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An examination of the antecedents and implications of patent scope

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ABSTRACT

This paper focuses on the concept of patent scope, and contributes to existing research in three ways. First, it offers a re-examination of the construct and identifies two dimensions of patent scope, (1) the *number of variations* of the core inventive idea identified in the patent, reflected in the number of claims in the patent (e.g. Merges and Nelson, 1994); and (2) the *positioning* of those variations in the inventive space, which is reflected in the number of technological classes in which patent examiners classify those claims. Second, it investigates the implications of patent scope for the firm's subsequent inventive performance, and finds that, when the scope of a patents spans across a higher number of technological classes, the extent to which the inventing firm itself succeeds in building on the knowledge underlying its own patent is lower. Third, it investigates the antecedents of scope, and suggests that prior investment in scientific knowledge and in related inventive experience are two factors that affect the scope of the patents that firms develop. The theoretical predictions elaborated in this paper are supported by an empirical examination of a longitudinal sample of firms in the photonics industry.

1. Introduction

Let us imagine the inventive space as a space that holds all the ideas that have already been created, as well as and those that have yet to be generated. We can imagine that each invention occupies a certain area within this inventive space, and its position reflects the technological domain with which it is associated. In such a characterization, we can think of a patent as the temporary right to exclude others from making, using or selling an invention positioned in that area of the inventive space in exchange for its eventual public disclosure (Gilbert and Shapiro, 1990; USPTO, 2014a). The possession of this right (at least in principle) can allow an inventor to appropriate the benefits generated from their invention (Kitch, 1977). However, it would have limited value if it did not protect the inventor against mere variations to the original idea (e.g., Scotchmer, 1991). The patent system addresses this concern by allowing inventors to specify the patent's 'full scope' (Kitch, 1977; Lanjouw and Schankerman, 1997; Levin et al., 1987; Merges and Nelson, 1994; Walker, 1995).

Specifically, a patent application is composed of two main components. The first is the specification of the invention, which describes the techno-economic problem faced by the inventing firm and provides a "precise characterization of the 'best mode' of solving the problem" (Merges and Nelson, 1994, p. 9). The second is a set of claims, each of which specifies possible improvements or variations that could be made to the patented invention to adapt it for different uses (Merges and Nelson, 1994; Walker, 1995). Consequently, it corresponds to an additional area of the inventive space that the applicant claims should be protected by the patent. For instance, the claim of an invention consisting of an electrical component that contains magnetic particles and a matrix of fibers[1] can specify that the magnetic particles can have a diameter ranging from about 1 nm to about 10 μm.[2]

The positioning of patent claims in the inventive space can vary. They can refer to marginal variations to the invention (e.g. the diameter of a component) or to more 'diverse' variations – for instance, to completely different materials of which the same component

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[1] This example is a simplification based on an existing patent in the field of photonics.

[2] Patent claims have a similar role both in the context of product and process innovation. In the first case they usually refer to variations to the invention's components, in the second usually refer to variations to the process that would lead to similar outcome(s). As the US patent law prohibits 'omnibus claims', i.e. those that are too general and do not provide clear guidelines as to what would constitute an infringement (Chiang, 2010; Walker, 1995), inventors are incentivized to specify explicitly in the claims section the potential variations to the invention that they consider to be part of the original invention (Walker, 1995). USPTO examiners also verify that claims refer to "enabling", "useful" and "operative" variations, in that they provide an advantage in genuinely solving the problem(s) that the invention addresses (Gambardella and Giarratana, 2013; USPTO, 2014a).

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could be made to adapt the invention to multiple applications. In spatial terms, if such alternatives were specified in the claims, the latter would be more distantly positioned from the original invention than the former. In the US patent system, the positioning of claims is captured by the technological classes to which the patent is assigned. When the patent examiners scrutinize the application documents, they attribute it to one mandatory classification, according to the class of the controlling patent claim, and then also to a variable number of additional classes, if the additional claims "fall" into other technological domains (USPTO, 2014b).

Building on these premises, this paper offers a re-examination of the concept of *patent scope* from the perspective of an inventing firm, identifying two dimensions to it: (1) the *number of variations* to the core inventive idea that are identified in the patent, which are reflected in the number of its claims (e.g. Merges and Nelson, 1994); and (2) the *positioning* of such variations in the inventive space, which is reflected in the number of technological classes in which the patent examiners classify such claims. While patents can vary along both dimensions, existing research has generally overlooked this issue. This paper argues that a higher number of claims might allow the inventing firm to build on its patented knowledge (e.g. Hall et al., 2005; Kitch, 1977; Merges and Nelson, 1994); but, when the patent claims are classified across multiple classes, the extent to which the inventing firm is itself able to appropriate and build on the knowledge underlying the patent may decrease.

Having shown that both these dimensions are important in affecting the strength of the protection a patent grants, this paper addresses the following questions: What enables the identification of a greater number of patent claims, and what determines the positioning of such claims across a greater number of technological domains? Surprisingly, there has been limited research exploring the antecedents of patent scope. In this paper, I build on research on the role of science in the inventive process (e.g., Fleming and Sorenson, 2004; Narin, 1994; Narin et al., 1997) and on analogical processes (e.g. Gavetti et al., 2005; Gick and Holyoak, 1980; Hofstadter, 2001), and identify firms' prior investments in scientific knowledge and in related inventive experience as two factors affecting patent scope. The theoretical predictions elaborated in this paper are supported by an empirical examination of a longitudinal sample of firms in the photonics industry.

The rest of the article is organized as follows. In Section 2 I explore the concept of patent scope, its implications and antecedents. In Sections 3 and 4, I describe the empirical setting, data, econometric specifications, estimation results, and in Section 5 I discuss the paper's contribution, implications for future research and limitations.

2. Theory and hypotheses

2.1. Patent breadth, patent width and patent scope: prior theoretical and empirical research

Using slightly different definitions, prior research has generally referred to the constructs of 'patent breadth', 'patent width' or 'patent scope' when referring to the level of leniency used by the regulator in granting exclusion rights to patentees (e.g. Denicolo', 1996; Gilbert and Shapiro, 1990; Green and Scotchmer, 1995; Klemperer, 1990; Matutes et al., 1996; Merges and Nelson, 1990, 1994; Scotchmer, 1991). Despite the value of these contributions, existing research in this area overlooks some important issues.

First, most of it builds on the idea that – given a certain degree of leniency on the part of the regulator in examining patent cases – an inventing firm will take full advantage of it, for instance by specifying in the patent claims all the possible variations to the invention that the regulator is likely to permit. This requires assuming that the full set of possible variations to an invention is known to (or could easily be identified by) the inventor at the time of the patent application (i.e. Merges and Nelson, 1990, 1994). This paper relaxes this assumption, in that it suggests that the scope of a patent is also determined by firms' ability to identify a higher number of variations. Because this ability likely varies across firms, this paper explores the antecedents of this heterogeneity – which have not been considered in most prior research.

Second, in investigating the implications of patent scope, most prior research has focused on its implications for social welfare (e.g. Denicolo', 1996; Green and Scotchmer, 1995; Klemperer, 1990; Merges and Nelson, 1990, 1994; Scotchmer, 1991). This paper extends prior research by showing how the scope of patents affects the extent to which the inventing firm is able to build on its own prior patents compared to other firms.

Finally, existing research has not provided precise guidance as to the operational interpretation of the construct of patent scope. Some studies have suggested that the scope of a patent can be measured as the number of technological classes in which its claims are classified (e.g. Lerner, 1994; Nerkar and Shane, 2003; Shane, 2001), building on the idea that a patent with broader scope would include more distant applications. Reflecting, instead, the idea that a patent with a broader scope covers a greater number of variations to the invention, other studies have measured the scope of a patent as the number of claims it includes (e.g. Lanjouw and Schankerman, 1997). This paper extends prior research by recognizing that the number of claims in a patent, and the number of classes in which those patent claims are classified reflect different dimensions of the patent scope construct, and suggests that its operationalization should take both dimensions into account. Table 1 provides a synthesis of prior research on these issues, and compares the assumptions and findings of prior studies.

