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An examination of the antecedents and implications of patent scope

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a r t i c l e i n f o

a b s t r a c t

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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);](#_bookmark82) 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.

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**1. Introduction**

solving the problem” ([Merges and Nelson, 1994,](#_bookmark82) 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](#_bookmark82) [and](#_bookmark82) [Nelson,](#_bookmark82) [1994;](#_bookmark82) [Walker,](#_bookmark82) [1995).](#_bookmark82) 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](#_bookmark0) can specify that the magnetic particles can have a diameter ranging from about 1 nm to about 10 µm.[2](#_bookmark1)

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

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 occu- pies 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 inven- tion positioned in that area of the inventive space in exchange for its eventual public disclosure ([Gilbert and Shapiro, 1990; USPTO,](#_bookmark48) [2014a).](#_bookmark48) The possession of this right (at least in principle) can allow an inventor to appropriate the beneﬁts generated from their inven- tion ([Kitch, 1977).](#_bookmark67) However, it would have limited value if it did not protect the inventor against mere variations to the original idea (e.g., [Scotchmer, 1991).](#_bookmark81) The patent system addresses this con- cern by allowing inventors to specify the patent’s ‘full scope’ ([Kitch,](#_bookmark67) [1977; Lanjouw and Schankerman, 1997; Levin et al., 1987; Merges](#_bookmark67) [and Nelson, 1994; Walker, 1995).](#_bookmark67)

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

1 This example is a simpliﬁcation based on an existing patent in the ﬁeld of pho-

tonics.

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 com- ponents, 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,](#_bookmark76) [2010;](#_bookmark76) [Walker,](#_bookmark76) [1995),](#_bookmark76) 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).](#_bookmark87) 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).](#_bookmark37)

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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 inven- tion 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 applica- tion 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).](#_bookmark88)

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);](#_bookmark82) 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);](#_bookmark57) 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 identiﬁca- tion of a greater number of patent claims, and what determines the positioning of such claims across a greater number of tech- nological 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)](#_bookmark38) and on analogical processes (e.g. [Gavetti et al., 2005; Gick and Holyoak,](#_bookmark44) [1980; Hofstadter, 2001),](#_bookmark44) and identify ﬁrms’ prior investments in scientiﬁc knowledge and in related inventive experience as two factors affecting patent scope. The theoretical predictions elabo- rated 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](#_bookmark3) I explore the concept of patent scope, its implications and antecedents. In Sections [3 and 4,](#_bookmark9) I describe the empirical setting, data, econometric speciﬁcations, estimation results, and in Section [5 I](#_bookmark25) discuss the paper’s contribution, implications for future research and limitations.

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).](#_bookmark81) 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;](#_bookmark39) [Merges](#_bookmark39) [and](#_bookmark39) [Nelson,](#_bookmark39) [1990,](#_bookmark39) [1994;](#_bookmark39) [Scotchmer,](#_bookmark39) [1991).](#_bookmark39) 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 mea- sured as the number of technological classes in which its claims are classiﬁed (e.g. [Lerner, 1994; Nerkar and Shane, 2003; Shane, 2001),](#_bookmark74) 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,](#_bookmark72) [1997).](#_bookmark72) 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 operationaliza- tion should take both dimensions into account. [Table 1](#_bookmark4) 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](#_bookmark53) [et al.,](#_bookmark53) [2013;](#_bookmark53) [Green](#_bookmark53) [and](#_bookmark53) [Scotchmer,](#_bookmark53) [1995;](#_bookmark53) [Hall](#_bookmark53) [et al., 2005; Kitch, 1977; Merges and Nelson, 1994; O’Donoghue,](#_bookmark53) [1998; Scotchmer, 1991).](#_bookmark53) Existing research has identiﬁed an associ- ation between patents’ scope and the subsequent inventive activity that builds on them, as measured by the number of ‘forward cita- tions’ the patent receives (e.g. [Lerner, 1994).](#_bookmark74) 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., ‘exter- nal’ citations). While self-citations reﬂect the ﬁrm’s internalization of the knowledge underlying its own inventions ([Belenzon, 2012;](#_bookmark63) [Hall et al., 2005; Trajtenberg, 2002),](#_bookmark63) 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 knowl-

edge 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).](#_bookmark58) A higher number of claims should act as a deterrent to other ﬁrms from building on the knowledge underlying the patent, as it cor- responds to an increased probability that a new invention in that area might infringe at least one of the patent’s claims ([Kitch, 1977;](#_bookmark67) [Merges and Nelson, 1994; Scotchmer, 1991).](#_bookmark67) It might also reﬂect

**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 gener- ally 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’,](#_bookmark39) [1996;](#_bookmark39) [Gilbert](#_bookmark39) [and](#_bookmark39) [Shapiro,](#_bookmark39) [1990;](#_bookmark39) [Green](#_bookmark39) [and](#_bookmark39) [Scotchmer,](#_bookmark39) [1995;](#_bookmark39) [Klemperer, 1990; Matutes et al., 1996; Merges and Nelson, 1990,](#_bookmark39) [1994; Scotchmer, 1991).](#_bookmark39) 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 specify- ing in the patent claims all the possible variations to the invention that the regulator is likely to permit. This requires assuming that

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**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)](#_bookmark69)

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

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. 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)

*Theoretical*

[Gilbert and Shapiro](#_bookmark48) [(1990)](#_bookmark48)

