 1 along with the estimates of PatVal-EU in Gambardella et al. (2008). The table explains the methodology we used. InnoS&T estimated that the expected value of patents is about 10 million euros, the estimated median is about 591 thousand euros, and the mode is 2 thousand euros. The estimated mean and median are higher than PatVal-EU because InnoS&T asks for the value of the whole set of connected patents. Table 1 also reports mean, median and mode of the value of patents divided by the number of patents in the set. This provides a more comparable measure with PatVal-EU. In this case, estimated mean, median and mode are respectively 4.6 million, 338 thousand and 2 thousand. These values are closer to PatVal-EU.

Table 1
Estimated distribution of patent values.

Parameters (000euros)	InnoS&T		PatVal-EU
	Value of portfolio (15,311 obs.)	Average value of patent in portfolio (11,760 obs.)	Single patent (8217 obs.)
Mean	10,473.4	4598.03	3138.6
Median	591.2	338.34	397.4
Mode	1.9	1.8	6.4

Portfolio = set of technically connected patents. Assumes log-normal distribution of value and retrieves mean, median and mode using mean and standard deviation of the log of the mid-point of value classes as parameters of the associated normal distribution. See Table 8 of Gambardella et al. (2008) for details. Values adjusted by lower proportion of German patent values because German Inventor's Act provides German inventors with an anchor evaluation.

One limitation of these survey-based studies is that they provide a subjective estimate. Also, all three surveys oversample important patents, either by design (to capture a sizable share of patents in the right tail) or because, in the case of PatVal-EU and InnoS&T, EPO patents are likely to be more important patents. In both surveys they are direct EPO applications or a subsequent EPO application after an initial national filing that preserves in any case the priority date.

With these caveats in mind, Scherer and Harhoff (2000), PatVal-EU, and InnoS&T show remarkably similar patterns and estimates. The skewed distributions are also consistent with the findings of Pakes (1985) and Schankerman and Pakes (1986), and the subsequent literature that uses stock market news or renewal fees. Subjective estimates and the oversampling of important patents suggest that the survey-based measures overestimate means, medians, and modes. At the same time, estimates of patent rights using renewal fees are underestimates because, as we said, they measure a lower bound of the future discounted stream of profits under which it is not worth renewing the patent. Clearly, the high estimated means of the survey-based measure is not representative of the value of a randomly drawn patent. The vast majority of patents have no value and only a few patents are very valuable. As a matter of fact, PatVal-EU and InnoS&T find much lower medians and modes than the mean.

The survey-based measures do not seem to be affected by specific industries or more generally by industry characteristics. From InnoS&T, we find a similar skewed distribution as in Fig. 1 in six macro-industries defined by Torrisi et al. (2016): Electrical Engineering; Instruments; Chemicals; Process Engineering; Mechanical Engineering; Consumption and Construction. The only relevant difference is in Chemicals and Pharmaceuticals where we find a fatter right tail. On further inspection, this fatter right tail is largely concentrated in the pharmaceutical industry, where, as expected, we find the largest share of patents worth more than a few hundred million euros.

Table 2 reports the value of patent portfolios equivalent to Table 1 for these macro-industries. As the table shows, mean, median and mode of the log-normal distribution are fairly similar, suggesting that the aggregate patterns do not underlie important industry differences. Again, the only difference is Chemicals, and in particular Pharmaceuticals, where we find a higher mean and median, but a similar mode. This suggests that in these industries the skewness of the distribution of values is higher, and there are quite valuable patents in the right tail.

Kogan et al. (2017) estimate similar orders of magnitudes of the value of patents as survey-based measures using stock market news on the day of the announcement of the patent. Compared to past studies on financial market news about patents and knowledge assets more generally, the notable contribution here is that Kogan et al. (2017) is a

Table 2
Estimated distribution of patent values by macro-industries.

Parameters (000euros)	Electrical Engineering (3663 obs.)	Instruments (2501 obs.)	Chemicals (3004 obs.) (*)	Process Engineering (2110 obs.)	Mechanical Engineering (2944 obs.)	Consumption & Construction (1089 obs.)
Mean	9163.0	11,263.9	28,448.2 (37,205.9)	7878.8	4446.8	5888.5
Median	477.1	662.9	1179.3 (1299.2)	543.8	409.5	441.5
Mode	1.3	2.3	2.0 (1.6)	2.6	3.5	2.5

InnoS&T values of portfolio by industries computed as in Table 1. See Torrisi et al. (2016) for definition of macro-industries. (*) Values of Biotechnology and Pharmaceuticals & Cosmetics in parenthesis (804 obs.)

very comprehensive study covering US firm patents between 1926 and 2010. They find an even higher median value of patents than survey-based measures, 3.2 million in 1982 US dollars. They compare this figure with the PatVal-EU figures and recognize this difference. They argue that their sample is only composed of public firms, and that financial evaluations may incorporate the value of future patents that spring from the focal patent.

2.2. Returns to patents

The high values of patents open the natural question of the returns of these investments. Again, for returns based on stock market news we can refer back to the surveys or studies that focus on these measures. Here we look at alternative approaches.

Arora et al. (2008) employ survey-based measures to estimate a structural model of the returns to R&D investments in US manufacturing. They estimate that patents yield on average a 60 % patent premium with respect to R&D in these industries. In Arora et al. (2008) the patent premium is not the value of the invention, but the additional private return produced by the monopolistic ownership of the invention. This is a quite high return, which raises the question whether these monopolistic returns are too high as a source of incentives to innovate.

Gambardella et al. (2017) provide additional evidence on the returns to patented inventions. They use the InnoS&T survey-based measure of the value of patent portfolios. Technically connected patents may reflect, on the one hand, more complex technologies or technologies with different potential applications, or, on the other hand, an increase in the strength of protection irrespective of an increase in the complexity of technology or the breadth of potential applications (Ziedonis, 2004).

The paper shows that twice as many man-months invested in a project that produces a given number of technically connected patents (that is, a 100 % increase in man-months) raises the value of the portfolio by 46 %. Given the same investment in man-months, they find that twice as many patents make the value of the portfolio nearly twice as big (100 % increase). Thus, increases in the number of patents affect value in an important way.

Another way to think about these results is that twice as many man-months increases the average value of patents in the portfolio by 46 %, while an increase in the number of patents leaves this average value unaltered. Thus, the value of the portfolio is proportional to the number of patents. The proportionality factor is then a crucial determinant of the value of both individual patents and the whole portfolio.

Gambardella et al. (2017) also find heterogeneous returns to the number of patents in the portfolio. For example, they find higher returns to the size of portfolio in pharmaceutical and biotech, which are likely to reflect more important and complex inventions than in other industries, where we are more likely to observe isolated inventions. The returns to the number of inventions are also higher when feedback from customers are important, which suggests adaptation of inventions to differentiated needs around a core invention.

The returns to larger portfolios are higher when blocking rivals is an important motivation for patenting, suggesting that larger portfolios raise the value of protection. Thus, overall, the study finds that the value of larger portfolio depends on both protection and genuinely more complex inventions. This also shows the importance of the new measure of technical relations among patents collected by the InnoS&T survey. This measure, unavailable from patent documents, and different from patent families, which only measure the legal reach in different countries, made it possible to estimate the extent to which technically interconnected patents raise the value of a patent portfolio. Then, in conjunction with other measures, Gambardella et al. (2017) also provide evidence of the extent to which this depends on spillovers that increase the value of the portfolio of innovations or on the increase in protection created by the technical interconnections.

