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The (Anti-) Competitive Effect of IPRs

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Abstract

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**JEL Codes:** O31, O32, O34, D22

**Key Words:** patents, innovation, competition, simultaneous system
1 Introduction

Intellectual property rights (IPRs) are meant and designed to foster innovation. They are comprised of patents, designs, circuit layouts, plant breeders’ rights, trademarks, and geographic indications, allowing firms and individuals to appropriate the benefits from ideas, innovations, and creations through an exclusive commercial right, which would otherwise be non-excludable. Lockean theories of property aim to justify the unilateral appropriation of some unknown good by the first person(s) to discover or alter it through own labour (Widerquist 2010). Different from that, economists argue their case by the need to appropriate the returns of own effort as an incentive to do R&D (Schumpeter 1911/1912). Depending on one’s philosophical persuasion, the benefit of commercial excludability either rewards or lends unto creators the rightful due of their innovation.

Given these considerations, however, the empirical evidence is surprisingly mixed. One can attribute this ambiguity to two phenomena that confound identification:

1. IPRs incentivise innovation and hence raise R&D by the increased of returns.

2. IPRs strengthen a firm’s market position and reduce competition, which may lower or raise R&D effort.

We believe the mixed evidence in the literature comes from the fact that usually these two impacts are jointly observed and not sufficiently disambiguated in empirical research designs. Endogeneity is therefore a major issue. In this case, competition affects the incentives to invest in R&D, the success of which determines the use of IPRs, which then feeds back on competition.

Our objective is to separate these effects by expanding the structural model of competition and innovation introduced in Peneder & Wörter (2014) and adding an equation for the individual firms’ use of IPRs. More specifically, we estimate a system of simultaneous equations relating (i) IPR use, (ii) competition, (iii) R&D incentives and (iv) innovation outcomes within a circular chain of causal effects.

We estimate the system for a large sample of companies responding to the Swiss Innovation surveys from 1999 to 2015. The main findings support the view that there is an inverted-U relationship between competition and research effort. In addition, the estimates show that the effectiveness of IPRs increases the probability of own R&D. Furthermore, better appropriability conditions at the industry level raise the number of competitors, presumably by allowing more companies to stay in the market. Finally, individual firms face fewer competitors if they use IPRs, which again impacts on R&D incentives via the aforementioned inverted-U relationship.

This paper is organized as follows. Section 2 surveys relevant findings from the IPR and innovation literature. In Section 3, we present the conceptual framework and the hypotheses to be tested. In Section 4 we discuss the data and variables, followed by the econometric results in Section 5. Section 7 concludes and points the direction for future research.
2 Selected findings from the literature

We center our discussion of the existing literature on the relation between intellectual property and innovation, the firm’s choice to use intellectual property, and its effect on competition. The first relation has been studied the longest, and there is a fair amount of literature on the relation between IPRs and innovation. IPR choice and strategy have both been explored in the specialist literature – there are a number of studies that show how firms use intellectual property to their advantage, be it filing strategies, secrecy, etc. Many of these are ad hoc analyses that explain a particular phenomenon like strategic patenting or secrecy, e.g. Harhoff et al. (2014), Lampe (2012). The actual competitive distortions that IPRs introduce to the market and according second-order effects have received less attention. It is in filling that gap in the literature that our research aims to contribute.

2.1 IPRs and Innovation

The empirical literature still lacks strong evidence with respect to whether intellectual property rights enhance or inhibit innovation at a system level. Michele Boldrin and David K. Levine who are perhaps the most visible, if not most vocal, academic critics (Boldrin & Levine 2008a). This empirical task has become more difficult over time because all of the counter-factual cases have been disappearing from the map as jurisdiction after jurisdiction has chosen to adopt the same legal framework for intellectual property rights culminating in the 1995 TRIPs disciplines of the WTO, which essentially erased any policy distinction for the major nations. Since then, the WIPO and WTO have played an even bigger role in guiding national policy. The patent prosecution highway is another example of uniformity being internationally enforced in the world IP space. While this undoubtedly lowers the cost to internationalised companies of using the global IP system, it has the side effect of removing heterogeneity and thereby any chance for policy experimentation.