2.2. The implications of patent scope

I argue that both the number of a patent's claims and their positioning across classes affect firms' ability to appropriate the 'inventive' returns from their inventions. Prior literature in this area has emphasized that all patents embody the opportunity for further development, and can act as a springboard for future inventions (Ahuja et al., 2013; Green and Scotchmer, 1995; Hall et al., 2005; Kitch, 1977; Merges and Nelson, 1994; O'Donoghue, 1998; Scotchmer, 1991). Existing research has identified an association between patents' scope and the subsequent inventive activity that builds on them, as measured by the number of 'forward citations' the patent receives (e.g. Lerner, 1994). However, this research does not distinguish between citations received from subsequent patents developed by the inventing firm itself (i.e. 'self-citations'), and those received from patents developed by others (i.e., 'external' citations). While self-citations reflect the firm's internalization of the knowledge underlying its own inventions (Belenzon, 2012; Hall et al., 2005; Trajtenberg, 2002), external citations indicate that other players have internalized part of the knowledge underlying the original invention and succeeded in building on it. Hence, from the standpoint of the inventing firm's appropriability, the value of self- and external citations differs substantially.

A deep understanding of both the codified and tacit knowledge elements underlying the patent should, in principle, give the original inventing firm an advantage in conceiving subsequent developments more easily and more quickly than other firms (e.g. Arora, 1996; Giarratana and Mariani, 2014; Katila and Ahuja, 2002). A higher number of claims should act as a deterrent to other firms from building on the knowledge underlying the patent, as it corresponds to an increased probability that a new invention in that area might infringe at least one of the patent's claims (Kitch, 1977; Merges and Nelson, 1994; Scotchmer, 1991). It might also reflect

Table 1
Literature overview.

Author(s), Year and type of contribution	Key construct relevant to this paper	Perspective considered	Assumptions about the inventing firms' incentives and the sources of welfare loss	Characteristics of the inventive process	Key findings
Klemperer (1990) *Theoretical*	Patent width: extent of similarity allowed by the regulator between the focal invention and those developed by other firms ("How similar a drug should a competitor be allowed to sell?" p. 113)	Policy maker. The objective is to identify the optimal patent policy (i.e. the ideal combination of patent width and patent length) that maximizes social welfare accounting for the inventing firm's incentives	The inventing firm is incentivized by the profits at time *t*, which are defined as a function of patent width. Firms are only allowed to choose their prices as a function of patent width, which is set at the system level Welfare losses originate from two sources: 1. Consumption switching to less preferred product varieties; 2. Consumption switching out from the product category	Innovative activity ceases after one patent is awarded. Hence, the inventing firm's utility is affected only by the profits associated with the product variety it produces (which embodies the invention)	Even if increasing the width of a patent increases the monopolistic power granted to the inventing firm, greater patent width may be the optimal choice "if for each consumer the value of consuming the preferred variety is higher than the value of consuming no variety of the product by the same monetary amount" (p. 115)
Gilbert and Shapiro (1990) *Theoretical*	Patent breadth: the flow rate of profits available to the patentee while the patent is in force, which is determined by the regulator through various policies (e.g. exclusive territories, tying arrangements, antitrust laws. . .). In all cases breadth translates into the maximum price that the patentee can charge for the product that embodies the invention	Policy maker. The objective is to identify the optimal patent policy (i.e. the ideal combination of patent breadth and patent length) that maximizes social welfare accounting for the inventing firm's incentives	The inventing firm is incentivized by profit at time *t*, which corresponds to patent breadth. Welfare losses originate from consumption that is switched out of the product category	Innovative activity ceases after one patent is awarded and – hence – the inventing firm's utility is affected only by profits associated with the current invention	In a homogenous good market, the optimal policy involves patents of infinite length whenever increasing the breadth of the patent is increasingly costly – in terms of deadweight loss
Denicolo' (1996) *Theoretical*	Patent breadth: defined by the various instruments used by the government to limit the extent of the monopoly the inventing firm enjoys over a new technology it has developed (p. 249)	Policy maker. The objective is to optimize the inventing firm's incentives to invent as well as social welfare. It extends earlier literature to the case in which many firms race for a patent	Incentives are not only determined by the profits earned by each patentee, but also by the profits earned by non-innovators and by the profits earned after the patent expires. In addition to being originated by reductions in the level of investment in R&D, social loss also originates from inefficiencies (i.e. duplication of entry costs, inefficient productions . . .)	The paper considers the case of a single invention rather than a sequence of inventions	Narrowing patent breadth leads to more competition in the product market; this increases social welfare only to the extent that social welfare increases more rapidly than the incentives to innovate decrease as the patent is narrowed. This depends on the nature of the competition, which can be more or less efficient. If competition is less efficient, narrowing the breadth of the patent increases the output of less efficient firms
Kitch (1977) *Theoretical*	Patent scope: scope "accorded by the patent system to the inventing firm's patent claims (p. 267)	Policy maker	Contrast between the reward theory (i.e. patent system as a device that enables an inventing firm to capture the returns from its investment in the invention) and the prospect theory (i.e. patent system as a device used to increase the output from resources used for technological innovation)	Innovative activity is cumulative Firms have different types of knowledge and resources (p. 277) that they can apply in the invention process. Contracting can be used to give different parties different areas to explore	Patents with a broad scope should be granted to enable inventing firms to develop their inventions that have a potential for significant improvement in an orderly fashion

Table 1 (*Continued*)

Author(s), Year and type of contribution	Key construct relevant to this paper	Perspective considered	Assumptions about the inventing firms' incentives and the sources of welfare loss	Characteristics of the inventive process	Key findings
Scotchmer (1991), Green and Scotchmer (1995) *Theoretical*	Patent breadth: "Leniency of the courts in interpreting the novelty requirement of patents" (Matutes et al., 1996, p. 80). Compared to the first order invention, increase in quality required from a second order invention so that the second invention does not constitute an infringement (Green and Scotchmer, 1995)	Policy maker. The objective is to investigate the use of patent protection and cooperative agreements among firms to protect incentives for cumulative research	The inventing firm is incentivized by profits generated through first- and second-order inventions, earned by selling the invention as a product, or by licensing it to firms that have developed products that infringe on the focal firms' patent. Patent breadth does not change the per-period joint profits (which are fixed), but only their division between sequential inventing firms. Social loss originates from reductions in the level of investment in R&D	Innovative activity is sequential and inventions are subject to multiple stages of modification and improvement. Firms have different types of expertise that allow them to develop different applications of the first invention	Profit erosion due to invention of derivative improvements by other firms may be mitigated by increasing patent breadth or by permitting cooperative ex-ante agreements. However, when there is uncertainty about the value of second order inventions and cooperation is permitted, the optimal breadth can be finite
Merges and Nelson (1990, 1994), Cohen and Lemley (2001) *Theoretical*	Patent scope: "allowed" breadth of the patents claims, as determined by the patent policy	Policy maker. The objective is to determine the patent scope that does not hinder technical progress	Profits are not exclusively a function of the breadth of the patent, but also of superior design, production and marketing. Moreover, the inventing firm has a natural advantage in terms of lead time. In addition, increasing breadth does not necessarily provide firms with incentives to invent in the area protected (i.e. firms sometimes "sit on their monopoly positions"). Social loss originates from reductions in the level of investment in R&D and from the consequent limitation of technical progress	Technical advance is sequential and connected and often cumulative. Heterogeneity in firms' capabilities is recognized, especially in identifying "the developmental opportunities associated to an invention" (Merges and Nelson, 1994; p. 7)	The impact of the breadth of patents on subsequent inventing in a field depends on the topography of technical advantage in a field, i.e. whether technical progress requires diversity of capabilities versus express coordination. The case of the software industry, studied by Cohen and Lemley (2001), is an example of an industry in which patents of wide breadth might be granted, but where this is unlikely to promote progress in the industry
Matutes et al. (1996) *Theoretical*	Patent Scope: leniency of the courts in granting claims of innovations that are not fully developed	Policy maker. The objective is to identify the ideal combination of patent scope and patent length taking into account both the inventing firm's incentives to invent and social welfare	Inventing firms are incentivized by the profits they can make from the invention in the "patenting" and "non-patenting" case. Without the patent, inventing firms have incentives to wait before they introduce the applications developed on the basis of their technology in order to avoid imitation that can happen through reverse engineering. Social loss originates from delay in the diffusion of the knowledge related to the basic innovation (i.e. delayed disclosure)	Innovative activity is cumulative. The knowledge associated with the invention is necessary to develop further innovations. The number of applications that can be derived from an invention is part of common knowledge	Scope generates higher levels of welfare than length because it anticipates the period during which other firms can introduce applications of their own, and because patent holders have more flexibility to decide when to exercise their property rights