The value of patents raises the additional question of who appropriates these rents within the organizations of patent holders. Kline et al. (2019) uses the estimated returns by Kogan et al. (2017) to show that workers capture on average 30 % of the value of patents in the form of higher wages. This share rises to 60 % for workers employed by the company since the year of patent application. This raises another issue because the paper also shows that men and workers in the top 50 % of the earning distributions are more likely to capture these rents. Thus, firms do not capture all the surplus generated by patented inventions, and they raise inequality among workers.

This suggests that potential inequality across firms or individuals is only in part produced the traditional rationale of patents as monopolistic rights to motivate inventors to invent. Kline et al. (2019) show that the rents accruing to more senior and reputed workers stem from the fact that these individuals are costlier to replace, and thus companies pay them rents. Policies that support wider education and thus a wider supply of qualified workers may then raise the surplus that accrues to company managers and shareholders because there will be a more competitive supply of talented workers. However, qualified workers may create their own firms. A wider set of people could then earn rents from patented inventions through their own firms. We highlight this point in the next section when we discuss the value of patented inventions for new firms.

2.3. Uses of patents

The value of patents also calls for a better understanding of how patent owners use their patents. In particular, firms of different size tend to use patents in different ways. Larger firms have greater incentives to use patents internally because they have the downstream assets to exploit them, while smaller firms have relatively higher incentives to license patents because they are less likely to own extensive downstream assets. Non-profit institutions, such as academic institutions or government research centers, do not have the same commercialization goals. They are less likely to patent their inventions and more likely to license them conditional on patenting.

Larger firms are also more likely to underutilize their patents. On the one hand, the fixed cost of their research activities reduces the marginal cost of producing new patents, and thus they generate more patents than they can or want to exploit; on the other hand, they face a stronger potential "cannibalization" effect because large-firm inventions are more likely to compete with existing products of the company (Arrow, 1962). Larger and smaller firms may also differ in the extent to which they use patents strategically to block rivals because bigger firms have larger market shares to protect. Overall, the different potential uses of patents suggest that the value of patents can differ according to the strategies that agents adopt to enjoy returns from them, and more generally according to the use of patents.

Larger firms own the vast majority of patents. Using data on 2.3 million firms in 12 European member States, OHIM (2015) finds that 10.4 % of large firms (> 250 employees) own patents vis-à-vis only 0.8 % of SME (250 employees or less). Thus, patenting is far more common among large firms than SME. A recent EUIPO (2021) study provides similar results using 2007–2019 data on a representative sample of 127,199 firms in all 28 European States. In this sample, 0.9 % of SME own patents vs 17.8 % of large firms.

The InnoS&T survey (Torrisi et al., 2016) confirms this picture. As Table 3 shows, large firms cover the bulk of EU patent applications (more than two-thirds) in the InnoS&T sample, with very large firms (>5000 employees) covering >50 %. SME cover slightly more than one-fifth, and universities and other research labs cover shares in the range of one-digit figures. This sets the stage of our discussion. Firms account for the vast majority of patents, and most patents belong to large or very large firms.

Not only does the InnoS&T survey provide a comprehensive assessment of the use of patents, but also of the differences in the use of patents by firm size. In what follows, we focus on the uses of 8144 patents by firms or individuals in the survey. We distinguish among five main uses of patents: 1) Internal commercial use; 2) Licensing or sale of patents; 3) Creation of start-up; 4) Strategic use; 5) Sleeping patents.

Internal commercial use indicates that firms embody patented inventions in products or services that they sell. Licensing provides other parties with the right to use the patent. In this case, the patent holder retains the ownership of the patent. Patent holders can also sell the patent. They use, instead, the patent strategically when they prevent others from using the invention. Finally, quite a few patents are left unused. These five uses are not mutually exclusive. For example, owners may use the patent internally, but also license it; or they can prevent others from using the invention, but they also use it.

Using data from the InnoS&T survey, Table 4 reports the shares of *commercial use*, *strategic non-use*, and *sleeping patents*. Commercial use distinguishes between *internal use* by the applicant to product goods and services, patent *licensing*, *sales* of patent, or whether the patent was used to create a *start-up*. Torrisi et al. (2016) defines strategic non-use as patents not used commercially and such that the respondents check 4 or 5 (important or very important) on a 1–5 Likert scale to the question whether the motivation of the patent is to block rival innovations. Of course, respondents may tick 4 or 5 to patents used commercially in one of the forms indicated above. However, strategic non-use only denotes cases in which this motivation comes with the non-commercial use of the patent. Sleeping patents denote patents not used commercially and not motivated by blocking rivals (1–3 on the Likert scale.) The table also distinguishes among small firms (<100 employees), medium firms (100–250 employees) and large firms (> 250 employees.)

Table 3
Share of EU patent applications by type of applicants.

Type of applicant	Shares
SME (≤ 250 employees)	22.9 %
Large Firms (> 250 employees)	68.8 %
(Firms with ≥ 5000 employees)	(52.1 %)
Government Research Organizations	2.6 %
Universities and Higher Education	3.9 %
Others (Hospital, Foundations, Private Organizations, Others)	1.8 %
Total	100.0 %

Based on 20,325 EU patent applications from the InnoS&T survey with available information on ultimate parent applicant.

Table 4
Uses of patents by firms.

	Commercial Use (%)			Strategic non-use (%)	Sleeping (%)
	Type of commercial use	%	Total		
Small firm (<100 empl.)	Internal use	66.0	76.5	14.5	9.0
	Licensing	16.7			
	Sale	12.2			
	Start-up	17.9			
Medium firm (100–250 empl.)	Internal use	73.9	77.0	15.5	7.4
	Licensing	8.6			
	Sale	4.3			
	Start-up	5.6			
Large firm (>250empl.)	Internal use	54.8	56.2	29.5	14.3
	Licensing	2.7			
	Sale	4.2			
	Start-up	1.0			
Total	Internal use	57.6	60.6	26.3	13.1
	Licensing	6.4			
	Sale	4.3			
	Start-up	4.0			

Based on 8144 EU patent applications by firms and individuals from the InnoS&T survey. Use of patents defined by responses to survey questions. Commercial use = respondents state that patent was used internally, licensed, sold, or for creating a start-up. More answers are possible. Strategic non-use = respondents state that blocking rival is an important reason for patenting (4 or 5 on 1–5 Likert scale) and patent is not used commercially. Sleeping = complement to strategic non-use and patent not used commercially. See Torrisi et al. (2016) for details.

The table shows that commercial use accounts for 60.6 % of the patents, strategic non-use for 26.3 %, and 13.1 % are sleeping patents. Commercial uses focus mostly on internal use. However, licensing or sale account for a sizable fraction, over 10 %, and 4 % of patents are used to create start-ups. Also, because, as noted in Section 2.1, InnoS&T oversamples important patents, it is possible that these figures underestimate the share of non-use, especially by larger firms.

The most important differences are across firms of different sizes. SME exhibit a higher rate of commercial use of patents (over 3/4th), while large firms use slightly >50 % of their patents. Large firms show a systematically higher share of unused patents for both strategic and non-strategic reasons. As noted, large firms invest sizable fixed costs in R&D. They generate more innovations at lower marginal costs, and thus select which innovations they develop. Smaller firms are instead more focused in their R&D strategies, and they are more likely to use their patents.

The more striking differences, however, regard the licensing strategies. Overall, small firms license or sell nearly 30 % of their patents vis-à-vis nearly 7 % by large firms. Medium firms are in between: they license or sell circa 13 % of their patents. This evidence is consistent with our earlier discussion that small firms have a comparative advantage in licensing or selling their patents to firms with stronger production and commercialization assets.