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

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 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

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

*Theoretical*

[Denicolo’ (1996)](#_bookmark39)

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

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

*Theoretical*

[Kitch (1977)](#_bookmark67)

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

*Theoretical*

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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),](#_bookmark81) [Green and](#_bookmark49) [Scotchmer](#_bookmark49) [(1995)](#_bookmark49)

Patent breadth: “Leniency of the courts in interpreting the novelty requirement of patents” ([Matutes et al., 1996,](#_bookmark80)

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)](#_bookmark49)

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

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

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 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

*Theoretical*

[Merges and Nelson](#_bookmark81) [(1990, 1994),](#_bookmark81)

[Cohen and](#_bookmark77) [Lemley (2001)](#_bookmark77)

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

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;](#_bookmark82) 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),](#_bookmark77) 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

*Theoretical*

[Matutes et al.](#_bookmark80) [(1996)](#_bookmark80)

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

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

*Theoretical*

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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)](#_bookmark74)

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

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

Broader patent scope (patent classes) is associated with greater numbers of external forward citations; greater probability of litigation; higher market valuation of the ﬁrm

*Empirical*

[Lanjouw and](#_bookmark72) [Schankerman](#_bookmark72) [(1997)](#_bookmark72)

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

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

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

*Empirical*

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);](#_bookmark82) 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),](#_bookmark77) [Green and Scotchmer (1995),](#_bookmark49) [Kitch (1977),](#_bookmark67) [Matutes et al.](#_bookmark80) [(1996),](#_bookmark80) [Merges and Nelson](#_bookmark81) [(1990, 1994); Scotchmer](#_bookmark81)

[(1991)](#_bookmark81) 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)

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the inventing ﬁrm’s strategic intention itself to reduce the likeli- hood 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 pur- sue developments of its invention across all potential domains (e.g. [Chang,](#_bookmark75) [1995;](#_bookmark75) [Merges](#_bookmark75) [and](#_bookmark75) [Nelson,](#_bookmark75) [1994;](#_bookmark75) [Penrose,](#_bookmark75) [1959;](#_bookmark75) [Peteraf,](#_bookmark75) [1993).](#_bookmark75) 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)](#_bookmark89) and the less credible it can be that it will do so ([Caves, 1984; Lieberman](#_bookmark73) [and](#_bookmark73) [Montgomery,](#_bookmark73) [1988).](#_bookmark73) 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.,](#_bookmark43) [2007; Gans et al., 2008).](#_bookmark43) 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.

contextualized to any speciﬁc application setting in their original conception, being derived directly from abstract principles ([Arora](#_bookmark61) [and Gambardella, 1994b).](#_bookmark61)

The conceptualization of technological problems in abstract terms fostered by science facilitates the navigation of the techno- logical 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](#_bookmark38) [and](#_bookmark38) [Sorenson, 2004),](#_bookmark38) 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,](#_bookmark38) p. 912), allowing alternative prob- lems and solutions to be evaluated via an ‘ofﬂine’ search process ([Gavetti and Levinthal, 2000; Lippman and McCall, 1976; Nelson,](#_bookmark45) [1959).](#_bookmark45) 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 elec- trons can be trapped in the energy gaps of a lattice ([Benabid, 2006;](#_bookmark64) [Russell, 2003).](#_bookmark64) Because scientiﬁc knowledge improves ﬁrms’ ability to comprehend, assimilate and recombine knowledge from more distant domains ([Gambardella, 1995; Gruber et al., 2013),](#_bookmark40) the dis- tance 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. The antecedents of patent scope: scientiﬁc knowledge and related inventive experience*

Although many applications of an invention may only emerge over time ([Cattani,](#_bookmark68) [2005;](#_bookmark68) [Rosenberg,](#_bookmark68) [1998),](#_bookmark68) inventing ﬁrms are incentivized to try to identify as many of these variations as possi- ble to increase their pre-emptive advantage over their competitors ([Aljalian,](#_bookmark55) [2005;](#_bookmark55) [Ceccagnoli,](#_bookmark55) [2009;](#_bookmark55) [Chiang,](#_bookmark55) [2010).](#_bookmark55)[3](#_bookmark8) This implies thinking beyond the particular manifestation of its idea that the inventing ﬁrm has currently conceived ([Kitch, 1977; Merges and](#_bookmark67) [Nelson, 1994).](#_bookmark67) Hence, I build on the assumption that the identiﬁ- cation 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 fac- tors 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.

*2.3.2. Related inventive experience and patent scope*

Firms can also develop general knowledge schemes from their actual engagement with concrete experiences ([Arora](#_bookmark59) [and](#_bookmark59) [Gambardella,](#_bookmark59) [1994a;](#_bookmark59) [Cattani,](#_bookmark59) [2005;](#_bookmark59) [Fosfuri](#_bookmark59) [and](#_bookmark59) [Tribo’,](#_bookmark59) [2008;](#_bookmark59) [Gavetti et al., 2005; Hofstadter, 2001; Levinthal and March, 1993;](#_bookmark59) [Levinthal, 1995).](#_bookmark59) When similar problems are encountered several times, ﬁrms are likely to derive general schemas for understand- ing and solving problems of that nature, which are then stored in their knowledge bases ([Gick and Holyoak, 1980; Hofstadter, 2001).](#_bookmark47) 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,](#_bookmark44) [2001; Holyoak and Thagard, 1989).](#_bookmark44)