Table 1 (*Continued*)

Author(s), Year and type of contribution	Key construct relevant to this paper	Perspective considered	Assumptions about the inventing firms' incentives and the sources of welfare loss	Characteristics of the inventive process	Key findings
Lerner (1994) *Empirical*	Patent Scope: breadth of the patent protection, represented by the breadth of claims in each patent. Operationalized as the number of technological classes in which a patent is classified	Policy maker/inventing firm. The purpose is to empirically examine the impact of patent scope on a firm's economic value	By pioneering an empirical investigation into the construct of patent scope and its impact on firms' valuation, the paper provides support for the theoretical idea that the scope of patents can exert a relevant impact on the inventing firms' incentives, as well as being an important policy instrument	The paper reflects the cumulative nature of the invention process, in that it investigates the impact of the scope of a patent on the subsequent (external) citations it receives	Broader patent scope (patent classes) is associated with greater numbers of external forward citations; greater probability of litigation; higher market valuation of the firm
Lanjouw and Schankerman (1997) *Empirical*	Patent Scope: breadth of claims in each patent. Operationalized as the number of claims included in a patent. Number of patent classes included in the analyses as a control variable	Policy maker/inventing firm. The purpose is to identify the factors that contribute to patent litigation and understand whether patent litigation dilutes the incentives provided by the patent system	Not only the returns from patenting but also its costs (e.g. the potential costs of litigation) affect the incentives to invent	The paper reflects the cumulative nature of the invention process, in that it investigates the impact of the scope of a patent on the subsequent (external) citations it receives, and on patent litigation	Patents that are broader in scope – in the sense that they embody more claims – will be more exposed to potential infringement and thus litigation. Patents that are classified in a higher number of classes are associated with a lower probability of litigation
This paper	Patent scope refers to the space of the exclusion right actually covered by a patent. The present paper *extends prior theoretical research* in that: it suggests that the actual area covered by a patent also depends on the inventing firm's ability to identify variations to the core invention and not just on the regulator's leniency. The paper *extends prior theoretical and empirical research* in that it recognizes that patent scope can vary along two distinct dimensions. (1) The *number of variations* to the core inventive idea identified in the patent, reflected in the number of claims in the patent (e.g. Merges and Nelson, 1994); and (2) the *positioning* of those variations in the inventive space, which is reflected in the number of technological classes in which those claims are classified by patent examiners	The present paper *extends prior research* in that: (1) It takes a firm (as opposed to a policy) perspective; (2) it investigates the impact of patent scope on firm's ability to build on their patents compared to other firms (3) It explores the antecedents of patent scope	The strength of protection provided by the patent varies depending on both the number of variations identified (included in the patent claims) and their positioning in the inventive space (i.e. patent classes) and it may affect the extent to which the inventing firm will build on the patent compared to other firms	The present paper *builds on* Cohen and Lemley (2001), Green and Scotchmer (1995), Kitch (1977), Matutes et al. (1996), Merges and Nelson (1990, 1994); Scotchmer (1991) in that: (1) it recognizes that the inventive activity does not cease after the first invention, but rather is cumulative or sequential; and (2) it recognizes that firms have different types of knowledge and resources that they can apply in the invention process. This paper *extends these prior studies* in that it suggests that firms' heterogeneity can also affect the identification of variations to the core invention that can be included in the patent claims (as opposed to affecting only the development of subsequent inventions)	Holding other conditions constant, the higher the number of claims in the patent and the lower the number of technological classes in which a patent's claims are classified, the greater the extent to which the inventing firm will build on it compared to other firms. The greater the firm's scientific knowledge, the greater the number of claims in its patents and the greater the number of technological classes its patent claims will be classified in. The greater the firm's related inventive experience, the greater the number of claims in its patents and the lower the number of technological classes its patent claims will be classified in

the inventing firm's strategic intention itself to reduce the likelihood that others can invent in the areas surrounding the patented invention.

However, holding the number of claims in a patent constant, the strength of these mechanisms will be reduced if those claims are positioned across multiple technological domains. In this case the focal firm may be less likely, compared to other firms, to have the internal capabilities or complementary assets required to pursue developments of its invention across all potential domains (e.g. Chang, 1995; Merges and Nelson, 1994; Penrose, 1959; Peteraf, 1993). In addition, the more dispersed the domains to which an invention contributes are, the more difficult it can be for the focal firm to focus its attention across all of them (Ocasio, 1997) and the less credible it can be that it will do so (Caves, 1984; Lieberman and Montgomery, 1988). In fact, the inventing firm might have developed the patent with a broader technological span with the intention of harvesting licensing revenues, rather than to further technological developments on all fronts itself (Gambardella et al., 2007; Gans et al., 2008). Patents classified in more different classes will also have greater visibility, and be more likely to 'cross' more firms' search processes. Hence, they will be more likely to be built on by others. Thus:

Hypothesis 1. Holding other conditions constant, the extent to which an inventing firm will build on its patent compared to other firms increases with the number of patent claims but decreases with the number of technological classes in which the patent's claims are classified.

2.3. The antecedents of patent scope: scientific knowledge and related inventive experience

Although many applications of an invention may only emerge over time (Cattani, 2005; Rosenberg, 1998), inventing firms are incentivized to try to identify as many of these variations as possible to increase their pre-emptive advantage over their competitors (Aljalian, 2005; Ceccagnoli, 2009; Chiang, 2010).[3] This implies thinking beyond the particular manifestation of its idea that the inventing firm has currently conceived (Kitch, 1977; Merges and Nelson, 1994). Hence, I build on the assumption that the identification of potential variants to an invention can be facilitated by the factors that enable the inventing firm to abstract from that invention's local context, and to scout for potential solutions – or elements of such solutions – in different settings. I identify two factors that can lead to this outcome, i.e. the levels of a firm's scientific knowledge and of related inventive experience in its knowledge base.

2.3.1. Scientific knowledge and patent scope

Extant literature has suggested that science can alter the way the invention search processes operate (e.g., Narin, 1994; Narin et al., 1997; Fleming and Sorenson, 2004). I suggest it can also lead to the development of a broader scope for patents by facilitating abstraction. First, scientific knowledge provides firms with a repertoire of abstract principles derived from general theories and laws (Arora and Gambardella, 1994a,b; Mowery, 1981; Rosenberg, 1990), and greater familiarity with these general principles facilitates the abstraction of new technological problems (Bresnahan and Gambardella, 1998). Second, using scientific knowledge in the invention process increases the likelihood that inventions are less contextualized to any specific application setting in their original conception, being derived directly from abstract principles (Arora and Gambardella, 1994b).

The conceptualization of technological problems in abstract terms fostered by science facilitates the navigation of the technological environment in multiple directions and the recombination of different elements of identified solutions, and so further expands the overall set of possible solutions to problems (Fleming and Sorenson, 2004), i.e. the number of potential variations to the core inventive idea. This suggests that:

Hypothesis 2a. The greater the firm's scientific knowledge, the greater the number of claims in its patents.

The use of scientific knowledge in the invention process can also lead to the identification of more distant variations to the invention. Science gives firms a quick "glimpse of the possible" (Fleming and Sorenson, 2004, p. 912), allowing alternative problems and solutions to be evaluated via an 'offline' search process (Gavetti and Levinthal, 2000; Lippman and McCall, 1976; Nelson, 1959). For instance, the invention of photonic-crystal fibers – a new class of optical fibers – was developed through the transfer of knowledge from the principles of quantum mechanics to the field of optics, and built on the theoretical idea that light could be trapped in photonics 'bandgaps' in a similar way to how electrons can be trapped in the energy gaps of a lattice (Benabid, 2006; Russell, 2003). Because scientific knowledge improves firms' ability to comprehend, assimilate and recombine knowledge from more distant domains (Gambardella, 1995; Gruber et al., 2013), the distance of an invention's variations that can be identified by relying on scientific knowledge is likely to increase. Thus:

Hypothesis 2b. The greater the firm's scientific knowledge, the greater the number of technological classes its patent claims will be classified in.