Since large firms produce more patents, even if they license or sell only 7 % of their patents, they provide the market with a greater supply of technology. This simply suggests that the market for technology is populated by both small and large firms. Moreover, Bloom et al. (2013, Table IX) show that large firms create more technological spillovers than smaller firms. Their patent licensing and sales are one vehicle that can give rise to these spillovers. At the same time, small firms generate the classical benefits of a division of labor based on comparative advantages. Moreover, because they have limited commercialization assets, they are less likely to compete with their buyers in the product markets, making buyers less concerned about purchasing technologies from them.

This also raises the question whether the value of the patents offered in the market for technology is lower than the value of patents that companies use internally, and whether this wedge is different for small and large firms. We use the InnoS&T data to answer this question. Table 5 reports the estimated value of patents for which we have this information in the InnoS&T survey that are either used internally, or licensed or sold, by small, medium and large firms. We focus on these patents because, given that they are used, the inventors probably have an anchor to assess value more credibly. Since InnoS&T reports the value of all the set of interconnected patents, we looked at the average value of patents in the portfolio. However, the results are the same if we look at the portfolio made of one patent, for which the average value is the exact value of the patent.

The table shows no clear difference in value between patents used internally, licensed or sold. We show both average and median because the skewed distribution of value suggests that the mean may be affected by outliers at the right tail. The table shows quite some variability. However, there is no clear pattern. The table reports the same information for the total citations of the focal patent. Again, no clear pattern emerges; if anything, licensed patents seem to have slightly more citations on average. Overall, we conclude that patents transacted in the market for technology do not seem to be less valuable than patents used by firms internally.

Small firms also use a larger share of their patents to launch start-ups. Table 4 showed that 17.9 % of their patents are associated with the creation of a start-up vis-à-vis 5.6 % and 1 % in the case of medium and large firms. This is a manifestation of the same phenomenon. On the one hand, small firms have a greater comparative advantage in creating new firms that pursue specific technological opportunities; on the other hand, many of them are probably themselves the start-up generated by the patent. At the same time, even if only 1 % of large-firm patents generate start-ups, the higher number of large-firm patents implies that they generate quite a few start-ups. Therefore, like for patent licensing or sale, both small and large firms can actively contribute to the rise of start-ups from patents.

More generally, all this suggests that, apart from internal use, patented inventions can encourage the diffusion of technology in the form of technology markets or creation of new firms. Both large and small firms can be active suppliers in these markets, or they contribute to innovation by creating new firms.

Finally, we confirm these patterns using information about the motivations for patenting of firms of different sizes. Torrisi et al. (2016) show data on the motivations for patenting of the 8144 patents of firms and individuals in their InnoS&T sample. We report these data in Table 6.

Table 5
Value of patents used internally vs licensed or sold.

	Average value of patents in the portfolio (000 euros)		Total citations	
	Internal use	Licensed or sold	Internal use	Licensed or sold
Small firm (< 100 empl.)	Mean = 9873 Median = 650 Obs. = 874	Mean = 9057 Median = 650 Obs. = 473	Mean = 0.86 Median = 0 Obs. = 1062	Mean = 1.46 Median = 1 Obs. = 548
Medium firm (100–250 empl.)	Mean = 8115 Median = 267 Obs. = 361	Mean = 4475 Median = 650 Obs. = 74	Mean = 0.83 Median = 0 Obs. = 460	Mean = 1.38 Median = 0 Obs. = 95
Large firm (> 250empl.)	Mean = 6607 Median = 260 Obs. = 3494	Mean = 5513 Median = 333 Obs. = 537	Mean = 1.15 Median = 0 Obs. = 5033	Mean = 1.33 Median = 1 Obs. = 716

Based on EU patent applications by firms and individuals from the InnoS&T survey that were either used internally or licensed or sold. Average of value of patents in the portfolio of the focal patent that was internally used or licensed or sold. Total citations refer instead to the focal patent.

Table 6
Motivation for patenting by firms (Likert scale: 1–5).

	Commercial Use	Licensing	Cross-licensing	Prevent imitation	Block rivals
Small firm (<100 empl.)	4.57	3.53	2.30	4.22	3.62
Medium firm (100–250 empl.)	4.45	2.76	2.17	4.23	3.74
Large firm (>250 empl.)	4.32	2.86	2.80	4.10	3.87
Total	4.37	2.96	2.69	4.13	3.83

Based on 8144 EU patent applications by firms and individuals from the InnoS&T survey. Average of the 1–5 responses (1 = not important; 5 = very important). Multivariate tests of differences across means by firm size statistically significant at $p < 5$ %. See Table 3 in Torrisi et al. (2016).

The table shows that commercial use and prevention from imitation are by far the most important reasons for patenting, with small differences across firms of different size. Thus, firms of any size patent primarily to exploit innovations commercially and to protect themselves from imitation. If anything, the motivations for commercial use and prevention of imitation are slightly higher for small firms. This confirms that small firms have stronger incentives to patent to exploit the innovation and they are more concerned about imitation.

Licensing is more important for small firms then large firms, while cross-licensing is more important for large firms. This suggests that small firms are motivated by licensing, while large firms tend to barter licenses in cross-licensing deals. Torrisi et al. (2016) report that the motivation for cross-licensing is higher in the electrical engineering macro-sector (which includes electronics). As well known, cross-licensing is typical of the broadly defined electronics industry. The importance of licensing for small firms is sizably more important than the importance of cross-licensing for large firms. This strengthens the perspective that licensing represents an important strategic option of small firms. The table also shows that patenting just for blocking rivals is relatively more important for large firms.

3. The broader value of patents in society

3.1. Patents as signals

An important function of patents is that they offer an independent assessment on the innovation potential of firms and inventors. Innovation and innovation capabilities are surrounded by uncertainty. In general, it is difficult to predict the ability of a firm or inventor to produce innovations. Past information helps, but in the case of innovations a good deal of the inputs to the innovation process are intangibles, such as experience, dedication, or ability. Signals can then help to evaluate potential performance better.

Clearly, the problem is more important for firms or inventors for whom we do not have good past information. For larger and more established firms this is a lesser concern. The concern is more serious for new firms. To the extent that new firms and entrepreneurs are important vehicle of economic growth, the potential of patents to improve the evaluation of these firms has important implications for our societies. Better evaluations help investors to make more productive investments by picking the right firms for financial support or acquisition.

Hsu and Ziedonis (2013) provide evidence of the signaling function of patents. Using data on 370 venture-backed start-ups in the semiconductor industry, they show that firms that hold patents receive greater support in their early stages and when their founders have less experience and are less known. This qualification is important. If the effect was relevant in other stages and for more experienced founders, we would be unable to distinguish between the classical property function of patents and their signaling function. Start-ups could receive greater support simply because patents imply that they own relevant economic assets. The fact that this effect is stronger in earlier stages and for less reputed entrepreneurs, for whom, presumably, investors have less information, suggests that the signaling function matters.

The InnoS&T data confirms this perspective. Another motivation for patenting is reputation. In Torrisi et al. (2016), Table 3), reputation as a motivation for patenting obtained an average index of 3.19 for small firms, 2.96 for medium firms and 2.78 for large firms. These differences are all statistically significant. While Hsu and Ziedonis show that investors use patents to make evaluation of firms for which they have less information, InnoS&T shows that small firms realize this opportunity and are motivated to patent for this reason as well. Small firms seem to understand that, for them, patents have value as signals. The incentive is smaller for larger firms that do not have a similar need to establish their reputation.

Farré Mensa et al. (2020) extend both the representativeness of the analysis and the results of Hsu and Ziedonis (2013). They use data on 34,215 first-time applications filed by US start-ups since 2001 that received a final decision by December 31, 2013. Their methodology uncovers the causal relation between patents and the performance of new firms. They find that the grant of a patent increases considerably firm's growth, sales, employment, and future patented inventions.