Hence, some authors have tried to overcome this lack of evidence by exploiting history. Petra Moser’s work in this field is exemplary – she offers novel examples of innovation from throughout history be it in the form of world’s fairs (Moser 2013), absence of patenting Moser & Voena (2012), presence of copyright Giorcelli & Moser (2016), or patent pools (Lampe & Moser 2015). Much of her work highlights the fact that innovation can exist with or even despite intellectual property rights. Using long-term historical policy data, the picture that Lerner (2009) paints is one in which the advent of an intellectual property system does not bring much in the way of more innovation. In fact, it tells more of a story of dependence where the core economies extend their IP regime over the peripheral economies with most of the benefits accruing to the foreign holders of IPRs. However, having to go back a 100 to 200 years to uncover substantial IP policy variation makes analogies to the current international system a difficult sell.

At the other end of the spectrum, we have some contemporary industry studies that hone in narrowly on the effects of IPRs that provide more qualitative evidence. In a study
of the wireless communication industry, Teece et al. (2014) conclude that innovation takes place in spite of the patent wars – and that there is considerable dead-weight loss. Using changes in U.S. judicial practice with respect to software patents, Bessen & Hunt (2007) find little evidence that stronger software patent rights have induced R&D investments, employment of computer programmers, or productivity growth. Within that same industry, Huang et al. (2012) find that patents and copyright allow small independent software vendors to partner with a platform provider without being expropriated by the entrenched player (the authors use vendors developing for SAP as the example). In this sense, IPRs permit formal cooperation to benefit the end customer. While the value-added of this type of software eco-system is clear, it is less clear whether it is merely changing the mode of supply rather than creating a larger integrated player as would be the case in an IPR-less world.

In a more concentrated market, such as the pharmaceutical industry, where IP reigns supreme in terms of the amount of value it can create in the face of an inelastic demand curve, Qian (2007) finds little to no evidence that a stronger IP regime boosts innovation. Worth noting is that he does find empirical evidence for a U-shaped relation between IPR strength in a country and the amount of innovation, first posited theoretically by Gallini (1992). In an even more narrow case study, Williams (2013) shows that private IP related to the human genes held by Celera slowed down progress in the field. Perhaps most disturbing about the findings in his micro-study is that this loss of innovation was persistent and/or permanent. The stylized fact that patents might disincentivize subsequent innovations was raised over 230 years ago by the Secretary of the Vevey Economic Society, who wrote that an inventor is, “Contented by his privilege\(^1\), [an inventor] hastens to gain much whilst his invention has the merit of novelty, and he dream not of even perfecting it” (Muret 1776, p. 124). In modern parlance, the patent or privilegium granted after a breakthrough invention would not be followed up by incremental invention because it would cost more R&D.

This strategy of less subsequent innovation is implied by the theory of persistent monopoly presented in Gilbert & Newbery (1982). It holds that entrenched firms have an incentive to conduct R&D to deter entrants regardless of a patent (but patents do boost the rewards for doing so). A crucial assumption is that a patent requires R&D expenditures, and that “[t]he complexities of research and development limit preemptive patenting to exceptional circumstances. [Even basic development of new products] can make the cost of entry deterrence by preemptive patenting excessively costly.” This assumption that preemptive patenting is too costly to be viable was perhaps reasonable during that industrial era, given the 1973 study whereupon it is likely based, but it no longer reflects what is known about how patents are used strategically today in complex technologies (Harhoff et al. 2014). Chen & Schwartz (2013) rejects the idea that a monopolist does not innovate, and has even more of an incentive to innovate, provided the monopolist can coordinate

\(^1\)The historical records seem to indicate that local governments in Switzerland would occasionally grant both a prize and “privilegium”, a type of monopoly, for the discovery of some particularly useful inventions.
prices across the product lines to avoid cannibalising its own revenue, it has an incentive to innovate.

Whatever the theoretical relation between market power and patenting, the lack of substantial policy variance has made adjudicating such theoretical disputes nigh impossible. The lack of policy evidence is so acute that economic researchers have resorted to experimentation in order to explore the effects of intellectual property policy. In a novel article, Brüggemann et al. (2016) set up a counter-factual experiment where subjects play scrabble, investing in letters, and are able to charge licensing fees for derived words. They measure innovation in terms of word extensions, word length, and word value. In the IPR condition, words are shorter and there are fewer extensions.