2.3.2. Related inventive experience and patent scope

Firms can also develop general knowledge schemes from their actual engagement with concrete experiences (Arora and Gambardella, 1994a; Cattani, 2005; Fosfuri and Tribo', 2008; Gavetti et al., 2005; Hofstadter, 2001; Levinthal and March, 1993; Levinthal, 1995). When similar problems are encountered several times, firms are likely to derive general schemas for understanding and solving problems of that nature, which are then stored in their knowledge bases (Gick and Holyoak, 1980; Hofstadter, 2001). Such schemas, and the settings they are derived from, then serve to identify candidate solutions for the new technological problems they face (Gavetti et al., 2005; Gick and Holyoak, 1980; Hofstadter, 2001; Holyoak and Thagard, 1989).

Relatedness in the experience accumulated by a firm increases the likelihood that a connection between prior experience and a current problem can be identified (Gentner and Landers, 1985; Gick and Holyoak, 1980; Holyoak and Thagard, 1989), as well as the repertoire of potential solutions for that problem (e.g. Cattani, 2005; Helfat and Lieberman, 2002). For instance, Corning's prior inventive experience in lasers, glass manufacturing and integrated circuits helped the company identify specific solutions to developing the first optical fibers (Cattani, 2006). This will facilitate the identification of useful variations to the invention's 'best mode' and, consequently, increase the number of claimed variations the inventing firm can incorporate in its patent documents. Hence:

Hypothesis 3a. The greater the firm's related inventive experience, the greater the number of claims in its patents.

However, relatedness in the firm's inventive experience is likely to reduce the distance between the variations identified. First, the relatedness of source settings can lead to an increase in similarity

[3] This statement has also found support in the qualitative evidence collected via interviews conducted with patent attorneys as a complement to this study's quantitative analysis. Specifically, interviewees confirmed that – within the boundaries of what is reasonable to claim in association with a certain invention – inventing firms are generally incentivized to identify the highest possible number of claims.

between the possible responses identified in the first place. Second, more experience in certain domains might create a form of "cognitive myopia" toward more distant domains (Cohen and Levinthal, 1990, 1994; Levinthal and March, 1993; March, 1988). Third, related experiences are likely to share many contextual elements, hence the generality of the maps and structures of phenomena derived from it – and the degree to which such maps can be effective as guides to approaching more distant contexts – might be lower (Hofstadter, 2001; Holland et al., 1989; Newell and Simon, 1972).

At the same time, past exploitation in a certain domain makes future exploitation within that same domain even more efficient, so increasing the opportunity cost of exploration beyond that domain, and reducing the incentives to explore more widely (Levinthal and March, 1993). Hence, the greater the level of related inventive experience in a firm's knowledge base, the less likely it is that it will engage in a broader search for variations to an invention, and thus:

Hypothesis 3b. The greater the firm's related inventive experience, the lower the number of technological classes its patent claims will be classified in.

3. Empirical context, methods and measures

3.1. Photonics

The empirical analysis is conducted on firms active in the photonics arena. Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon (The Photonics Directory, 2014). The word 'photonics' appeared in the late 1960s to describe a research field whose goal was to use light to perform functions that typically fell within the electronics domain, such as telecommunications and information processing. The broad span of photonics' applications ranges from energy generation to detection, communications and information processing, and includes technologies for the generation, emission, transmission, modulation, signal processing, switching, amplification and detection or sensing of light.

Both scientific and technical knowledge are important in this field. The basic scientific knowledge underlying photonics draws from physics and engineering, but a broad range of scientific knowledge bases are used within the field, including chemicals, material science, astronomy, optics and electronics. The photonics industry includes both small and large firms – specialized players as well as generalists. Firms' inventive experience also varies in this industry, because photonics components and products are used in multiple applications, such as material processing, signal analysis, imaging. During the period covered by the current study the field was known for its level of innovation (Stuck, 1998; Teich and Saleh, 1991). Patenting inventions is a common practice in photonics (Fearnside, 2007) and the question of the scope of patents is particularly meaningful in this field, where the level of standardization is low for many technologies – hence firms have greater freedom in choosing how to address each technological problem they face. Detailed information about the industry was collected from a set of fifteen interviews with industry experts, photonics scientists and academics, and patent attorneys in the United States and Europe. The qualitative data collected during these interviews were also used to validate the theory and the operationalization of the constructs developed in this study, as well as to support the interpretation of its results.

3.2. Sample and data

To test the hypotheses, I built a longitudinal data set containing information about a sample of photonics firms over a ten-year period (1993–2002). To define photonics and its boundaries I relied on an industry directory (*The Photonics Directory*, by Laurin Publishing), which lists all companies active in photonics' subfields. I selected all U.S. companies listed in the directory between 1993 and 2002, and extracted information on their key characteristics (e.g., independence status, size, age, location) for each year. The sample included both private and public firms, and so is generally representative of the different categories of firms active in high-technology contexts. It also included firms that entered or exited the industry during the period, limiting any survival bias.

I used firms' names and locations and matched them to patent assignee's names in the National Bureau of Economic Research (NBER) patents database. The NBER data set provides patent data consolidated at the parent portfolio level for public firms. For private firms, I used the D&B *Who Owns Whom* database to build a list of their worldwide subsidiaries for each year of the study. I then matched this list with the NBER data set to obtain the list of patents filed by each of the firm's subsidiaries, and finally, consolidated the list of patents at the parent firm level. This procedure resulted in the selection of 88,528 patents, held by 656 firms.

3.3. Variable definitions and operationalization

3.3.1. Number of variations to the invention and their positioning across technological domains

In the theory section of this paper I identified two core dimensions defining patent scope, i.e. the *number of variations* to an invention and the *positioning* of those variations across multiple technological classes. Following existing research, I operationalized the first dimension as the number of claims in the patent (i.e. Lanjouw and Schankerman, 1997; Merges and Nelson, 1994; Walker, 1995), information which I collected from the NBER patent dataset. I collected (from Google Patents) the number of unique three-digit technological classes in which each patent's claims were classified at the time of the patent application as reflecting the positioning of those claims across technological classes (USPTO, 2014b). I computed this measure using the USPTO patent classification, which provides two benefits relative to the International Patent Classification (IPC). First, it only classifies patents according to their claims – rather than considering the complete patent documentation (Gruber et al., 2013; USPTO, 2014b) – and, second, it emphasizes an invention's technical focus as opposed to its industrial uses (Lerner, 1994; USPTO, 2014b). Hence, the USPTO classification is appropriate to study how a firm's knowledge base leads to the development of the technical knowledge embodied in its patent claims.

3.3.2. Forward self-citations

Consistent with previous research, I used the total number of *forward self-citations* a patent receives as a measure of the ability of the inventing firm to internalize and build on its early knowledge (e.g. Hall et al., 2005). As forward citations are subject to truncation issues, I calculated this measure using two alternative time windows, i.e. a fixed four-year time window from the year of the patent grant, and the full time window from the date of the patent grant through to 2006. These windows are shorter than the full patent term, so the forward citations I considered occurred while the patent rights were still valid, allowing me to investigate the extent to which a patent's scope was effective in protecting the knowledge embodied in its claims from spilling over to other firms.

3.3.3. Scientific knowledge and related inventive experience

I referred to the characteristics of a firm's patents from year $t-5$ to $t-1$ (where t is the year of the focal patent application) as indirect indicators of the characteristics of its knowledge base in the years before that application (e.g. Ahuja and Katila, 2001;

Argote, 1999; Jaffe and Trajtenberg, 2002). The construct of *scientific knowledge* refers to the influence of science in the invention process. Previous studies have emphasized that references to scientific articles provide a reasonable indicator of the influence of science on the inventive process (Brusoni et al., 2005; Fleming and Sorenson, 2004; Narin et al., 1997; Tijssen, 2001). To measure this construct, I used the proportion of patents in the firm's knowledge base prior to year *t* which cited scientific articles to the total number of its patents. As a robustness check, I also calculated the total number of references to scientific articles in the firm's patents prior to year *t*. To calculate these variables I collected the full text of non-patent references in the firm's patents from the Patent Data Verse database (Lai et al., 2011) and then selected only the references to scientific articles using a combination of a search algorithm and manual checks.