They confirm that patents affect the chances of VC and IPO financing, as well as the chances of getting a loan using patents as collateral. Moreover, this effect is stronger for the first patents and when the entrepreneur is less experienced, making the evidence about patents as signals robust. They also find an important effect of patents in securing subsequent rounds of financing after the first one. Farré Mensa et al. (2020) interpret this finding as evidence that the property rights of patents also matter.

The more general point is that patents contribute to the rise and performance of high-quality small firms. They also help these firms to secure financing, which further helps their growth. Apart from the benefits accruing to the individual firms, we noted that the rise of new firms, and more transparent markets for supporting them, have social value. Therefore, patents contribute to the creation of this social value.

3.2. Patents and disclosure

Patents provide another important function, and this is that they disclose the content of the invention. As noted by Fromer (2009, p.539), such disclosure "indirectly stimulates others' future innovation by revealing to them the invention so that they can use it fruitfully when the patent term expires and so that they can design around, improve upon, or be inspired by the invention both during and after the patent term." (See also Cohen et al., 2002.)

The literature on the potential benefits of the disclosure function of patents is growing. Gross (2022) uses data on 11,000 US patent applications subject to a secrecy program during World War II that prevented inventors from disclosing their inventions or filings. The study shows that this program reduced follow-on invention and restricted commercialization.

Furman et al. (2021) study the expansion of US patent libraries between 1975 and 1997. In 1975 there were 20 patent libraries mostly in New England and to the East of Mississippi. In the same year the US Patent Office decided to embark on an effort to open at least one patent library in each US State in order to facilitate the consultation of patent documentation by inventors, attorneys or any other individuals. Furman et al. (2021) show that, on average, the opening of a library increased the number of patents produced within 15 miles from the library between 8 % and 20 %. The 15 miles range suggests easier access to the library, making it more credible that the availability of information has produced the effect they estimate. In this respect, they also show that the effect is weaker beyond 50 miles. They also find that the new patents after the opening of the library are not of lesser quality, suggesting that the new information has not produced less important innovations.

Furman et al. (2021) provide additional evidence suggesting that the disclosure of patent information is the mechanism of the effect that they observe. First, the increase is more pronounced in chemicals, where innovations are more likely to build on information about previous innovations. Second, the new patents produced after the opening of the library are more likely to use new words not used by previous local patents, but that are used by patents in other regions. This suggests that the new local patents are more likely to be affected by information about these geographically distant patents. Third, they find that the opening of libraries impacts new and old teams of inventors in the same way. This rules out the alternative explanation that the opening of libraries facilitated information exchange among inventors who did not interact before and now can meet in a common place, favoring the creation of new teams of inventors.

A stronger opportunity to identify the effects of disclosure comes from the introduction in 1999 of the US American Inventor's Protection Act (AIPA), that required publication of the content of the patent 18 months after filing for all patents filed on or after November 29, 2000. Before AIPA, publication occurred only after grant. This anticipated the time of publication that before AIPA had a lag of 3.5 years from filing. Basically, AIPA accelerated disclosure.

Hegde et al. (2022) uses this quasi-natural experiment to show that this acceleration in disclosure has had several interesting effects. This is a rigorous study that compares US patents before and after AIPA with twin European patents not subject to this shock. The study then disentangles the causal effect of disclosure through a difference-in-difference approach.

First, the study finds that disclosure increases the citations of other patents, suggesting that patented inventions build to a greater extent on one another. Second, citations occur more rapidly, suggesting that disclosure increases knowledge spillovers. Third, technological distance increases between technologically closer patents and decreases between technologically distant patents. This suggests that, on the one hand, research builds to a greater extent on extant research, and, on the other hand, it reduces potential duplications. Finally, patents are less likely to be rejected and increase by circa 6 %.

To be sure, while patents have a positive effect on future patents because of the disclosure of invention, they could discourage follow-on innovations because other parties may have to obtain authorization to commercially exploit incremental innovations from the owner of the original patent. The importance of this follow-on effect is still an open question that patent scholars have not yet nailed down unambiguously (Williams, 2017).

Two careful empirical studies on this topic are Galasso and Schankerman (2015) and Sampat and Williams (2019). Galasso and Schankerman (2015) use the random allocation of judges to patent cases to compare counterfactual invalidated and non-invalidated patents litigated in courts. Invalidated patents still represent prior art, and therefore they are still cited by future patents. Galasso and Schankerman (2015) then show that invalidated patents, which lose the patent rights, are more likely to be cited than their counterfactual non-invalidated patents. While patent citations could reflect strategic choices of firms, typically made by patent attorneys (Corsino et al., 2019), the conclusion of this study is that patents may discourage innovations that build on them.

In contrast, Sampat and Williams (2019) do not find important limitations of follow-on innovations in the particular case of patents on human genes. Galasso and Schankerman (2015) also find heterogeneity of the follow-on effect across technological fields. Moreover, their analysis focuses by construction on patents litigated in courts, which is a selected sample of patents. They also show that the observed effect is produced only by invalidated patents of large firms, and the citations typically come from small firms. Overall, this confirms that the average effect of patents on follow-on innovations is ambiguous; at the same time, there is heterogeneity across technological fields and patent owners.

Thus, while there seems to be a socially relevant effect of patent disclosure on other inventions, the effect on inventions that build specifically on the core invention (follow-on invention) is more ambiguous. This is a good example of the need for new data, studies, and experiments to understand more deeply the disclosure function of patents, its heterogeneous effects and conditions, and its mechanisms, as we discuss in Section 4.

3.3. Patents and markets for technology

Patents contribute to the rise of markets for technology in which producers of innovation license or sell their technological outcomes to other firms that produce and commercialize the goods. This is a potentially efficient process in that the abilities and organizational structures that are most effective in producing innovation are not always the best ones to produce and commercialize the goods.

Teece (1986) first noted that organizations can exploit their innovations either internally, by carrying out the production and commercialization of goods and services, or by providing others with the right to use the technology. He pointed out that internal exploitation depends on the ownership of complementary assets for production and commercialization. The incentives to license or sell the technology depend instead on the extent to which the technology suppliers can appropriate the returns from the transaction. Teece argues that patents are crucial because without them buyers can take advantage of the technology, even if the parties do not conclude the transaction.

The antecedent of this insight is that contracts for the exchange of knowledge are hard to write (Teece, 1988). These contracts are inherently ambiguous and incomplete because the object of the contract (an innovation, a new piece of knowledge) cannot be defined *ex-ante* in detail. This creates the conditions for bilateral opportunism that reduces the incentives of both parties to enter these contracts.

Arora (1995) solves this problem by defining the conditions under which the parties can write a contract for the exchange of technology in spite of the ambiguities that these contracts entail, and the role of patents in these contracts. Contracts for technology exchange are typically composed of two parts. On the one hand, suppliers sell a codified component of the technology, such as a design or a blueprint, that can be protected by a patent; on the other hand, they sell complementary services that cover tacit components such as expertise in using the technology. Arora (1995) shows that an ideal contract has two installments. The buyers first provide an initial installment for the supply of the codified part of the technology. Then, the suppliers provide the know-how in the form of services such as training or other similar activities. After the supply of the know-how the buyers pay the second installment.

Patents play a crucial role in this process. The tacit component of the supply is hard to protect and to nail down in the contract because it requires unobserved efforts and activities on the part of the suppliers. At the same time, if the suppliers put the right effort, they run the risk that after buyers learn from them about the use of technology, buyers can renegotiate opportunistically the second payment claiming breaches of the contract that cannot be proven in courts because of the contract's ambiguities and incompleteness. However, if the codified component of the technology is protected by a patent, and the contract establishes that the suppliers provide the right to use the patent only after the second installment, the suppliers can deny this right. If the buyers are unable to use the codified components, unless they infringe the patent, the value of using the tacit component may be severely undermined.