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](#_bookmark46) [and](#_bookmark46) [Landers,](#_bookmark46) [1985;](#_bookmark46) [Gick and Holyoak, 1980; Holyoak and Thagard, 1989),](#_bookmark46) as well as the repertoire of potential solutions for that problem (e.g. [Cattani,](#_bookmark68) [2005;](#_bookmark68) [Helfat](#_bookmark68) [and](#_bookmark68) [Lieberman,](#_bookmark68) [2002).](#_bookmark68) For instance, Corning’s prior inventive experience in lasers, glass manufacturing and integrated circuits helped the company identify speciﬁc solutions to develop- ing the ﬁrst optical ﬁbers ([Cattani,](#_bookmark70) [2006).](#_bookmark70) 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 experi- ence, 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

*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,](#_bookmark85) [1994;](#_bookmark85) [Narin](#_bookmark85) [et al.,](#_bookmark85) [1997;](#_bookmark85) [Fleming](#_bookmark85) [and](#_bookmark85) [Sorenson,](#_bookmark85) [2004).](#_bookmark85) I suggest it can also lead to the development of a broader scope for patents by facili- tating 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,](#_bookmark59) [1990),](#_bookmark59) and greater familiarity with these general principles facil- itates the abstraction of new technological problems ([Bresnahan](#_bookmark65) [and Gambardella, 1998).](#_bookmark65) Second, using scientiﬁc knowledge in the invention process increases the likelihood that inventions are less

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 quan- titative 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.

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between the possible responses identiﬁed in the ﬁrst place. Sec- ond, more experience in certain domains might create a form of “cognitive myopia” toward more distant domains ([Cohen](#_bookmark36) [and](#_bookmark36) [Levinthal, 1990, 1994; Levinthal and March, 1993; March, 1988).](#_bookmark36) 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](#_bookmark62) [Simon, 1972).](#_bookmark62)

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](#_bookmark79) [March, 1993).](#_bookmark79) Hence, the greater the level of related inventive expe- rience 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 expe- rience, the lower the number of technological classes its patent claims will be classiﬁed in.

period (1993–2002). To deﬁne photonics and its boundaries I relied on an industry directory (*The Photonics Directory*, by Laurin Pub- lishing), 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 pri- vate 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. Empirical context, methods and measures**

*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 dimen- sions 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 operational- ized the ﬁrst dimension as the number of claims in the patent (i.e. [Lanjouw and Schankerman, 1997; Merges and Nelson, 1994;](#_bookmark72) [Walker, 1995),](#_bookmark72) 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,](#_bookmark88) [2014b).](#_bookmark88) I computed this measure using the USPTO patent classi- ﬁcation, which provides two beneﬁts relative to the International Patent Classiﬁcation (IPC). First, it only classiﬁes patents accord- ing to their claims – rather than considering the complete patent documentation ([Gruber](#_bookmark50) [et al.,](#_bookmark50) [2013;](#_bookmark50) [USPTO,](#_bookmark50) [2014b)](#_bookmark50) – and, sec- ond, it emphasizes an invention’s technical focus as opposed to its industrial uses ([Lerner,](#_bookmark74) [1994;](#_bookmark74) [USPTO,](#_bookmark74) [2014b).](#_bookmark74) 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.

*3.1. Photonics*

The empirical analysis is conducted on ﬁrms active in the photonics arena. Photonics is the technology of generating and har- nessing light and other forms of radiant energy whose quantum unit is the photon ([The Photonics Directory, 2014).](#_bookmark84) The word ‘pho- tonics’ 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 informa- tion processing. The broad span of photonics’ applications ranges from energy generation to detection, communications and infor- mation 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 knowl- edge bases are used within the ﬁeld, including chemicals, material science, astronomy, optics and electronics. The photonics indus- try 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 analy- sis, imaging. During the period covered by the current study the ﬁeld was known for its level of innovation ([Stuck, 1998; Teich and](#_bookmark82) [Saleh,](#_bookmark82) [1991).](#_bookmark82) Patenting inventions is a common practice in pho- tonics ([Fearnside, 2007)](#_bookmark41) and the question of the scope of patents is particularly meaningful in this ﬁeld, where the level of standard- ization 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.

*3.3.2. 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](#_bookmark57) [et al.,](#_bookmark57) [2005).](#_bookmark57) As forward citations are subject to trun- cation 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

*3.2. Sample and data*

*t* − 5 to *t* − 1 (where *t* is the year of the focal patent application)

To test the hypotheses, I built a longitudinal data set contain- ing information about a sample of photonics ﬁrms over a ten-year

as indirect indicators of the characteristics of its knowledge base in the years before that application (e.g. [Ahuja](#_bookmark51) [and](#_bookmark51) [Katila,](#_bookmark51) [2001;](#_bookmark51)

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[Argote, 1999; Jaffe and Trajtenberg, 2002).](#_bookmark51) The construct of *scien- tiﬁc knowledge* refers to the inﬂuence of science in the invention process. Previous studies have emphasized that references to sci- entiﬁc articles provide a reasonable indicator of the inﬂuence of science on the inventive process ([Brusoni et al., 2005; Fleming and](#_bookmark66) [Sorenson, 2004; Narin et al., 1997; Tijssen, 2001).](#_bookmark66) 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 num- ber 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)](#_bookmark71) 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 classiﬁ- cation developed by [Hall et al. (2001),](#_bookmark56) who reclassiﬁed the main USPTO three-digit patent classes into a set of two-digit technologi- cal 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*.