The construct of *prior related inventive experience*, in contrast, pertains to the amount of experience in a firm's knowledge base related to the focal invention. To assess whether a patent in the firm's portfolio was related to the focal patent, I used the classification developed by Hall et al. (2001), who reclassified the main USPTO three-digit patent classes into a set of two-digit technological subcategories, based on the extent to which they relate to each other. I calculated this measure as the proportion of patents that were assigned to a primary technological class related to that of the focal patent to the total number of patents the firm applied for in the years prior to year *t*. As a robustness check, I also calculated this measure as the total number of related patents applied by the firm in the years prior to *t*.

3.3.4. Controls

The analyses controlled for *firm size*, i.e. the number of its employees in year *t*, *firm age*, i.e. the number of years elapsed from its establishment to year *t*, and *firm's knowledge stock*, i.e. the number of patents for which it had applied over the five years before year *t*. To control for firms' differential ability to leverage their prior experience in the inventive process, I included the variable *knowledge leverage*, i.e. the proportion of self-citations over the total number of backward citations appearing in the firm's patents during years $t-1$ to $t-5$ (adapted to the context of this study from the leverage measure used by Cattani, 2005). I included controls for the novelty of the technology, as the exploration of novel technological areas offers firms opportunities to preempt a higher number of 'spots' in the inventive space with variations to their inventions, leading to the identification of a higher number of claims. Such claims could potentially be assigned to multiple technology classes, due to lack of established technological knowledge to guide the patent examiners (e.g. Guellec and van Pottelsberghe de la Potterie, 2000). But, when the technology underlying the invention is more novel, the number and diversity of variations to an invention may be lower, due to the fact that more novel contexts are characterized by greater uncertainty, and most of the connections with other technological domains will still be unknown.

To capture – at the patent level – the extent to which the firm had developed the patent by elaborating on established versus more recent knowledge, I introduced the variable *technological novelty*, i.e. the inverse of the median age in years of the patent's backward citations (Oriani and Sobrero, 2008). I also included *technology life cycle* fixed effects for each technological domain. Each *technology life cycle*$_{ij}$ fixed effect equals 1 if the patent application year equals i and the technology class of the patent equals j, (with $i = 1\ldots I$, and $j = 1\ldots J$, where I equals 10 years in the sample and J equals 410 technology classes represented in the sample specified at the three-digit US classification level), and 0 otherwise. To control for any remaining source of unobserved heterogeneity I included *firm and industry subfield* fixed effects in the analysis. Table 2 shows the variables and descriptive statistics, and Table 3 shows the correlations between the main variables in the analysis.

3.4. Model estimation and econometric issues

I use a linear regression model at the patent level of analysis to test Hypothesis 1, where I estimate the number of self-citations received by a patent as a function of the *number of claims*, the *number of classes*, a set of control variables (firm *scientific knowledge*, firm *related inventive experience*, firm *knowledge stock*, *technological novelty*, firm *size*, firm *age*, firm *knowledge leverage, total forward citation*) and *firm-, subfield and technology life cycle – fixed effects*. To test Hypotheses 2a, 3a, 2b and 3b I use two linear regression models at the patent level where the dependent variables are, respectively, patent claims and patent classes. These variables are estimated as a function of the firm's *scientific knowledge*, firm *related inventive experience*, the control variables (firm *knowledge stock*, *technological novelty*, firm *size*, firm *age*, firm *knowledge leverage*) and *firm-subfield and technology life cycle-fixed effects*. In the linear regression models, I took the natural logarithm of all the variables on the right and left hand sides of the equations to address any skewness in the data.

4. Estimation results and robustness checks

4.1. Patent scope and self-citations

Table 4 reports the result of the models in which the dependent variable is the number of self-citations a patent receives. Model 4.1 is the baseline model and includes all the control variables. The two independent variables, i.e. *number of claims* and *number of classes*, are added separately in Models 4.2 and 4.3, while Model 4.4 includes them both. Results from the full model (4.4) show that the number of self-citations a patent receives is positively associated with the number of claims in it ($\beta = 0.014$; $p < 0.01$), but is negatively associated with the number of patent classes it is assigned to ($\beta = -0.020$; $p < 0.01$): these results support Hypothesis 1. This implies that, at the sample mean of both the dependent and the independent variables, an increase of one standard deviation in the number of claims in a patent is associated with an increase of 2.8% in the number of self-citations, and, conversely, an increase of one standard deviation in the number of classes is associated with a decrease in the number of self-citations of 2.75%. These effects are highly significant, even though their magnitude is not very large. It must be taken into account that the effects are estimated at the individual patent level, and so may have greater economic significance for firms holding large portfolios of patents. In addition, it is important to recognize that the economic value of inventions building on a firm's patents is not linearly related to their number: even a few very successful follow-up inventions can contribute considerably to a firm's economic performance.

To check the robustness of these results, I have run several alternative models. First, in Model 4.5, I replicated the same analyses on a subsample of patents in photonics technological classes only.[4]

[4] The USPTO classification does not include a specific class for photonics patents. I relied on the assumption that if photonics firms had the same probability of patenting in any US patent class as all other firms, the proportion of patents applied in each class by photonics firms to the total number of patents they applied for should (in principle) be equal to the proportion of patents applied in that class by all firms in the NBER database to the total number of patents applied across all classes by all firms in the NBER database. However, if these two proportions differed (with the first proportion being higher) this could be interpreted as indicating that photonics firms had an higher propensity to patent in that class compared to other firms in the NBER database, and that that class was particularly relevant to the photonics industry. I referred to the non-consolidated sample of corporate entities directly active in

Table 2
Descriptive statistics.

	Description	Obs	Mean	S.D.	Min	Max
Patent scope						
Number of claims	Patent level. Number of claims in the patent	88,528	15.516	11.881	1.000	318.000
Number of classes	Patent level. Number of unique technological classes in which the claims of the patent are classified	88,528	1.577	0.831	1.000	10.000
Antecedents						
Firm scientific knowledge (from $t-5$ to $t-1$)	Firm-year level. Number of patents applied by the firm in years from $t-5$ to $t-1$ citing scientific articles over the total number of patents applied by the firm in years from $t-5$ to $t-1$	88,528	0.077	0.062	0.000	1.000
Firm related inventive experience (from $t-5$ to $t-1$)	Firm-year-technology level. Number of patents in technological classes related to the one of the focal patent applied by the firm in years from $t-5$ to $t-1$ over the total number of patents applied by the firm in years from $t-5$ to $t-1$	88,528	0.141	0.158	0.000	1.000
Implications						
Self-forward citations (from t to $t+4$)	Patent level. Number of self-citations received by the patent from t (time of the patent grant) to $t+4$	88,528	0.620	1.980	0.000	54.000
Total forward citations (from t to $t+4$)	Patent level. Number of total forward citations received by the patent from t (time of the patent grant) to $t+4$	88,528	4.857	7.843	0.000	176.000
Controls						
Firm knowledge stock (from $t-5$ to $t-1$)	Firm-year level. Number of patents applied by the firm in the years from $t-5$ to $t-1$	88,528	3185.358	2416.666	0.500	9764.874
Technological novelty	Patent level. Inverse of the median age (in years) of the patent's backward citations	88,528	0.605	0.227	0.056	1.000
Firm size	Firm-year level. Number of employees in year t	88,528	3933.585	14,127.840	2.000	480,000.000
Firm age	Firm-year level. Number of years elapsed from the firm's establishment to year t	88,528	60.710	32.212	1.000	180.000
Firm knowledge leverage	Firm-year level. Number of backward citations made by the firm to its own patents (in the patents applied by the firm in years from $t-5$ to $t-1$) over the total number of backward citations appearing in the patents applied by the firm in years from $t-5$ to $t-1$	88,528	0.125	0.079	0.000	0.600

Table 3
Pairwise correlations between variables ($N=88{,}528$).[a]