In a provocatively titled, “How much should society fuel the greed of innovators?”, Dosi et al. (2006) hold that intellectual property rights are not the primary mechanism by which firms appropriate value. In their study of US industries secrecy is the number one mechanism by which innovators profit from their innovations. They go on to emphasize that IPRs are more germane to determining the winners and losers and less the actual ability of seeing the technological opportunities.

Harhoff et al. (2014) find a loose dichotomy between simple and complex inventions where patents can be used very strategically in the latter case by holding up rival firms in their innovation. Using different methods and data, Lampe & Moser (2015) also find that complexity plays a role, whereby patents provided a legal nucleus for coordinated action in the form of patent pools, and leads to less innovation and is a type of innovation cartel. Marengo et al. (2012) formalizes this idea by distinguishing between product complexity and product quality. Using simulations of their formal model, they show that a type of anti-commons effect dominate for the complex products yielding lower rates of innovation.

Beyond patent pools, Schmalensee (2009) presents a strategic model around patent holders forming a cartel around standards, but concludes that it would be hard to formulate a policy that does not bias the current policy in one particular group’s favor. Spulber (2013) points out that the market structure is endogenous, and suggests “that there is little economic foundation for concerns about: (1) “patent holdup” and “standards holdup; (2) “technology lock-in; (3) “royalty stacking”; and (4) “patent thickets”. Using survey data, Hall et al. (2013) find that only a small percentage of innovative firms use formal IP rights, and that innovation is negatively associated with formal IPRs.

Beyond these studies trying to explain the benefits of IPRs, there has been a fair amount of work that puts firm choice at the center. Section 2.2 explores this aspect.

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2“Strategic use of the patent system arises whenever firms leverage complementarities between patents to attain a strategic advantage over technological rivals. This is anticompetitive if the main aim and effect of strategic use of the patent system is to decrease the efficiency of rival firms’ production (Harhoff et al. 2014, 22).”
2.2 Firm Choice for Appropriation with IPRs

Moving beyond the more policy oriented literature into theoretical territory, Teece (1986) covers a lot of the conceptual factors that go into appropriation of the returns from innovation. Kwon (2012) develops a model that shows how strengthening IP rights can lower innovation outcomes when the propensity to patent is low initially. Using a sample of German manufacturing firms, Slivko (2012) demonstrates that the effectiveness of patent protection positively affects firms’ propensity to innovate.

One of the key questions is whether IPRs simply favor the larger entrenched players. Jensen & Webster (2006) answers that question in the negative by showing that the propensity for SME’s to use IPRs is equal or even larger than that of large firms conditional on their industry and opportunity to innovate. Product complexity, which implies information search costs, could be the decisive determinant in this respect. Gallini & Scotchmer (2002) hold that IPRs are the best mechanism for innovation when the value and costs of innovation cannot be observed or known by the agent that would benefit from the innovation, e.g. in fundamental research. IPRs lose their effectiveness when information is diffuse, as in the complex invention case observed by many authors. They show that the competitive effects of IPRs depend much on the type of innovation, e.g. cumulative vs. discrete or the breadth of the invention. They offer theoretical arguments for why (government) procurement and prizes are alternative mechanisms and function when the innovation can be well defined.

Greenhalgh & Rogers (2006) find a synergistic effect between market power and the use of IPRs. In other words, a patent in the hands of a startup is not worth the same as that same patent in the hands of a multi-national corporation. Perversely, in this sense the incentives to innovation accrue to those firms already with the largest incentive to innovate. Their work is interesting because it hints at why we observe that dominant firms may continue to innovate despite their market power.