This provides the suppliers with a tool that balances the potential opportunism of the buyers, reducing their incentives to renege the contract. At the same time, if the second installment is sufficiently large, the suppliers have the right incentives to provide the right amount of know-how. Thus, a proper balance of the two installments, along with patent protection, can provide the right balance to make these contracts viable. Clearly, if the buyers do not need the supply of services, the first installment concludes the contract. However, the protection provided by patents is still important because buyers could use it without providing the suppliers with a fair price for the technology.

Arora et al. (2001) and Gans et al. (2002) provide extensive evidence that when firms have complementary resources to produce and commercialize the final goods, they integrate their innovations in these final applications. However, they also provide evidence that the lack of these capabilities encourages the suppliers to sell their technologies only if they can appropriate their returns because they are protected by patents. In particular, Arora and Ceccagnoli (2006) use systematic data on the licensing strategies of US firms. They show that protection encourages technology licenses and this incentive is stronger in the case of firms without manufacturing capabilities.

All this is consistent with our discussion in the previous sections. Patents encourage in particular the productivity of small firms and their incentives to license. To the extent that these firms are vehicles for innovation and growth, patents serve this wider purpose in our societies.

Moreover, there is growing evidence that patents provide related functions associated to markets for technology. Gans et al. (2008) show that most patent licensing occurs at the time of the patent grant, which, they argue, is associated with the reduction of uncertainty about claims and the extent of protection. Again, this points to the fact that clear property rights help technology trade. Hegde and Luo (2018) use the AIPA quasi-natural experiment to show that post-AIPA patents are more likely to be licensed. This suggests that the disclosure function of patents makes market for technology more transparent and more efficient. Finally, markets for technology raise the opportunity to use patents for other purposes. Hochberg et al. (2018) show that when markets for technology function well, and patents can be sold, they can be used as collaterals in funding deals, raising the opportunities of funding and the transparency of the funding process.

Galasso et al. (2013) use data on patents owned by individual US inventors and show that not only do the benefits of a division of labor in technology markets depend on comparative advantages in the generation of innovation, but also on comparative advantages in the enforcement of the property rights. They argue that only the relatively more valuable patents of individuals are traded, and because they are more valuable, they are also more likely to be litigated. Empirically, they show that, indeed, these patents are more likely to be litigated. Moreover, they show that, when the risk of litigation is higher, patents are more likely to be transferred to large firms, which have a stronger ability to enforce them. This makes them less likely to be litigated.

Since they focus on individual US inventors, it is hard to generalize whether the efficiency of the division of labor depends on a comparative advantage in the ability to generate innovations or to enforce patent rights. However, in both cases, this is an efficient outcome because either it allocates resources according to the ability to produce or exploit innovations commercially, or to counter litigation, and therefore reduce costly litigations in patent trade. As a matter of fact, Galasso et al. (2013) show that inventors enjoy higher gains from patents trade, and the underlying division of labor increases their incentives to innovate.

Markets for technology have started to rise since the end of the XX century. Athreye and Cantwell (2007) collected systematic data on licensing receipts and showed that they increased sharply since the 1980s, along with an increase in patenting. Graham et al. (2018) show similar signs of increase in patent transactions in the first decade of the new millennium. However, they also document that the increasing trend might have come to an end.

According to Arora et al. (2001), the rise in markets for technology stems from several concomitant factors. The growing role of software and the scientific of industrial activities have contributed to the codification of a good deal of industrial knowledge and innovations. This has made it easier to define the object of innovation, which has had, in turn, two implications. On the one hand, it has made imitation easier; on the other hand, it has made patentability easier because it is easier to identify the object of protection. This has created the opportunities to identify technology, eased the object of transaction, and eased the way to protect it. In addition, software and the greater scientific-intensity of industrial knowledge have encouraged the creation of general-purpose technologies (GPT). These GPT have potentially more applications than the producers can pursue, encouraging them to supply them to others.

As widely documented (e.g. Arora et al., 2001; Hall and Ziedonis, 2001), the opportunity to supply technologies through markets has become a valuable strategic option for smaller firms. This, however, is also the potential explanation for the tapering off of these markets in recent years. As discussed in the previous sections, large firms hold most patents. Thus, the ability of small firms to feed this market has limits. Only if the large firms also become suppliers in this market, we can expect them to grow further.

3.4. Patents and GPT

The supply of GPT is another important angle of our discussion. GPT play an important role in that they can give rise to considerable benefits for society because they have vast applications. The question is whether patents provide greater incentives to produce them, or they monopolize knowledge that has wide potential uses with the implication that owners of GPT patents can concomitantly several applications, including those that the owner does not develop. The answer to this question is not easy. We can provide elements in favor and against it, and the best way to proceed is, as usual, to find the ideal solution to this trade-off.

Gambardella and McGahan (2010) show that with dedicated technology, appropriability is the only way to earn bargaining power and rents in technology transactions. The technology can only be supplied to a small number of firms and industries. This reduces bargaining power and thus the ability to gain rents in transactions. Conversely, GPT widens the potential buyers, including buyers in distant product markets. Bargaining power still depends on individual transaction, but the upside is that suppliers can sell the technology to several distant buyers. Thus, even if they earn small rents from each buyer, they can enjoy profits by selling to many of them. In other words, they can shift from earning profits thanks to the intensive margin, for which they need bargaining power, to earning profits thanks to the extensive margin, for which they can rely on their ability to find new applications, as opposed to their bargaining power in each transaction.

The shift from the bargaining power in each transaction to the ability to find new applications switches attention from the property rights on the core invention to the ability to produce innovations, which is de facto the search for new applications. Finding new applications imply, for example, alliances and collaborations with many firms and industries, and therefore it is a costly activity (e.g. Thoma, 2009). This is itself hard to do without some form of protection in the basic technology. Moreover, Conti et al. (2019) show that the opportunity to develop GPT often comes with the incentive to abandon the markets of applications, becoming a specialized producer of the GPT. This reduces the downside of GPT patenting because the owner of the GPT does not have an incentive to monopolize the application markets.

Using the InnoS&T data, Gambardella et al. (2021) confirm Teece's original intuition that the appropriability provided by patents raises the incentives of firms to license dedicated technologies. They find a mixed effect for GPT. For some industries and firms, the strength of appropriability is less important to motivate the licensing of GPT; in others it is still important. This mixed finding is consistent with our discussion. Simply put, even if they do not own production and commercialization assets, the producers of GPT do not rely only on protection, but can take advantage of their ability to find new application firms or industries to which they can sell their technology.

At the same time, it is hard to think that we cannot provide GPT producers with some form of protection. Apart from protecting them from imitation, patenting protects them from the risk that other patents, either some version of the unpatented GPT, or some applications, block their ability to exploit the GPT commercially. Moreover, GPT patents serve as signals. For example, holders of these patents can use citations to patents coming from different firms and industries as independent evidence of the GPT nature of their technology, with implied opportunities to secure funding or to highlight the quality of the firm and its outcomes. Similarly, disclosing GPT patents helps, nearly by definition, follow-on innovations. Of course, the tradeoff is that patent examination, and policies more generally, ought to pay special attention to avoid that they add scope to these patents that already have a potentially wide scope.