		1	2	3	4	5	6	7	8	9	10	11
1.	Number of claims	1.000										
2.	Number of classes	0.030	1.000									
3.	Firm scientific knowledge (from $t-5$ to $t-1$)	0.115	0.060	1.000								
4.	Firm related inventive experience (from $t-5$ to $t-1$)	0.091	−0.073	0.056	1.000							
5.	Self-forward citations (from t to $t+4$)	0.085	0.002	0.026	0.063	1.000						
6.	Total forward citations (from t to $t+4$)	0.110	0.048	0.103	0.007	0.432	1.000					
7.	Firm knowledge stock (from $t-5$ to $t-1$)	−0.107	−0.070	−0.166	−0.219	−0.069	−0.105	1.000				
8.	Technological novelty	−0.036	−0.010	−0.045	0.016	0.048	0.007	−0.161	1.000			
9.	Firm size	−0.002	0.020	0.026	−0.034	0.046	0.026	−0.013	0.073	1.000		
10.	Firm age	−0.037	−0.003	−0.109	−0.185	0.032	−0.026	0.091	0.072	0.222	1.000	
11.	Firm knowledge leverage	−0.071	−0.003	−0.199	−0.063	0.094	−0.029	0.140	0.066	0.026	0.374	1.000

[a] Correlation coefficients with absolute value greater than 0.003 are significant at the 95% level; correlation coefficients with absolute value greater than 0.007 are significant at the 99% level.

photonics and identified the set of three-digit primary US technological classes in which these companies patented. For each technological class j identified in the non-consolidated sample, I calculated the proportion of patents in that class to the total number of patents in the sample across all J classes, $\left(n_{\mathrm{PH}j}/\sum_{j=1}^{J} n_{\mathrm{PH}j}\right)$ in the period under consideration. I calculated the same proportion using all patents in the NBER database, $\left(n_{\mathrm{NBER}j}/\sum_{j=1}^{J} n_{\mathrm{NBER}j}\right)$, referring to the same set of classes J in the same period). I then compared these two proportions, using a z test to assess whether the difference between them was statistically significant. I retained in the sample all the classes that satisfied two conditions: (1) $n_{\mathrm{PH}j}/\sum_{j=1}^{J} n_{\mathrm{PH}j} > n_{\mathrm{NBER}j}/\sum_{j=1}^{J} n_{\mathrm{NBER}j}$; (2) the difference was statistically significant at the 99% confidence level. This procedure resulted in the selection of 74 classes (details available on request).

Second, Model 4.6 reports the results of the analyses conducted using the full time window available after the patent grant to calculate the number of forward citations patents received.[5] Third,

[5] For comparison purposes, in Model 4.7 I use the number of external citations received by a patent as the dependent variable. Consistent with the theory developed in this paper, the results show that an increase in patent claims is associated with a decrease in the number of external forward citations received by the patent, while an increase in the number of patent classes is associated with an increase in the number of external citations it received. Model 4.8 considers the total number of forward citations received by the patent as the dependent variable, and the results show that both claims and classes are positively associated with it.

Table 4
Linear regression estimates of patents' self-forward citations.[a]

	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
	Linear regression	Linear regression	Linear regression	Linear regression	Linear regression	Linear regression	Linear regression	Linear regression
Sample	All patents, four year window from patent grant date	All patents, four year window from patent grant date	All patents, four year window from patent grant date	All patents, four year window from patent grant date	Photonics patents, four year window from patent grant date	All patents, full window from patent grant date	All patents, full window from patent grant date	All patents, full window from patent grant date
Variables	Ln(1 + self-forward citations)	Ln(1 + self-forward citations)	Ln(1 + self-forward citations)	Ln(1 + self-forward citations)	Ln(1 + self-forward citations)	Ln(1 + self-forward citations)	Ln(1 + external forward citations)	Ln(1 + total forward citations)
Ln(number of claims)		0.014*** (0.002)		0.014*** (0.002)	0.012*** (0.003)	0.020*** (0.002)	−0.004*** (0.001)	0.126*** (0.004)
Ln(number of classes)			−0.019*** (0.004)	−0.020*** (0.004)	−0.015*** (0.005)	−0.017*** (0.004)	0.015*** (0.002)	0.111*** (0.007)
Ln(1 + firm scientific knowledge)	−0.530*** (0.088)	−0.540*** (0.088)	−0.528*** (0.088)	−0.537*** (0.088)	−0.683*** (0.114)	−0.689*** (0.096)	0.131*** (0.046)	−0.279* (0.146)
Ln(1 + firm rel. inv. experience)	0.300*** (0.021)	0.298*** (0.021)	0.294*** (0.021)	0.293*** (0.021)	0.252*** (0.027)	0.336*** (0.022)	−0.151*** (0.012)	0.111*** (0.037)
Ln(1 + firm knowledge stock)	−0.063*** (0.010)	−0.065*** (0.010)	−0.063*** (0.010)	−0.065*** (0.010)	−0.050*** (0.013)	−0.056*** (0.011)	0.029*** (0.005)	−0.098*** (0.017)
Ln(1 + technological novelty)	0.039*** (0.013)	0.040*** (0.013)	0.039*** (0.013)	0.040*** (0.013)	0.052*** (0.017)	0.031** (0.014)	−0.021*** (0.008)	−0.075*** (0.024)
Ln(firm size)	0.007*** (0.002)	0.007*** (0.002)	0.007*** (0.002)	0.007*** (0.002)	0.004 (0.003)	0.005** (0.002)	−0.006*** (0.001)	−0.011*** (0.004)
Ln(firm age)	0.059 (0.040)	0.061 (0.040)	0.059 (0.040)	0.060 (0.040)	−0.006 (0.061)	0.004 (0.044)	−0.034 (0.024)	−0.198*** (0.072)
Ln(1 + firm knowledge leverage)	−1.239*** (0.147)	−1.230*** (0.147)	−1.237*** (0.147)	−1.227*** (0.147)	−1.560*** (0.208)	−1.387*** (0.157)	0.257*** (0.087)	−1.509*** (0.247)
Ln(1 + total forward citations)	0.257*** (0.002)	0.256*** (0.002)	0.258*** (0.002)	0.256*** (0.002)	0.218*** (0.003)	0.280*** (0.003)	0.932*** (0.001)	
Firm fixed effects	Included	Included	Included	Included	Included	Included	Included	Included
Subfield fixed effects	Included	Included	Included	Included	Included	Included	Included	Included
Technology life cycle fixed effects	Included	Included	Included	Included	Included	Included	Included	Included
Constant	−0.198 (0.169)	−0.390** (0.162)	−0.354** (0.162)	−0.385** (0.162)	0.000 (0.241)	−0.417** (0.180)	0.178** (0.090)	1.526*** (0.274)
Observations	88,528	88,528	88,528	88,528	51,156	88,528	88,528	88,528
R-squared	0.370	0.371	0.370	0.371	0.327	0.382	0.934	0.347

[a] Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

because many patents receive zero self-citations, in the linear regression models I used a log-transformed measure of the dependent variable plus 1. To control for the robustness of the results against the use of this transformation, I replicated the analyses using two additional models. First, I considered the count of self-forward citations as the dependent variable in a Negative Binomial regression model with robust standard errors (reported in Table 5, Model 5.1). Second, in Model 5.2, I considered the proportion of self-forward citations to the total number of forward citations received by the patent as an alternative dependent variable, and estimated the results using a fractional logit regression model (Papke and Wooldridge, 1996). The results of all these alternative specifications support the results reported in Table 4.

4.2. *Scientific knowledge, related inventive experience and patent scope*

Table 6 reports the estimation results of the models in which the number of claims in the patent is a function of firm scientific knowledge and related inventive experience (and other control variables). Specifically, Model 6.1 includes the control variables only, and Models 6.2, 6.3 and 6.4 add the independent variables sequentially. The estimates in the full model (6.4) suggest that both scientific knowledge and related inventive experience are positively associated with the number of claims included in the patent ($\beta = 0.663$, $p < 0.01$; $\beta = 0.065$, $p < 0.05$, respectively), supporting Hypotheses 2a and 3a. Hence, at the sample mean of both the dependent and the independent variables, an increase of one standard deviation in the level of the firm's scientific knowledge is associated with an increase of 3.8% in the number of patent claims, while an increase of one standard deviation in the level of related inventive experience is associated with an increase of 0.90% in the number of claims in a patent.