When it comes to using patents, firms use patents both in the classic sense to protect inventions, but also strategically to block competitors; this can be measured by the number of patent oppositions (Blind 2009). Even where inventions can be well circumscribed by patents rights, such as in the chemical and pharmaceutical industries, Harhoff et al. (2014) find preemptive filings to create stumbling blocks, which then work their way out in oppositional proceedings or litigation. There is much more literature delving into optimal firm patent strategy, which we do not cover here. Firms will disclose inventions actively when the legal externality of another firm patenting the technology would be high (Ponce 2011). This is more likely to occur for smaller firms where the complementary capacity is missing and larger competitors have the means to defend the patents. Koenen & Peitz (2015) develop a model for how firms can profit from filings and pending patents even if there is no invention.

In short, Pisano (2006) summarises the situation as follows: “Increasingly, appropriability regimes are endogenously influenced by the behaviors and strategies of firms themselves (p. 1128).” In other words, firms shape a commercial model around how they can use IPRs.
By endogenizing the strength of a firm’s IP portfolio, we seek to incorporate this idea into our model below.

2.3 Competition and IPRs

IPRs tend to decrease the value of a focal firm. In other words, the mere existence of a company holding IPRs in a domain lowers the value of competing firms (McGahan & Silverman (2006)).

Gilbert (2006) emphasizes that the relation between competition, innovation and IPRs is highly context specific and develops a series of models to illustrate the point. In a similar vein, Acemoglu & Akcigit (2012) develop a model to illustrate the dynamic inter-relation between IPRs and competition — they point out that reducing IPR strength for the leaders could have the counter-intuitive outcome of less innovation via the fact that a subset of firms push the frontier and that knowledge then diffuses through other firms.

Boldrin & Levine (2008b) show that innovation need not rely on market power, and that in practice there are a number of ways in which firms can recoup innovation costs – showing that barriers to entry, first-mover advantage in publishing, and specialized expertise can all sustain innovation without IPRs. Perhaps the empirical counterpart to this theoretical piece is Helmers et al. (2014), who look at various appropriation strategies. They make the distinction between formal and informal IP rights. Informal IP rights are secrecy, confidentiality agreements. They consider lead time and design complexity of a unique concept of “informal IP rights” as well.

A theoretical paper close to our concerns can be found in DeBrock (1985). He analyses the patent rent within the context of strategic rivalry and points out that much of the rent accruing to the patenting firm dissipates in the form of R&D expenses by other firms. In other words, patents may provide a reward to the winner of the race, but the game is zero sum. His analysis raises the fundamental policy question of whether patents may induce firms into a wasteful type of R&D competition.

2.4 Related work

Adjacent to the main thrust of our paper, we would like to note that our work closely relates to the debate on whether competition is conducive or obstructive to innovation. In both theoretical and empirical analysis, any kind of relationship appears to be possible, as the many surveys of the literature demonstrate (e.g. by De Bondt and Vandekerkhove 2012; Cohen (2010); Gilbert 2006; Aghion and Griffith 2005; or Reinganum 1989). The seminal works on this relation hold that competition hurts innovation because a surplus is required to maintain it (Schumpeter, 1911, 1942), but can also foster it when firms are further driven to seek out consumer utility and exploit it through R&D (Arrow, 1962). Later Kamien and Schwartz (1976) as well as Aghion et al. (2005) developed Scherer’s 1967 idea of a sweet-spot or inverted U-shape relation between competition and innovation.
into rigorous formal models.\footnote{Using U.K. and U.S. manufacturing data, Hashmi (2013), for example, find a U-shaped relation between innovation, as measured by citation weighted patents, and competition in the USA, and an inverted U-shape in the UK (cf. Table 2); he posits that the U.K. manufacturing does not exhibit the leader-follower pattern show in Aghion et al. (2005). This relation between market power and innovative competition could simply be theoretically indeterminate; Žigić & Maçi (2011) delve specifically into this issue and show that with free entry, competition can be intensive even if there is high concentration in a technological industry.}

Testing a structural model with endogenous determination of both competition and innovation, Peneder & Wörter (2014) as well as Friesenbichler & Peneder (2016) provided empirical evidence for an inverted-U relationship for large firm samples from such diverse datasets as the Swiss Innovation Survey or the Business Environment and Enterprise Performance Survey (BEEPS) conducted in Eastern Europe and Central Asia.\footnote{The survey is conducted by the EBRD in conjunction with the World Bank.} Working with the same kind of survey data, the current paper builds on their core model of a non-linear relationship between competition and R&D in order to control for their joint and endogenous impact on IPRs within a consistent simultaneous system. Our focus then is on extending that model by the endogenous choice of IPR use.