4. Evidence-based management and policies for patents

4.1. Open questions about patents

The gist of this article is that patents have many functions and play many roles in modern societies. The classical trade-off is between the monopolization of the inventive idea to restore incentives and its *ex-post* diffusion. The studies discussed in this paper suggest that patents can produce other externalities for society. However, we need more studies to understand the different functions and implications of patents under different contexts and conditions, including whether and when the extent or importance of the social functions of patents mitigates its classical trade-off.

Patents is a complex topic. This makes it difficult to produce reasonable estimates of the net "overall" effect of patents for society. The many effects and implications of patents imply that this statement is not even testable. A more effective exercise is to encourage several studies that focus on specific effects. They can produce a detailed map of problems and potential solutions to undertake evidence-based managerial or policy actions that, among other things, can help to optimize the trade-off between private and social functions of patents.

4.2. Patent agencies and other stakeholders as promotors of causal evidence and experiments

A key step forward compared to the current practice would be to encourage more studies that, instead of starting from available data, start from relevant questions about patents followed by the definition of clear research designs to address these questions.

This is a change in perspective. Patent agencies make data available from patent files in convenient formats, typically digitalized. This is a very valuable service, but in most of the cases the goal is to provide general information and descriptions, not to make analysis or decisions. Descriptive data are useful both because general information is useful, and because they can be used to produce analysis. However, these data exist because they are part of the patent document. They are not generated to make analyses, and today researchers do their best to see how they can use these data analytically and to address relevant scientific or policy questions.

The main limitation of starting from data rather than questions, is that questions, and the underlying research designs, tell us which data we need to answer the questions. The outcomes of decisions are effects produced by a cause, the decision. Thus, in order to understand the implications of decisions we need to understand the cause-effect relations between the action underlying the decision, which is the cause, and the goal of the decision, which is the effect that we aim at. However, in order to understand cause-effect relations, we need to study counterfactuals, which are crucial to identify causal mechanisms.

To be sure, quite a few patent studies have addressed relevant questions, and they have provided good identifications, especially in recent years. Some of the papers discussed in this article are good examples. Scholars have exploited quasi-natural experiments produced by policies, laws, new interventions (such as AIPA), or they have devised intriguing identification strategies (e.g., random assignment of judges or patent examiners). However, we can only address questions about causality that exploit the events that we can find or the available data. This leaves out many important questions, and makes the reason for answering some questions rather than others unsystematic.

This plea is not isolated. Ouellette (2015) makes a similar case. She argues that *lab experiments*, *field experiments*, and *policy experimentalism* are three tools that can help to make better policies, and discusses their application in the context of patents. Most interestingly, Ouellette (2015) supports her claims with a quotation from Angus Deaton (2010) in which the Nobel Prize winner in economics argues that it is critical to understand mechanisms, or theories, because learning from evidence is intrinsically related to learning about theorized mechanisms, that is about *why* things work and not *whether* things work (Ouellette, 2015: 117).

Lab experiments enable researchers and policy makers to get a better understanding of the effects of policies or of the behavior of relevant agents. However, lab experiments reproduce unrealistically the "clean" conditions of labs. Field experiment solve this problem. However, they also run under the ideal conditions of an experiment rather than really "true" conditions. More generally, they have internal validity, for the sample and context in which they are used, rather than a general external validity. Moreover, they are useful for addressing specific relations of cause and effects, when the goal is to test a specific policy or behavioral mechanism.

The goal of patent experimentalism is to observe heterogeneous behavior consistent with a general framework. Ouellette (2015) makes, among the others, the example of the European Commission, which sets general framework goals and then observes alternative implementations of actions, for instance in different member States, within the goals of the general framework. In the context of patents, this calls for setting general broad goals or frameworks, for instance in patent examination, within patent agencies, or in patent adjudication, within courts, and then observe how different parties develop different ways to comply with the general rules, including focus groups in which the parties involve discuss their approaches and learn from each other. Moreover, these tools can be combined, for example by randomly assigning conditions like in lab or field experiments and discuss heterogenous outcomes and approaches across groups.

Agencies that manage and collect patent data can play two critical roles. First, together with relevant stakeholders and institutions, they can help to raise relevant questions. Second, they can help to collect data or to design experiments that address them.

As an example of the importance of developing studies that identify causal effects, OHIM (2015) and EUIPO (2021) are two important and comprehensive studies that use large representative samples of European firms to show that patents increase labor productivity, particularly of small firms. However, as the studies acknowledge, these are correlations, and thus we cannot conclude that patents cause the effects that we observe. If we showed instead that the relation is causal, we could draw policy conclusions – for example that helping small firms to protect their inventions through patents increases their productivity. Correlations do not allow us to draw this conclusion. For instance, patents may simply proxy for the ability of these firms to innovate.

Patent agencies, firms or other relevant stakeholders or institutions can help researchers to think and design analyses that allow for these identifications of mechanisms that answer specific questions. They can then help to collect data for these studies in two ways. On the one hand, they can collect data that provide the exogenous variations needed for identification. On the other hand, they can design and run experiments. This requires that, for relatively small samples, they deliberately change conditions in the patenting process for a treatment group and compare outcomes with a control group using classical difference-in-difference experimental analyses to identify average effects or even heterogenous effects in combination with the patent experimentalist approach suggested by Ouellette (2015). Today, an increasing number of organizations (government or firms) are using experiments to understand better the actions they can take (Luca and Bazerman, 2020). These experiments can inform policy and managerial actions about patents both in companies and the Patent Offices.

4.3. New questions, data, and designs of experiments

4.3.1. Broad framework

This article has identified areas in which we can raise relevant questions about patents. Of course, as noted in the introduction, this article is not exhaustive and there could be many more relevant questions than the ones highlighted below.

With this caveat in mind, Fig. 2 provides a visual representation of potential actions for data collection and topics or questions. There are three main activities to produce relevant data about patents: 1) collection of new data to address specific questions, such as data on patent transactions to better understand markets for technology; 2) collection of data on exogenous variations and design of corresponding experiments; 3) links between patent data and other datasets (e.g. applicants or inventors).

These activities and data can feed into four areas of topics and questions: patent values, social values of patents, inventor studies, management of patent examination.

4.3.2. Patent value

Starting with patent values, the studies discussed in Section 2 provide some reference point. The value of patents differs considerably across context and conditions. Moreover, we need to understand better the distinction between value of patented inventions and value of patent rights. We also need to understand mechanisms and determinants of the value of patents, and the differences in these mechanisms and determinants either between value of patented inventions vs value of patent rights, or across contexts and conditions. Apart from a scholarly perspective, from a policy perspective understanding this heterogeneity is crucial for a better understanding of problems in order to devise actions focused on specific problems or conditions.

A framework for estimating patent values has to start with recognizing that the *ex-post* value of patents has a transaction-specific component. Since most of these transactions are bilateral, the equilibrium price is going to be anywhere within the reservation prices of the buyer and seller (e.g. Gans and Stern, 2010). The exact equilibrium price will depend on the bargaining power of the parties, which in turn depends on idiosyncratic conditions such as the competition that they face in buying or selling the patent, the specific goals and context in which they will be using the patents, the characteristics of the specific buyers and sellers, and other such elements.

In addition, as showed by Choudhury et al. (2020), patent lawyers, or anyone who writes the patents, are likely to change their language, sometimes strategically, to establish the novelty of the patent or to affect the strength of protection. This makes it harder to identify patent quality based on a stable body of language.

All this suggests that a fruitful line of inquiry would be to test specific contexts and conditions to assess the value of patents under specific circumstances of interests to policy-makers or firms and other agents – such as the value of patents of a particular firm or set of firms (e.g. small firms) for evaluation (financing or acquisition), or the value of patents associated to a particular technology or market. To do so, the best approach would be to collect evidence by designing and running lab, field, or survey-based experiments based on randomized control trials, or by using data from patent statistics and surveys together with natural or quasi-natural shocks to uncover causal relations and mechanisms.