[Table 2](#_bookmark11) shows the variables and descriptive statistics, and [Table 3](#_bookmark12) 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,](#_bookmark5) where I estimate the number of self-citations received by a patent as a function of the *number of claims*, the *num- ber of classes*, a set of control variables (ﬁrm *scientiﬁc knowledge*, ﬁrm *related inventive experience*, ﬁrm *knowledge stock*, *technologi- cal 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](#_bookmark6) 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 *scientiﬁcknowledge*, 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](#_bookmark15) 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 (*ˇ* = 0.014; *p* < 0.01), but is nega- tively associated with the number of patent classes it is assigned

*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 num- ber 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 *knowledgeleverage*, i.e. the proportion of self-citations over the total number of backward citations appearing in the ﬁrm’s patents dur-

to (*ˇ* = −0.020; *p* < 0.01): these results support [Hypothesis 1.](#_bookmark5) 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 indi- vidual patent level, and so may have greater economic signiﬁcance for ﬁrms holding large portfolios of patents. In addition, it is impor- tant 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 alter- native models. First, in Model 4.5, I replicated the same analyses on a subsample of patents in photonics technological classes only.[4](#_bookmark10)

ing years *t* − 1 to *t* − 5 (adapted to the context of this study from the

leverage measure used by [Cattani, 2005).](#_bookmark68) I included controls for the novelty of the technology, as the exploration of novel technolog- ical 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,](#_bookmark54) [2000).](#_bookmark54) 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 character- ized 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](#_bookmark90) [and](#_bookmark90) [Sobrero,](#_bookmark90) [2008).](#_bookmark90) I also included *technology life cycle* ﬁxed effects for each technological domain.

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 patent- ing 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 indus- try. I referred to the non-consolidated sample of corporate entities directly active in

Each *technology life cycle* ﬁxed effect equals 1 if the patent appli-

*ij*

cation year equals *i* and the technology class of the patent equals *j*, (with *i* = 1*. . .I*, and *j* = 1*. . .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.

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**Table 2**

Descriptive statistics.

Description

Obs

Mean

S.D.

Min

Max

*Patent scope* Number of claims Number of classes

Patent level. Number of claims in the patent Patent level. Number of unique technological classes in which the claims of the patent are classiﬁed

88,528

88,528

15.516

1.577

11.881

0.831

1.000

1.000

318.000

10.000

*Antecedents*

Firm scientiﬁc knowledge (from *t* − 5 to *t* − 1)

Firm-year level. Number of patents applied by

88,528

0.077

0.062

0.000

1.000

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

Firm related inventive

Firm-year-technology level. Number of patents

88,528

0.141

0.158

0.000

1.000

experience (from *t* − 5 to

in technological classes related to the one of the focal patent applied by the ﬁrm in years

*t* − 1)

from *t* − 5 to *t* − 1 over the total number of

patents applied by the ﬁrm in years from *t* − 5

to *t* − 1

Patent level. Number of self-citations received by the patent from *t* (time of the patent grant) to *t* + 4

Patent level. Number of total forward citations received by the patent from *t* (time of the patent grant) to *t* + 4

*Implications*

Self-forward citations (from *t* to *t* + 4)

88,528

0.620

1.980

0.000

54.000

Total forward citations (from *t* to *t* + 4)

88,528

4.857

7.843

0.000

176.000

*Controls*

Firm knowledge stock

Firm-year level. Number of patents applied by

88,528

3185.358

2416.666

0.500

9764.874

(from *t* − 5 to *t* − 1)

the ﬁrm in the years from *t* − 5 to *t* − 1

Technological novelty

Patent level. Inverse of the median age (in

88,528

0.605

0.227

0.056

1.000

years) of the patent’s backward citations

Firm-year level. Number of employees in year *t* Firm-year level. Number of years elapsed from the ﬁrm’s establishment to year *t*

Firm-year level. Number of backward citations made by the ﬁrm to its own patents (in the

Firm size Firm age

88,528

88,528

3933.585

60.710

14,127.840

32.212

2.000

1.000

480,000.000

180.000

Firm knowledge leverage

88,528

0.125

0.079

0.000

0.600

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

**Table 3**

Pairwise correlations between variables (*N* = 88,528).a

1

2

3

4

5

6

7

8

9

10 11

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

11.

Number of claims Number of classes

1.000

0.030

0.115

0.091

0.085

0.110

1.000

0.060

Firm scientiﬁc knowledge (from *t* − 5 to *t* − 1)

1.000

0.056

0.026

0.103

Firm related inventive experience (from *t* − 5 to *t* − 1)

−0.073

1.000

0.063

0.007

Self-forward citations (from *t* to *t* + 4) Total forward citations (from *t* to *t* + 4)

0.002

0.048

1.000

0.432

1.000

Firm knowledge stock (from *t* − 5 to *t* − 1)

−0.107

−0.070

−0.166

−0.219

−0.069

−0.105

1.000

Technological novelty Firm size

Firm age

Firm knowledge leverage

−0.036

−0.010

−0.045

0.016

0.048

0.046

0.032

0.094

0.007

0.026

−0.161

1.000

0.073

0.072

0.066

−0.002

0.020

0.026

−0.034

−0.013

1.000

0.222

0.026

−0.037

−0.003

−0.109

−0.185

−0.026

0.091

0.140

1.000

0.374 1.000

−0.071

−0.003

−0.199

−0.063

−0.029

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.