3 Conceptual Framework

3.1 Assumptions and Hypotheses

Our approach combines a generic core Schumpeterian model issuing from innovation literature with a systems equation strategy. We thus nestle our research within the literature on IPRs, competition and innovation and aim to represent the model by a series of assumptions and hypotheses meant to capture those effects. By this distinction, \textit{assumptions} refer to relationships that have already been explained and tested on different data (or may come close to truisms, which are nevertheless needed to close the model). In contrast, we refer to \textit{hypotheses}, when the focus is on core impacts related to IPRs.

Figure 1 summarizes their joint structure in the form of a probabilistic graphical model. Arrows indicate the presumed direction of causal impacts, aiming for an accurate dissection of indirect effects via the respective intermediary variables. Those in circles represent the endogenous variables of the model. The variables put in squares represent selected exogenous variable that are of particular interest. The system in Equation 5 provides further detail, while Section 3.2 describes the full set of exogenous controls and exclusionary restrictions that we used in the estimations.
In short, the received literature brings us to the following basic assumptions:

**A1:** *Competition affects the R&D effort, possibly by an inverted U-shaped relationship.*

**A2:** *More R&D effort raises the probability that a firm innovates.*

**A3:** *Innovation allows a firm to pull away from competition.*

Having gotten some of the theoretical housekeeping out of the way, we now turn to the heart of our investigation, namely the use of intellectual property rights. Thereby, a core tenant of the model is that the industry governs to a large extent, which appropriability mechanisms are available, and how they are used.\(^5\)

\(^5\)For example, music companies cannot avail themselves of the patent system, and the pharmaceutical
To begin with, we focus on the impact of general appropriability conditions at the industry level as characterized by the taxonomy of Peneder (2010), which was created from a large sample of respondents to the European Union’s Community Innovation Survey. The first hypothesis links that industry level regimes developed for the EU companies with the individual IPR use of our Swiss firms:

**H1:** If technological regimes offer favourable appropriability conditions, then firms are more likely to use IPRs.

Furthermore, we expect that favourable appropriability conditions at the industry level foster competition:

**H2:** If technological regimes offer favourable appropriability conditions, then the market can support more competitors.

This hypothesis may seem counter-intuitive, since firms apply IPRs exactly to appropriate the returns from their innovation by means of restricting competition. But here the explicit distinction between industry and firm-level effects is of importance. What the hypothesis says, is that for an industry where appropriability tends to be high, a plethora of tiny walled gardens may arise and persist because firms can protect their innovation. This is different from the impact of individual firm choices for a given technological regime at the industry level, to which we will turn in Hypothesis 6. Ideally, the structural model should identify both the meso- and micro-level impacts as independent effects.

Turning to micro-level choices, we interpret data on the firm’s “effectiveness of IPRs” as an exogenous technological or industry-determined characteristic, which offers a valid exclusionary restriction to identify the firm’s R&D expenditures and actual IPR use:

**H3a:** If firms perceive IPRs to be effective, then they are more likely to engage in their own R&D activities.

**H3b:** If firms perceive IPRs to be effective, then they tend to spend more on R&D.

**H4:** If firms perceive IPRs to be effective, then they are more likely to use them.

Furthermore, intellectual property rights are conditional on having a novel product. Consequently, it follows that:

**H5:** If firms innovate, then they are more likely to use IPRs.

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sector does not typically use copyright. Moreover, intellectual property rights and licensing play key roles in these two industries, but are not essential for the oil and gas sectors where average field costs dictate production.
Finally, for a given industry and according technological regime (see Hypothesis 2), the actual use of IPRs help the individual firm to keep its competitors at a distance.

**H6: If firms use IPRs, then they tend to have fewer competitors.**

Except for the vector of general control variables, this set of four assumptions and six hypothesis provide a full description of the core model. In the following section, we outline how to test these hypotheses.