For example, in the spirit of Luca and Bazerman's (2020) call for running experiments within companies, patent agencies may ask a selected sample of patent applicants to state with their application the minimum price at which they are willing to sell the patent, asking for instance a question such as the one in Scherer and Harhoff (2000), or the PatVal-EU and InnoS&T surveys did. They could cut the sample in different ways according to the relevant questions they want to address

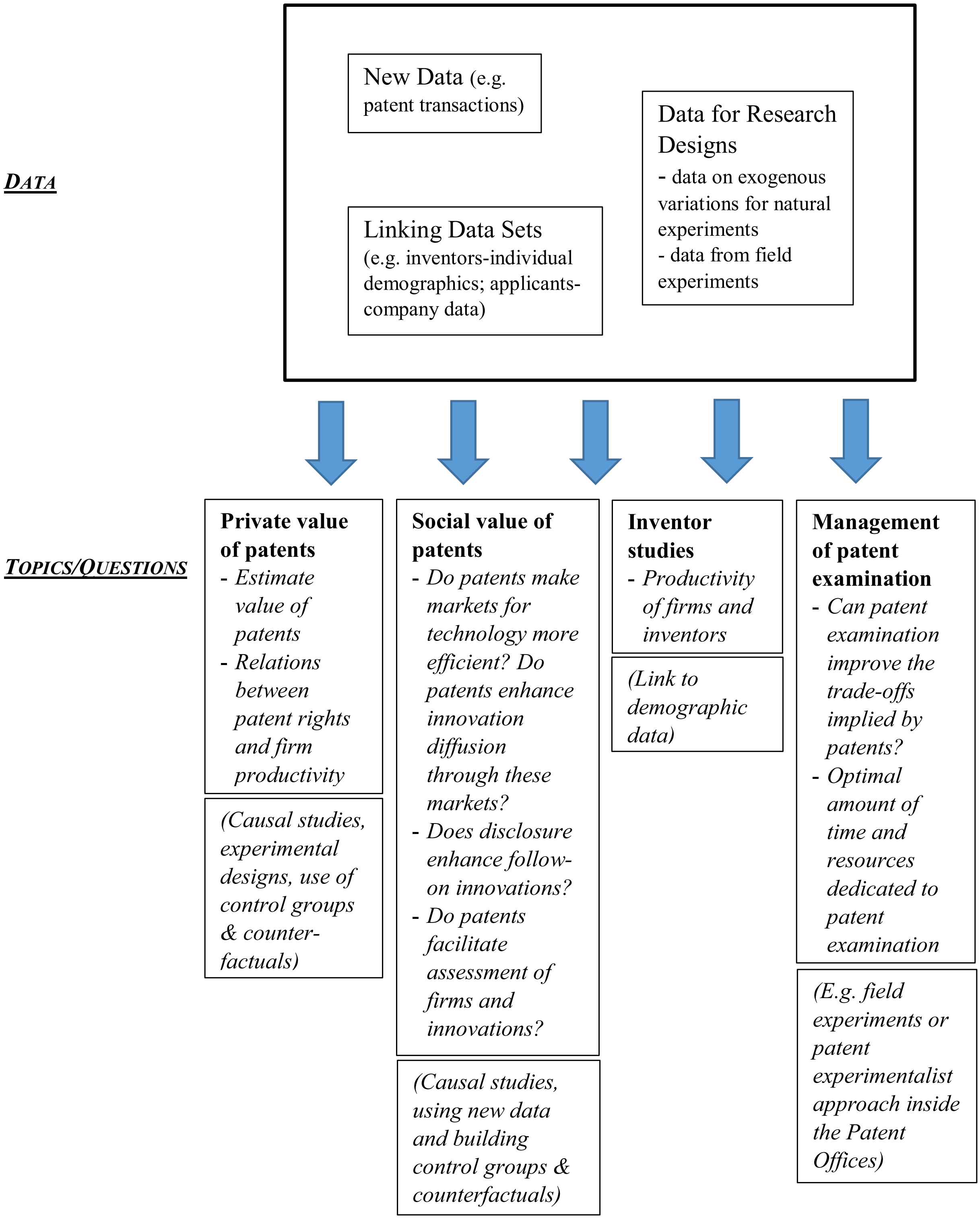

Fig. 2. Research designs and patent data collections in patent economics.

(e.g. smaller vs larger firms, or types of inventions), and find treatment and control conditions that enable them to identify causal effects and mechanisms of the determinants of the value of patents they are interested in.

Recently, there has been an upsurge in the use of text analysis and natural processing language to estimate patent quality, as a proxy of patent value (e.g. Higham et al., 2020; Hsu et al., 2020). Extensive textual information in patents offer notable opportunities to employ these techniques, and we should look forward to the development of these techniques in the context of patents. However, to the extent that these approaches aim at predicting patent quality or value, an important caveat should apply. The skewed distribution of patent values casts serious doubt on our ability to predict the value of individual patents because skewed distributions are most challenging to make predictions about individual or small sets of patents.

Less challenging would be to estimate the average value of groups of patents. However, more generally, the point is that these approaches ought to be complemented with effective design of experiments so as to estimate clear causal and treatment effects. In other words, given the skewed distribution of patent values, these approaches ought to be thought of as advanced measurement opportunities within clear experimental designs. We then ought to rely on collaborations between agencies and scholars to create these designs and collect the relevant data, including textual data, that allow for their implementation.

The combination of text data with measures such as the values produced by the PatVal-EU or InnoS&T surveys, or with stock market news measures of values, could give rise to studies that overcome the limitations of both the sheer use of text data to make predictions, and the measures from surveys or financial news.

In particular, these more comprehensive studies could adopt approaches such as the one applied by Kleinberg et al. (2018) to the bailout decisions of New York judges. The problem of this paper is to find how to predict the probability that a non-released defendant would not reiterate the crime if released, which is not observed. The paper first finds a reasonably exogenous measure of judge leniency (based on judge values) and then estimates the probability of reiterating a crime by released defendants (which can be observed) from a randomly selected share of the sample (the "training sample"). It then uses the parameter estimates to predict the probability of reiterating the crime in the remaining share of the sample (the "prediction sample") conditional on release by using a shock the exogenous measure of judge leniency. In so doing, the paper estimates by how much a more lenient judge raises type I error (probability of reiteration given release) vs type II error (probability of no reiteration given no release) compared to a less lenient judge.

The advantage of this approach is that with a standard treatment applied to the entire sample (e.g. leniency of judges as an instrument for release) we only estimate the effect of the treatment. The approach by Kleinberg et al. (2018) allows for flexibly adjusting all the parameters of the estimation to the two groups by using the estimated parameters of the training sample to make inferences in the prediction sample. In their paper they show that this approach yields better predictions. Clearly, such an analysis is highly data demanding, but this is not a major concern in patents given the vast potential samples.

Analyses of this kind could be run at different levels. The most basic level would validate measures. Researchers could predict patent values from text measures using survey-based measures or news in the stock market as dependent variables in a training sample. They could then employ other samples to estimate the extent of the match between text measures and these direct measures of patent values. This analysis could help to perfect both measures. Given the vast number of patent observations it could be performed within specific domains of patents to control for the likely heterogeneity or to focus on an area of interest.

At another level, researchers could work with data on actual transactions and the values of patents exchanged. By finding good instruments for why some patents are transacted and others are not, researchers could apply the same methodology of Kleinberg et al. (2018) to identify differences in values between transacted and non-transacted patents. Clearly, this can also help to validate the survey-based or financial news measures, which could then be used more extensively to make predictions about patent values.