Table 7 reports the results of the model specifications in which the number of patent classes are estimated as a function of firm scientific knowledge and related inventive experience. Model 7.1 reports the control variables only and models 7.2, 7.3 and 7.4 add the independent variables sequentially. The coefficients in the full model (7.4) show that the number of patent classes is positively associated with scientific knowledge ($\beta = 0.155$, $p < 0.05$), but negatively associated with related inventive experience ($\beta = -0.271$, $p < 0.01$), results which support Hypotheses 2b and 3b. The estimates imply that, at the sample mean of both the dependent and independent variables, an increase of one standard deviation in the level of scientific knowledge is associated with an increase in the number of classes of 0.89% compared to the average value. In contrast, an increase of one standard deviation in the level of related inventive experience at the mean value of the sample is associated with a decrease of 3.75% in the number of classes in a patent, compared to the average value. Once again, these effects are calculated at the level of the individual patent, and so might be more relevant for firms that hold large patents portfolios.

Table 5
Negative binomial and fractional logit regression estimates of patents' self-forward citations.[a]

Sample Variables	5.1 Negative binomial regression All patents, four year window from patent grant date Self-forward citations	5.2 Fractional logit regression All patents, full window from patent grant date Proportion of self-forward citations to total forward citations
Ln(number of claims)	0.043***	0.043***
	(0.010)	(0.013)
Ln(number of classes)	−0.081***	−0.132***
	(0.017)	(0.022)
Ln(1 + firm scientific knowledge)	−1.030***	−1.191**
	(0.349)	(0.469)
Ln(1 + firm rel. inv. experience)	1.291***	1.520***
	(0.089)	(0.120)
Ln(1 + firm knowledge stock)	−0.349***	−0.411***
	(0.037)	(0.050)
Ln(1 + technological novelty)	0.207***	0.151**
	(0.054)	(0.074)
Ln(firm size)	0.051***	0.053***
	(0.008)	(0.010)
Ln(firm age)	0.382***	0.689***
	(0.142)	(0.206)
Ln(1 + firm knowledge leverage)	0.059	−0.706
	(0.480)	(0.687)
Ln(1 + total forward citations)	1.288***	
	(0.008)	
Firm fixed effects	Included	Included
Subfield fixed effects	Included	Included
Time fixed effects[b]	Included	Included
Technology fixed effects[b]	Included	Included
Constant	−5.240***	−3.226***
	(0.897)	(1.033)
Observations	88,528	66,687
Log likelihood	−64,950.284	−20,259.79781

[a] Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
[b] These models did not converge when the technology lifecycle fixed effects were included. Hence, to control for time- and technology-class level unobserved heterogeneity these models include time- and technology class-fixed effects (specified at the three-digit US classification level).

To test the robustness of these results, I replicated the analyses described in Tables 6 and 7 on a subsample of patents in photonics technological classes (see note 4) in models 6.5 and 7.5, respectively. In models 6.6 and 7.6, respectively, I replicate the analyses using the alternative measures for the core independent variables. The robustness of these results should also be evaluated against possible alternative explanations. One such explanation is that firms' knowledge bases and patenting behaviors might be characterized by patterns specific to certain technological classes, and not related to the mechanisms outlined in the hypotheses. However, the use of both firm and technological life cycle fixed effects in the analyses mitigates this risk. A second potential alternative explanation is that firms that have unrelated experience include 'unrelated' knowledge inputs in their patents' claims – material that is only loosely connected to the invention – and so they are eventually assigned to more different technological classifications. However, this alternate explanation was ruled out by the interviews conducted with the patent attorneys, who explained that, while inventors have the incentive to increase the number of claims in their patent applications, if the claims did not reflect 'meaningful' variations to the invention, they would be rejected by the patent examiners, delaying the overall patenting process and hence generating substantial losses for those inventors.

5. Discussion and conclusions

5.1. Core findings, previous research and implications for future research

This paper makes four contributions to the literature on patent scope. First, while most of the prior literature in this area has focused on the changes to the size of the inventive area covered by the patent rights determined by patent policy (e.g. Cohen and Lemley, 2001; Denicolo', 1996; Gilbert and Shapiro, 1990; Green and Scotchmer, 1995; Kitch, 1977; Klemperer, 1990; Merges and Nelson, 1990, 1994; Scotchmer, 1991), this paper suggests that the scope of patents also depends on firms' ability to identify a higher number of variations to their inventions that they can include in their patent claims. From a policy standpoint, this consideration implies that changes in the level of the regulator's leniency in the examination of inventions will not have the same impact for all inventing firms, as prior research has assumed. For instance, firms with low ability to identify variations to their inventions will not benefit much if the regulator applied greater tolerance in accepting patent claims. In contrast, a reduction in the regulator's leniency would penalize firms with greater ability to identify variations to their inventions more than firms with lesser ability to do so. It would be interesting for future research to investigate how this may affect the expected levels of social welfare.

Second, this paper shows that the extent to which the inventive firm itself builds on the knowledge underlying its patents is lower when its claims span across multiple technological classes. This allows us to better qualify the fundamental assumption of the existing literature – that broader scope is associated with a greater protection for the inventing firm (e.g. Gilbert and Shapiro, 1990; Kitch, 1977; Klemperer, 1990). Identifying claims falling across multiple classes might not necessarily provide the inventing firm with an advantage, as it might lead it to reveal connections of the inventive idea across a broader set of domains, while finding that it lacked the complementary capabilities, resources or the span of attention to pursue all those opportunities itself.

Table 6
Linear regression estimate of patents' claims.[a]

	6.1 Linear regression All patents Ln(number of claims)	6.2 Linear regression All patents Ln(number of claims)	6.3 Linear regression All patents Ln(number of claims)	6.4 Linear regression All patents Ln(number of claims)	6.5 Linear regression Photonics patents Ln(number of claims)	6.6 Linear regression All patents Ln(number of claims)
Ln(1 + firm scientific knowledge)		0.659*** (0.137)		0.663*** (0.137)	0.552*** (0.170)	
Ln(1 + firm related inventive experience)			0.063* (0.033)	0.065** (0.033)	0.210*** (0.044)	
Ln(1 + firm scientific knowledge, alternative measure)						0.100*** (0.012)
Ln(1 + firm related inventive, alternative measure)						0.011*** (0.003)
Ln(1 + firm knowledge stock)	0.169*** (0.015)	0.162*** (0.015)	0.168*** (0.015)	0.161*** (0.015)	0.208*** (0.020)	0.066*** (0.019)
Ln(1 + technological novelty)	−0.056*** (0.021)	−0.056*** (0.021)	−0.056*** (0.021)	−0.056*** (0.021)	−0.084*** (0.027)	−0.057*** (0.021)
Ln(firm size)	−0.011*** (0.003)	−0.012*** (0.003)	−0.011*** (0.003)	−0.012*** (0.003)	−0.008* (0.004)	−0.015*** (0.003)
Ln(firm age)	−0.102 (0.069)	−0.098 (0.069)	−0.100 (0.069)	−0.095 (0.069)	−0.130 (0.098)	−0.071 (0.069)
Ln(1 + firm knowledge leverage)	−0.983*** (0.212)	−0.794*** (0.216)	−0.992*** (0.212)	−0.802*** (0.217)	−1.434*** (0.290)	−0.589*** (0.218)
Firm fixed effects	Included	Included	Included	Included	Included	Included
Subfield fixed effects	Included	Included	Included	Included	Included	Included
Technology life cycle fixed effects	Included	Included	Included	Included	Included	Included
Constant	2.388*** (0.272)	2.382*** (0.272)	2.373*** (0.272)	2.367*** (0.273)	2.119*** (0.382)	2.572*** (0.273)
Observations	88,528	88,528	88,528	88,528	51,156	88,528
R-squared	0.163	0.164	0.163	0.164	0.148	0.164

[a] Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 7
Linear regression estimates of patents' classes.[a]