### 3.2 Structural Equation Model

In this section, we move from our conceptual representation to a more formal definition of the probabilistic graphical model. It can be summarized in terms of four equations that determine the four endogenous variables (R&D choice, R&D effort, innovation, IPR use and competition).

In order to identify the causal effects, we employ a 3SLS structural approach and exploit extra-sample industry variation and firm-level variables without parents as exclusion restrictions.

#### 3.2.1 R&D Choice and R&D Effort

Many firms never engage in R&D. Rather than being drawn from a well-behaved distribution, we consequently observe many zeros in the R&D data corresponding to these non-performers. Furthermore, there is often something qualitatively different about them as compared to R&D performers.

Two innovation opportunity functions specify for firm $i$ how competition affects the extensive margin $R_i$ and the intensive margin $E_i$ of R&D and estimate the impact of the number of competitors $C_i$ together with a vector of control variables $X$. Adding a nonlinear term $\gamma^{sq}$, we can test for an inverted-U relationship. The underlying rationale is that competition affects R&D incentives via the firm’s changing beliefs about the probability of a rival introduction of an innovation. Kamien & Schwartz (1976) present a model where firms perform R&D to time product introduction as a function of the number of its competitors $C_i$. Consistent with the prediction of an inverted-U relationship, we expect a positive sign for $\gamma$, and $\gamma^{sq}$ to be negative.

$$ E_i = \gamma_1 C_i + \gamma_1^{sq} C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta_1^i d^p_i + \delta_1^i d^e_i + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \chi_1 X_1,i + v_{1,i} $$ (1)

$X_i$ represents a vector of variables, and $v_i$ is an error term. The equation is identified with our exclusion restriction $\tilde{O}_s$. It is a sectoral taxonomy built from the European Union’s Community Innovation Survey (CIS) micro-data. $\tilde{O}_s$ accounts for exogenous sectoral contingencies of R&D expenditures referred to as opportunity conditions. It affects
the likelihood that an individual firm invests in its own R&D, whereas its impact on the innovation outcome is only indirect, through variation in R&D expenditures. By assumption and consistent with the causal structure of the model, the variable is therefore not correlated with the error term in the innovation production function. The same applies to the R&D dummy variable, which in the basic specification controls for the initial selection into R&D performing and non-performing firms.

### 3.2.2 Innovation Outcome

We come to the key definition of “innovation”, which can be measured in a number of different ways. Including new products, new processes, being first globally into a market, the share of sales issuing from new products on the market, the share of sales new to the firm. In this paper, we use a notion based on the sales share of products new to the market. The innovation production function relates the innovation outcome ($\text{Innovation}_i$) to the firm’s R&D effort. This corresponds to the assumption of the model in Kamien & Schwartz (1976) that more expenditures on R&D buy quicker completion of an innovation, raising the probability of winning an innovation race.

More R&D raises the probability of innovation success. Hence we expect the coefficient for R&D effort to be positive. While hardly offering a controversial relationship, the innovation production function is needed to close the system. In addition, the estimates will tell us about the impact of exogenous variables such as firm size, exports, age or foreign ownership on innovation success, conditional on the jointly determined level of R&D expenditures ($\text{RnDintensity}_i$). Their coefficients can thus be interpreted as impacts on the productivity of R&D.

$$I_i = \epsilon_2 E_i + \kappa_3 K_s + \chi_3 X_{3,i} + \nu_{3,i}$$  \hspace{1cm} (2)

For the exclusion restriction, we again employ a sectoral taxonomy built from the EU-CIS and therefore from data not in this sample. It represents the cumulativeness of knowledge $K_s$. Having chosen to perform R&D, we account for sectoral differences in the degree to which increasing returns to own knowledge creation affect the firm’s probability of innovation success. Conversely, the influence of increasing returns in knowledge creation on the use of IPRs or the intensity of competition depends on their impact on the probability of innovation success. Given the elaborate structure of our model, it is therefore only indirect and by assumption not correlated with the error terms in the following functions, which explain the use of IPRs and competition.