Second, Model 4.6 reports the results of the analyses conducted using the full time window available after the patent grant to cal- culate the number of forward citations patents received.[5](#_bookmark14) Third,

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

.

Σ

Σ

*J*

number of patents in the sample across all J classes, *n / n* in the period

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.

PH*j*

PH*j*

*j*=1

under consideration. I calculated the same proportion using all patents in the NBER

.

Σ

Σ

*J*

database, *n*

*/ n* , referring to the same set of classes J in the same

NBER*j*

NBER*j*

*j*=1

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

Σ

Σ

*J*

*J*

classes that satisﬁed two conditions: (1) *n / n > n*

*/ n* ; (2)

PH*j*

PH*j* NBER*j*

NBER*j*

*j*=1

*j*=1

the difference was statistically signiﬁcant at the 99% conﬁdence level. This procedure

resulted in the selection of 74 classes (details available on request).

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**Table 4**

Linear regression estimates of patents’ self-forward citations.a

4.1

Linear regression All patents, four year window from patent grant date Ln(1 + self- forward citations)

4.2

Linear regression All patents, four year window from patent grant date Ln(1 + self- forward citations)

4.3

Linear regression All patents, four year window from patent grant date Ln(1 + self- forward citations)

4.4

Linear regression All patents, four year window from patent grant date Ln(1 + self- forward citations)

4.5

Linear regression Photonics patents, four year window from patent grant date Ln(1 + self- forward citations)

4.6

Linear regression

All patents, full window from patent grant date

4.7

Linear regression

All patents, full window from patent grant date

4.8

Linear regression

All patents, full window from patent grant date

Sample

Variables

Ln(1 + self- forward citations)

Ln(1 + external forward citations)

Ln(1 + total forward citations)

0.014[\*\*\*](#_bookmark19) (0.002)

0.014[\*\*\*](#_bookmark19) (0.002)

0.012[\*\*\*](#_bookmark19) (0.003)

0.020[\*\*\*](#_bookmark19) (0.002)

−0.004[\*\*\*](#_bookmark19)

0.126[\*\*\*](#_bookmark19) (0.004)

0.111[\*\*\*](#_bookmark19)

(0.007)

Ln(number of claims)

(0.001)

0.015[\*\*\*](#_bookmark19) (0.002)

0.131[\*\*\*](#_bookmark19)

(0.046)

−0.019[\*\*\*](#_bookmark19)

−0.020[\*\*\*](#_bookmark19)

−0.015[\*\*\*](#_bookmark19)

−0.017[\*\*\*](#_bookmark19)

Ln(number of classes)

Ln(1 + ﬁrm scientiﬁc knowledge) Ln(1 + ﬁrm rel. inv. experience) Ln(1 + ﬁrm knowledge stock) Ln(1 + technological novelty)

Ln(ﬁrm size)

(0.004)

(0.004)

(0.005)

(0.004)

−0.530[\*\*\*](#_bookmark19)

−0.540[\*\*\*](#_bookmark19)

−0.528[\*\*\*](#_bookmark19)

−0.537[\*\*\*](#_bookmark19)

−0.683[\*\*\*](#_bookmark19)

−0.689[\*\*\*](#_bookmark19)

−0.279[\*](#_bookmark17)

(0.088)

0.300[\*\*\*](#_bookmark19) (0.021)

(0.088)

0.298[\*\*\*](#_bookmark19) (0.021)

(0.088)

0.294[\*\*\*](#_bookmark19) (0.021)

(0.088)

0.293[\*\*\*](#_bookmark19) (0.021)

(0.114)

0.252[\*\*\*](#_bookmark19) (0.027)

(0.096)

0.336[\*\*\*](#_bookmark19) (0.022)

(0.146)

0.111[\*\*\*](#_bookmark19) (0.037)

−0.151[\*\*\*](#_bookmark19)

(0.012)

0.029[\*\*\*](#_bookmark19) (0.005)

−0.063[\*\*\*](#_bookmark19)

−0.065[\*\*\*](#_bookmark19)

−0.063[\*\*\*](#_bookmark19)

−0.065[\*\*\*](#_bookmark19)

−0.050[\*\*\*](#_bookmark19)

−0.056[\*\*\*](#_bookmark19)

−0.098[\*\*\*](#_bookmark19)

(0.010)

0.039[\*\*\*](#_bookmark19) (0.013)

0.007[\*\*\*](#_bookmark19)

(0.002)

0.059

(0.040)

(0.010)

0.040[\*\*\*](#_bookmark19) (0.013)

0.007[\*\*\*](#_bookmark19)

(0.002)

0.061

(0.040)

(0.010)

0.039[\*\*\*](#_bookmark19) (0.013)

0.007[\*\*\*](#_bookmark19)

(0.002)

0.059

(0.040)

(0.010)

0.040[\*\*\*](#_bookmark19) (0.013)

0.007[\*\*\*](#_bookmark19)

(0.002)

0.060

(0.040)

(0.013)