	7.1 Linear regression All patents Ln(number of classes)	7.2 Linear regression All patents Ln(number of classes)	7.3 Linear regression All patents Ln(number of classes)	7.4 Linear regression All patents Ln(number of classes)	7.5 Linear regression Photonics patents Ln(number of classes)	7.6 Linear regression All patents Ln(number of classes)
Ln(1 + firm scientific knowledge)		0.172** (0.078)		0.155** (0.078)	0.223** (0.092)	
Ln(1 + firm related inventive experience)			−0.272*** (0.019)	−0.271*** (0.019)	−0.238*** (0.025)	
Ln(1 + firm scientific knowledge, alternative measure)						0.018*** (0.007)
Ln(1 + firm related inventive, alternative measure)						−0.034*** (0.002)
Ln(1 + firm knowledge stock)	0.002 (0.008)	−0.000 (0.009)	0.003 (0.008)	0.002 (0.009)	0.005 (0.010)	0.014 (0.011)
Ln(1 + technological novelty)	−0.029** (0.012)	−0.028** (0.012)	−0.027** (0.012)	−0.027** (0.012)	−0.005 (0.015)	−0.024** (0.012)
Ln(firm size)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	0.001 (0.003)	0.000 (0.002)
Ln(firm age)	−0.020 (0.040)	−0.018 (0.040)	−0.030 (0.040)	−0.029 (0.040)	−0.054 (0.055)	−0.021 (0.040)
Ln(1 + firm knowledge leverage)	0.012 (0.128)	0.061 (0.130)	0.050 (0.127)	0.095 (0.130)	0.281* (0.164)	0.083 (0.131)
Firm fixed effects	Included	Included	Included	Included	Included	Included
Subfield fixed effects	Included	Included	Included	Included	Included	Included
Technology life cycle fixed effects	Included	Included	Included	Included	Included	Included
Constant	0.285* (0.168)	0.284* (0.168)	0.349** (0.169)	0.347** (0.169)	0.928*** (0.211)	0.264 (0.168)
Observations	88,528	88,528	88,528	88,528	51,156	88,528
R-squared	0.205	0.205	0.207	0.207	0.170	0.208

[a] Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Third, this paper investigates the antecedents of patent scope, thus complementing prior research which has largely focused on its implications (e.g. Dechenaux et al., 2008; Gambardella and Giarratana, 2013; Lanjouw and Schankerman, 1997; Lerner, 1994; Shane, 2001). It suggests that firms' incentives to invest in some factors – such as scientific knowledge – that strengthen the protection provided by the patent by increasing the number of patent claims may be mixed, because such investments also increase the chances that those claims span multiple domains, an outcome that might increase knowledge spill-overs to other firms. Nevertheless, some firms might still be willing to develop patents spanning multiple domains, as it must be recognized that inventions by other firms that build on a focal firm's knowledge might not always constitute a bad outcome for the focal firm. For instance, Belenzon (2012) suggests that firms are sometimes able to reabsorb their spilled knowledge in subsequent periods, together with knowledge about the developments made by external inventors: this can act as a mechanism to help them escape the no-growth trap and achieve long term returns. In addition, inventions spawned by others might complement the original invention (Ahuja et al., 2013; Walsh et al., 2003).

Finally, this paper provides a new reflection on the operationalization of the construct of patent scope. While prior research in this area has used both patent claims and patent classes as alternative measures of patent scope (e.g. Lanjouw and Schankerman, 1997, 2004; Lerner, 1994; Merges and Nelson, 1994; Shane, 2001), this study suggests that, rather, they reflect different dimensions. Claims reflect the number of variations identified to an initial core invention; classes reflect the extent to which these variations are spread out in the technological space. The results of this study shed new light on the interpretation of previous empirical results that have used the number of technological classes in which the patent claims are classified as a measure of patent scope. For example, prior studies show that broader patent scope (measured as the number of IPC classes) is associated with a higher likelihood that a licensed invention will be commercialized as a product (Dechenaux et al., 2008), or by the establishment of a new firm (Shane, 2001). Along the same line of reasoning, Nerkar and Shane's (2003) results show that start-ups that have their patents classified in a higher number of classes are less likely to fail, although this effect is reduced in more concentrated industries, where the possession of marketing and manufacturing agreements are relatively more important to firm's survival. In a similar vein, Lerner (1994) predicts and shows that broader scope is positively associated with the valuations placed on firms during the venture capital investment process. On the contrary, Harhoff et al. (2003) investigate the relationship between the number of IPC classes in which a patent is classified and the patent's value, measured through a self-assessed measure ('how much did the patent contribute to the future profitability of the enterprise'), and find that the relationship between these two variables is consistently insignificant across all specifications.

These prior studies have built on the theoretical intuition that patents with broader scope should enjoy stronger protection against the risk of imitation. However, the results from this paper emphasize that, holding constant the number of claims, when the scope of patents spans multiple classes, firms' ability to build on them compared to other firms is lower; this might potentially even reduce the likelihood of the focal firm successfully commercializing the invention, in that other firms might have superior ability to build on that invention relative to the focal firm. Further, follow-up inventions may potentially be substitutes to the original ones: at the invention level, this might reduce the incentive to engage in the commercialization of the invention, while at the firm level, this might increase the hazard of firm failure.

Re-examining prior empirical research results by taking these considerations into account opens up many possible research avenues. Despite the value of these contributions in advancing our understanding of the role of patent scope at the invention and firm levels, the operationalizations employed by prior research have two main limitations. First, they do not consider that – holding the number of classes in which a patent is classified constant – the number of patent claims can vary. Second, in measuring the number of patent classes, prior studies have mostly used the IPC classification, which considers the complete technological information contained in the patent documentation (Gruber et al., 2013; USPTO, 2014b), rather than only the information contained in the patent claims, and so does not distinguish between patents that are classified in multiple classes because they build on diverse knowledge inputs (e.g. patents with higher technological diversity, as in Guellec and van Pottelsberghe de la Potterie, 2000, 2002), and ones that generate new knowledge that refers to different domains (i.e. closer to the theoretical definitions of patent scope).

Once we recognize this more nuanced picture, additional mechanisms emerge to explain the positive associations found by prior studies, beyond those to which past research has attributed the relationships. For instance, having patents classified in a higher number of classes may be associated with higher chances of a start-up surviving because it might be indicative of the fact that it has been able to develop a technology that is potentially applicable in more domains, which may be particularly helpful in the event that the original idea does not succeed (e.g. Gruber et al., 2008). A firm' ability to signal the broader applicability of its technology in the patent document itself might even yield a premium to its valuation by venture capitalists, who typically assess firm potential.

Similarly, in interpreting the insignificance of their results, Harhoff et al. (2003) provide a set of possible explanations such as the single- versus multi-industry approach or the potential difference between the US and German Patent Offices. In addition to those explanations, the evidence in the present paper suggests that the two dimensions of scope (i.e. patent claims and patent classes) might not co-vary perfectly; hence, distinguishing between them could lead to qualitatively different conclusions about the effect of patent scope on patent value. If patents classified into more classes were distributed between those that had many claims per class and others that had relatively few claims per class in the sample observed by Harhoff et al. (2003), one could observe a non-significant effect of more classes on patent value as they indeed found. The former group of patents would contribute to private value (the outcome that Harhoff et al. (2003) examined), but the latter would not. While the authors acknowledge the lack of patent claims among the controls as a limitation, the results from my study suggest that adding a control for patent claims might clarify our understanding of this relationship substantially.

5.2. Limitations

Finally, I acknowledge that there are some limitations to the study. First, the empirical test is based on a sample of patents developed by firms operating in the photonics industry. Although photonics shares many features with other high-tech industries, and the sample selected presents variety in the characteristics of the firms it includes, it would be interesting for future research to verify the consistency of these results across different settings. Second, in investigating the implications of patent scope, this paper focuses only on one performance dimension, i.e. a firm's ability in building on the knowledge underlying its patent. It would be interesting for future research to investigate other dimensions of firm performance more closely, making a distinction between the two dimensions of patents scope identified in this paper. A first step in this direction has been made by research that has investigated the relationship between patent scope and patent litigations. Within this stream, Lerner (1994) finds that the number of classes into which a patent is classified increases the chance that the patent is litigated, when the number of patent claims is not included as a control variable. Lanjouw and Schankerman (1997) estimate the probability of litigation as a function of the number of classes and the number of claims and, while they find that litigated patents have higher numbers of claims, they do not find a positive association between the number of patent classes and the probability of litigation. This suggests that considering the distinction between patent claims and patent classes in determining the strength of patent protection might lead to a better understanding of the results prior research has obtained in this area.

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