4.3.3. Social value of patents

Relevant data or designs of experiments can also shed more light on the social function of patents, from markets for technology to questions about the implications of disclosure or the signaling value of patents.

As far as markets for technology are concerned, we need to understand better how these markets work (e.g., the bargaining process, or other aspects of their nature and functioning), how we can make them for efficient, or how they can increase the diffusion of innovation or their value. Here again there will be heterogeneity depending on markets, the parties involved, the types of patents or technologies.

The process could start from addressing, using theoretical arguments, where we expect the effect of markets for technology to be most important (e.g., which types of firms, technologies, or contexts.) Then, relevant stakeholders and institutions could help to collect data on patent transactions, the parties involved, and other characteristics of the domain under consideration, as well as identify and collect the same data for a control group of counterfactual patents to make causal comparison. One could then move to other similar contexts and processes where we believe, from theory, that it is important to provide evidence about markets for technology.

As a concrete example, we mentioned in Section 3.3 that recent data suggests that the rise of markets for technology may have tapered off in the new millennium (e.g. Graham et al., 2018). Moreover, Tables 4-6 show that large firms license a smaller share of their patents, the value of the patents licensed by these firms is smaller, and larger firms have a lower motivation to license their patents. In sum, large firms own the bulk of patents in our economies, and thus they are important potential suppliers, but they are not active in this market. A discontinuous change in the strategy of large firms regarding licensing could then produce a new spin to the growth of markets for technology.

Arora et al. (2013) argue that the incentives of large firms to license has to do with the way they manage their intellectual property. Their model shows that when the decision to license is decentralized to the business units, they have more incentives to develop technologies internally, and fewer incentives to license, even when licensing is a more profitable option for the company. They then argue that one friction that prevents the growth of markets for technology is the lack of centralized management of intellectual property and licensing decisions in large firms. Both companies and societies would benefit from the increase in technology trade following a greater centralization of these activities in large firms. Data collections and experiments that agencies can run using data collected at the moment of patent application can test the validity of these theories and possibly mechanisms, actions and incentives that may remove these frictions and raise the growth of these markets.

Similarly, Birhanu and Gambardella (2021) show that, other things being equal, family firms, including large ones, have a bent against licensing and prefer to keep technologies unused rather than license them for a sort of behavioral attitude towards greater control of their assets. They use InnoS&T data, along with complementary data on the ownership of firms, to test this hypothesis. Thus, in this case, data and experiments could provide robustness checks on the validity of these findings. Assessing mechanisms that change this behavior is trickier compared to the previous case because while Birhanu and Gambardella (2021) show that family firms miss financial gains from their excessive propensity to control their assets. Thus, while the intervention has gains for the other parties involved, it may come at the expense of reduced non-pecuniary benefits on the part of family owners. Still, a better understanding of this problem, and of all its angles, may be critical to understand the opportunities that firms and society may have to enhance the growth of technology markets.

An additional relevant example comes from our discussion in Section 3.4. We argued that stronger protection of GPT have ambiguous welfare implications. On the one hand, they can monopolize technologies with several potential downstream applications, giving too much power to the patent owner. On the other hand, Bresnahan and Trajtenberg (1995) show that an ideal market structure is one in which the owners of these technologies specialize in producing them without entering the downstream market, a point reinforced by the theoretical analysis in Bresnahan and Gambardella (1998) and the empirical analysis in Conti et al. (2019). Data and experiments during the application process could shed important new light of this phenomenon, as well as its mechanisms and different implications for policy actions.

The same logic and process could be applied to the other topics we discussed in the previous section, particularly the disclosure or signaling effect of patents, or the impact of patents on follow-on innovations. In this respect, it is important that these designs focus on relevant contexts suggested by an ex-ante assessment of the problem. As discussed in this article, and extensively by the literature, the effects of patents are heterogeneous, and it is probably not that effective to think of average, overall effects of patents. We may obtain more effective insights by studying different specific context where we expect that the effects may actually differ.

4.3.4. Inventors and patent examination

Fig. 2 suggests two other realms of analysis. One is the analysis of inventors. This is another relevant topic, even though it does not have to do directly with the role of patents as providers of property rights. However, understanding the productivity of the inventors is likely to have important impacts on our understanding of the productivity of the innovation process. For example, Bhaskarabhatla et al. (2021) show that inventors' human capital is 5–10 times more important than firm capabilities for explaining the importance of inventor output.

Since standard patent data focus on patents not inventors, they do not provide demographic or other information about inventors. This information can help to address important questions about the productivity of inventors and the inventor process. Leading studies in the US (e.g., Bell et al., 2019) have linked information about inventors in patents with individual information from the Census or tax profiles.

Compliance with privacy policies and the European GDPR is a must in this area. However, we also need to understand clearly the trade-off. The European GDPR may well make it more difficult to administer surveys by researchers, which can stifle opportunities to learn and promote evidence-based policy and management of patents. We already have evidence of the importance of this issue. In a different context, Janssen et al. (2022) show that GDPR reduces the development of innovative apps, and we can easily see how this can extend to the deeper analysis of patent data that we advocate in this paper. This is clearly an area where agencies can help administer surveys, and more generally collecting data that comply with the rules but also help to run valuable studies. For example, Bell et al. (2019) used de-identified data of 1.2 million inventors linking patent and tax records. Moreover, such linked datasets could cover control groups of individuals or inventors to create adequate designs that identify theorized effects associated to relevant questions about the innovation process.

Finally, Fig. 2 suggests that one important area of research is the management of the patent examination process. Guidelines about patent examination represent concrete implementations of patent policies. For example, if rigorous studies show that, under some conditions, patents ought to be narrower in scope, patent examiners can implement stricter policies by adopting more stringent criteria about claims or scope. Of course, this is what patent examiners already do, but society may benefit, more generally, from clear guidelines stemming from rigorous studies that provide the basis for evidence-based management and policies.

Moreover, data on the patent examination process offer additional opportunities to understand causal implications about different effects, and then answer important questions about the implications of patents. Collecting the right data and implementing the right research design can help to address quite a few questions that are currently unanswered. Also, an overarching question in this area is whether society needs to invest more resources in the patent examination process. The rise in the number of patent applications is putting pressures on the time to accomplish patent examination. Most likely, these pressures lead to greater leniency because rejecting a claim is harder and more time consuming than accepting it.

Policies that call for an optimal degree of patent protection may then suffer from pressures in the patent examination process. Data and proper research designs may address this question – that is, they may study and test whether different aspects of the patent examination process affect the nature and implications of patents, and the extent to which we can implement managerial practices with socially desirable implications for the classical trade-off of patents or their social functions.

5. Conclusions

We need to understand better the private and social functions of patents. Discussing policies to achieve these goals is beyond the extent of this article. However, providing robust and detailed evidence about the nature and implications of patents is critical pre-condition for good policies and management practices about patents. While patent data are abundant, we are still in a world in which these data are not collected to produce evidence about relevant questions. This leaves important questions unanswered.

This article suggests that patent agencies, firms, stakeholders and other relevant institutions provide relevant questions, and create the conditions to collect data or to run field experiments that allow for causal identification of mechanisms. This is of the utmost importance to make policy or managerial decisions that depend on the deployment of these mechanisms.

It is probably now time to move beyond the "high-level" debate on whether patents are good or bad. We can do better by implementing serious and systematic evidence-based managerial and policy actions. To do so, society needs the collaboration of the agencies, institutions, stakeholders, and policy-makers who can help to set the questions and collect the right data to understand the deeper mechanisms with which we can address these questions.

Declaration of competing interest

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Data availability

Data will be made available on request.

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