0.052[\*\*\*](#_bookmark19) (0.017)

0.004

(0.003)

(0.011) 0.031[\*\*](#_bookmark18) (0.014) 0.005[\*\*](#_bookmark18) (0.002)

0.004

(0.044)

(0.017)

−0.021[\*\*\*](#_bookmark19)

−0.075[\*\*\*](#_bookmark19)

(0.008)

(0.024)

−0.006[\*\*\*](#_bookmark19)

−0.011[\*\*\*](#_bookmark19)

(0.001)

(0.004)

−0.006

−0.034

−0.198[\*\*\*](#_bookmark19)

Ln(ﬁrm age)

Ln(1 + ﬁrm knowledge leverage)

Ln(1 + total forward citations)

Firm ﬁxed effects Subﬁeld ﬁxed effects Technology life cycle

ﬁxed effects

Constant Observations

*R*-squared

(0.061)

(0.024)

0.257[\*\*\*](#_bookmark19) (0.087)

0.932[\*\*\*](#_bookmark19)

(0.001)

Included Included Included

(0.072)

−1.239[\*\*\*](#_bookmark19)

−1.230[\*\*\*](#_bookmark19)

−1.237[\*\*\*](#_bookmark19)

−1.227[\*\*\*](#_bookmark19)

−1.560[\*\*\*](#_bookmark19)

−1.387[\*\*\*](#_bookmark19)

−1.509[\*\*\*](#_bookmark19)

(0.147)

0.257[\*\*\*](#_bookmark19) (0.002)

Included Included Included

(0.147)

0.256[\*\*\*](#_bookmark19) (0.002)

Included Included Included

(0.147)

0.258[\*\*\*](#_bookmark19) (0.002)

Included Included Included

(0.147)

0.256[\*\*\*](#_bookmark19) (0.002)

Included Included Included

(0.208)

0.218[\*\*\*](#_bookmark19) (0.003)

Included Included Included

(0.157)

0.280[\*\*\*](#_bookmark19) (0.003)

Included Included Included

(0.247)

Included Included Included

−0.390[\*\*](#_bookmark18)

−0.354[\*\*](#_bookmark18)

−0.385[\*\*](#_bookmark18)

−0.417[\*\*](#_bookmark18)

0.178[\*\*](#_bookmark18) (0.090)

88,528

0.934

1.526[\*\*\*](#_bookmark19) (0.274)

88,528

0.347

−0.198

0.000

(0.241)

51,156

0.327

(0.169)

88,528

0.370

(0.162)

88,528

0.371

(0.162)

88,528

0.370

(0.162)

88,528

0.371

(0.180)

88,528

0.382

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 depend- ent 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,](#_bookmark20) 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](#_bookmark78) [and](#_bookmark78) [Wooldridge, 1996).](#_bookmark78) The results of all these alternative speciﬁcations support the results reported in [Table 4.](#_bookmark15)

[and 3a.](#_bookmark6) 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 experi- ence is associated with an increase of 0.90% in the number of claims in a patent.

[Table 7](#_bookmark31) 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 (*ˇ* = 0.155, *p* < 0.05), but neg-

atively associated with related inventive experience (*ˇ* = −0.271,

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

*p* < 0.01), results which support [Hypotheses](#_bookmark7) [2b](#_bookmark7) [and](#_bookmark7) [3b.](#_bookmark7) The esti- mates 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 con- trast, 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, com- pared 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 6](#_bookmark26) reports the estimation results of the models in which the number of claims in the patent is a function of ﬁrm scientiﬁc knowl- edge and related inventive experience (and other control variables). Speciﬁcally, Model 6.1 includes the control variables only, and Mod- els 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 associ- ated with the number of claims included in the patent (*ˇ* = 0.663, *p* < 0.01; *ˇ* = 0.065, *p* < 0.05, respectively), supporting [Hypotheses 2a](#_bookmark6)

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**Table 5**

Negative binomial and fractional logit regression estimates of patents’ self-forward citations.a

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

Sample Variables

0.043[\*\*\*](#_bookmark23) (0.010)

0.043[\*\*\*](#_bookmark23) (0.013)

Ln(number of claims)

−0.081[\*\*\*](#_bookmark23)

−0.132[\*\*\*](#_bookmark23)

Ln(number of classes)

Ln(1 + ﬁrm scientiﬁc knowledge) Ln(1 + ﬁrm rel. inv. experience) Ln(1 + ﬁrm knowledge stock) Ln(1 + technological novelty)

Ln(ﬁrm size)

(0.017)

(0.022)

−1.030[\*\*\*](#_bookmark23)

−1.191[\*\*](#_bookmark22)

(0.349)

1.291[\*\*\*](#_bookmark23) (0.089)

(0.469)

1.520[\*\*\*](#_bookmark23) (0.120)

−0.349[\*\*\*](#_bookmark23)

−0.411[\*\*\*](#_bookmark23)

(0.037)

0.207[\*\*\*](#_bookmark23) (0.054)

0.051[\*\*\*](#_bookmark23)

(0.008)

0.382[\*\*\*](#_bookmark23) (0.142)

0.059

(0.480)

1.288[\*\*\*](#_bookmark23) (0.008)

Included Included Included Included

(0.050) 0.151[\*\*](#_bookmark22) (0.074)

0.053[\*\*\*](#_bookmark23)

(0.010)

0.689[\*\*\*](#_bookmark23) (0.206)

Ln(ﬁrm age)

Ln(1 + ﬁrm knowledge leverage)

Ln(1 + total forward citations)

Firm ﬁxed effects Subﬁeld ﬁxed effects Time ﬁxed effects[b](#_bookmark24)

Technology ﬁxed effects[b](#_bookmark24)

Constant

Observations Log likelihood

−0.706

(0.687)

Included Included Included Included

−5.240[\*\*\*](#_bookmark23)

−3.226[\*\*\*](#_bookmark23)

(0.897)

88,528

−64,950.284

(1.033)

66,687

−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](#_bookmark26) on a subsample of patents in pho- tonics 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 char- acterized by patterns speciﬁc to certain technological classes, and not related to the mechanisms outlined in the hypotheses. How- ever, 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 inter- views 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 ‘mean- ingful’ 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.

focused on the changes to the size of the inventive area covered by the patent rights determined by patent policy (e.g. [Cohen and](#_bookmark77) [Lemley, 2001; Denicolo’, 1996; Gilbert and Shapiro, 1990; Green](#_bookmark77)

[and Scotchmer, 1995; Kitch, 1977; Klemperer, 1990; Merges and](#_bookmark77) [Nelson, 1990, 1994; Scotchmer, 1991),](#_bookmark77) 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 accept- ing 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 inven- tive 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;](#_bookmark48) [Kitch,](#_bookmark48) [1977;](#_bookmark48) [Klemperer,](#_bookmark48) [1990).](#_bookmark48) 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.

1. **Discussion and conclusions**
   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

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**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

6.6

Linear regression All patents Ln(number of claims)

Photonics patents Ln(number of claims)

0.659[\*\*\*](#_bookmark30) (0.137)

0.663[\*\*\*](#_bookmark30) (0.137) 0.065[\*\*](#_bookmark29) (0.033)

0.552[\*\*\*](#_bookmark30) (0.170)

0.210[\*\*\*](#_bookmark30)

(0.044)

Ln(1 + ﬁrm scientiﬁc knowledge)

Ln(1 + ﬁrm related inventive experience)

Ln(1 + ﬁrm scientiﬁc knowledge, alternative measure)

Ln(1 + ﬁrm related inventive, alternative measure)

Ln(1 + ﬁrm knowledge stock)

0.063[\*](#_bookmark28) (0.033)

0.100[\*\*\*](#_bookmark30) (0.012)

0.011[\*\*\*](#_bookmark30)

(0.003)

0.066[\*\*\*](#_bookmark30) (0.019)

0.169[\*\*\*](#_bookmark30) (0.015)

0.162[\*\*\*](#_bookmark30) (0.015)

0.168[\*\*\*](#_bookmark30) (0.015)

0.161[\*\*\*](#_bookmark30) (0.015)

0.208[\*\*\*](#_bookmark30) (0.020)

−0.056[\*\*\*](#_bookmark30)

−0.056[\*\*\*](#_bookmark30)

−0.056[\*\*\*](#_bookmark30)

−0.056[\*\*\*](#_bookmark30)

−0.084[\*\*\*](#_bookmark30)

−0.057[\*\*\*](#_bookmark30)

Ln(1 + technological novelty)

(0.021)

(0.021)

(0.021)

(0.021)

(0.027)

(0.021)

−0.011[\*\*\*](#_bookmark30)

−0.012[\*\*\*](#_bookmark30)

−0.011[\*\*\*](#_bookmark30)

−0.012[\*\*\*](#_bookmark30)

−0.008[\*](#_bookmark28)

−0.015[\*\*\*](#_bookmark30)

Ln(ﬁrm size)

(0.003)

(0.003)

(0.003)

(0.003)

(0.004)

(0.003)

−0.102

−0.098

−0.100

−0.095

−0.130

−0.071

Ln(ﬁrm age)

(0.069)

(0.069)

(0.069)

(0.069)

(0.098)

(0.069)

−0.983[\*\*\*](#_bookmark30)

−0.794[\*\*\*](#_bookmark30)

−0.992[\*\*\*](#_bookmark30)

−0.802[\*\*\*](#_bookmark30)

−1.434[\*\*\*](#_bookmark30)

−0.589[\*\*\*](#_bookmark30)

Ln(1 + ﬁrm knowledge leverage)

Firm ﬁxed effects Subﬁeld ﬁxed effects

Technology life cycle ﬁxed effects

Constant Observations

*R*-squared

(0.212)

Included Included Included 2.388[\*\*\*](#_bookmark30) (0.272)

88,528

0.163

(0.216)

Included Included Included 2.382[\*\*\*](#_bookmark30) (0.272)

88,528

0.164

(0.212)

Included Included Included 2.373[\*\*\*](#_bookmark30) (0.272)

88,528

0.163

(0.217)

Included Included Included 2.367[\*\*\*](#_bookmark30) (0.273)

88,528

0.164

(0.290)

Included Included Included 2.119[\*\*\*](#_bookmark30) (0.382)

51,156

0.148

(0.218)

Included Included Included 2.572[\*\*\*](#_bookmark30) (0.273)

88,528

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

7.6

Linear regression All patents Ln(number of classes)

Photonics patents Ln(number of classes)

0.172[\*\*](#_bookmark33) (0.078)

0.155[\*\*](#_bookmark33) (0.078)

0.223[\*\*](#_bookmark33) (0.092)

Ln(1 + ﬁrm scientiﬁc knowledge)

Ln(1 + ﬁrm related inventive experience)

Ln(1 + ﬁrm scientiﬁc knowledge, alternative measure)

Ln(1 + ﬁrm related inventive, alternative measure)

Ln(1 + ﬁrm knowledge stock)

−0.272[\*\*\*](#_bookmark35)

−0.271[\*\*\*](#_bookmark35)

−0.238[\*\*\*](#_bookmark35)

(0.019)

(0.019)

(0.025)

0.018[\*\*\*](#_bookmark35) (0.007)

−0.034[\*\*\*](#_bookmark35)

(0.002)

0.014

(0.011)

0.002

(0.008)

−0.000

0.003

(0.008)

0.002

(0.009)

0.005

(0.010)

(0.009)

−0.029[\*\*](#_bookmark33)

−0.028[\*\*](#_bookmark33)

−0.027[\*\*](#_bookmark33)

−0.027[\*\*](#_bookmark33)

−0.024[\*\*](#_bookmark33)

−0.005

Ln(1 + technological novelty)

(0.012)

0.001

(0.002)

(0.012)

0.001

(0.002)

(0.012)

0.001

(0.002)

(0.012)

0.001

(0.002)

(0.015)

0.001

(0.003)

(0.012)

0.000

(0.002)

Ln(ﬁrm size)

−0.020

−0.018

−0.030

−0.029

−0.054

−0.021

Ln(ﬁrm age)

(0.040)

0.012

(0.128)

Included Included Included 0.285[\*](#_bookmark34) (0.168)

88,528

0.205

(0.040)

0.061

(0.130)

Included Included Included 0.284[\*](#_bookmark34) (0.168)

88,528

0.205

(0.040)

0.050

(0.127)

Included Included Included 0.349[\*\*](#_bookmark33) (0.169)

88,528

0.207

(0.040)

0.095

(0.130)

Included Included Included 0.347[\*\*](#_bookmark33) (0.169)

88,528

0.207

(0.055) 0.281[\*](#_bookmark34) (0.164)

Included Included Included

0.928[\*\*\*](#_bookmark35)

(0.211)

51,156

0.170

(0.040)

0.083

(0.131)

Included Included Included 0.264

(0.168)

88,528

0.208

Ln(1 + ﬁrm knowledge leverage)

Firm ﬁxed effects Subﬁeld ﬁxed effects

Technology life cycle ﬁxed effects

Constant Observations

*R*-squared

a Robust standard errors in parentheses.

\* *p* < 0.1.

\*\* *p* < 0.05.

\*\*\* *p* < 0.01.

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Third, this paper investigates the antecedents of patent scope, thus complementing prior research which has largely focused on its implications (e.g. [Dechenaux](#_bookmark42) [et al.,](#_bookmark42) [2008;](#_bookmark42) [Gambardella](#_bookmark42) [and](#_bookmark42) [Giarratana, 2013; Lanjouw and Schankerman, 1997; Lerner, 1994;](#_bookmark42) [Shane, 2001).](#_bookmark42) It suggests that ﬁrms’ incentives to invest in some fac- tors – 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](#_bookmark63) [(2012)](#_bookmark63) 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.,](#_bookmark53) [2003).](#_bookmark53)

Finally, this paper provides a new reﬂection on the operational-

ization of the construct of patent scope. While prior research in this area has used both patent claims and patent classes as alter- native measures of patent scope (e.g. [Lanjouw and Schankerman,](#_bookmark72) [1997, 2004; Lerner, 1994; Merges and Nelson, 1994; Shane, 2001),](#_bookmark72) 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](#_bookmark42) [et al., 2008),](#_bookmark42) or by the establishment of a new ﬁrm ([Shane, 2001).](#_bookmark83) Along the same line of reasoning, [Nerkar and Shane’s (2003)](#_bookmark86) 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)](#_bookmark74) pre- dicts and shows that broader scope is positively associated with the valuations placed on ﬁrms during the venture capital invest- ment process. On the contrary, [Harhoff et al. (2003)](#_bookmark60) 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 pro- ﬁtability of the enterprise’), and ﬁnd that the relationship between these two variables is consistently insigniﬁcant across all speciﬁ- cations.

These prior studies have built on the theoretical intuition

that patents with broader scope should enjoy stronger protec- tion 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 success- fully 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 fail- ure.

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 num- ber 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),](#_bookmark50) rather than only the information contained in the patent claims, and so does not distinguish between patents that are classiﬁed in multi- ple classes because they build on diverse knowledge inputs (e.g. patents with higher technological diversity, as in [Guellec and van](#_bookmark54) [Pottelsberghe de la Potterie, 2000, 2002),](#_bookmark54) 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 mech- anisms 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).](#_bookmark52) 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](#_bookmark60) [et al.](#_bookmark60) [(2003)](#_bookmark60) provide a set of possible explanations such as the single- versus multi-industry approach or the potential dif- ference 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),](#_bookmark60) 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)](#_bookmark60) 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 inter- esting 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

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relationship between patent scope and patent litigations. Within this stream, [Lerner](#_bookmark74) [(1994)](#_bookmark74) 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)](#_bookmark72) 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 associ- ation 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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