### 3.2.3 IPR Use

Here we describe a firm’s IPR strategy with the generation of an actual IP right being conditional on a successful innovation. A firm needs to develop a new product to make
a trademark worthwhile, invent something to patent, mass produce something to warrant getting a design patent, produce a creative work to copyright. We term this \textit{IPRuse}, a firm-level variable, which reflects the firm’s use of intellectual property, which we believe is a function of the market environment and its own innovative activity. For this reason we endogenize it with respect to \textit{innovation} \((I_i)\). Moreover, we model the IPR use of the firm as a function of two exogenous variables reflecting the technological regime in which the firm operates: 1. the firm’s self-reported perception of the effectiveness of IPRs to protect innovations against copying \textit{IPR effectiveness} \(\pi_4 e_i\); 2. the general sector level usage of such rights, which we refer to as \textit{appropriability conditions} \(\tilde{\alpha}_5 \tilde{A}_s\).

The graph in Figure 1 demonstrates, how the presumably reverse causality between R&D and IPR strategy is resolved by means of a more fine-grained chain of effects that is intermediated by other endogenous variables. Aside from forms of strategic patenting and trademark, the impact of R&D on IPR use is largely conditional on some sort of (often minor) innovation. Conversely, the impact of IPR use on R&D incentives is conditional on their actual effect of reducing the number of competitors. For the purpose of identification, we break the endogenous cycle by using the industry level appropriability conditions aptype\_s(\tilde{A}_s) and the firm’s perception of the effectiveness of IPRs as exclusionary restrictions. Although we tested both, and both can function as a valid exclusion restriction, we prefer the firm’s perception. Theoretically it is more proximate to the R&D decision and the empirics seem to bear this out to a small degree. Empirically, including both improves the model, indicating the firm may not be unitary with respect to strategy and outcomes, or the survey respondent does not control IP strategy.

\begin{equation}
P_i = \iota_3 I_i + \epsilon_3 e_i + \delta_3 d_i^\epsilon + \tilde{\alpha}_3 \tilde{A}_s + \chi_3 X_{3,i} + \upsilon_{3,i}
\end{equation}

\section*{3.2.4 Competition}

The literature indicates competition is influenced by those same intellectual property rights and the innovation itself. The competition outcome function captures the effect of the endogenous competition situation of the firm and a vector of exogenous control variables \(X_i\) on the number of competitors. It represents a quintessential tenet of many industrial organization or Schumpeterian models of endogenous growth: firms invest in R&D in order to create an innovation, which grants fleeting market power (Aghion et al. 2005). The inclusion of the IPR in this same equation goes to the very heart of intellectual property rights that is designed to create a temporary exclusionary commercial right whose purpose is again to grant fleeting market power.

\begin{equation}
C_i = \iota_4 I_i + \epsilon_4 P_i + \delta_4 d_i^\epsilon + \delta_4 d_i^\epsilon + \tilde{\alpha}_4 \tilde{A}_s + \chi_4 X_{4,i} + \upsilon_{4,i}
\end{equation}
As in the Kamien-Schwartz '76 model, we assume that the rents from innovation depend on the characteristics of markets and technology and can either be fully appropriated by the innovator, or diffuse among a mixed ecology of innovation leaders and followers, who imitate and on average earn lower returns. In an ordinal ranking of firms that either do not apply new technologies, adopt them from external sources, or innovate on their own, we expect that a higher degree of innovation decreases the number of competitors.

The main exclusion restriction applies with regard to a sectoral taxonomy of appropriability conditions $\tilde{A}$, also derived from the EU-CIS. We consider that the characteristic differences in the distribution of appropriability measures at the industry level reflect exogenous sectoral contingencies, which correlate with the number of competitors by the individual firms. Furthermore, our model implies that the sectoral appropriability conditions affect innovation incentives only indirectly, that is if they have an influence on the intensity of competition. Consequently, they are uncorrelated with the error term in the innovation opportunity function. The same applies to population density and regulatory quality, which we assume to have a positive impact on competition, but exclude from the estimation of Equation (1).

Equation 5 summarizes the determination of our four endogenous variables within a joint system:

$$
\begin{pmatrix}
E_i \\
I_i \\
P_i \\
C_i
\end{pmatrix} =
\begin{pmatrix}
\gamma_1 C_i + \gamma_1^0 C_i^2 + \rho_1 R_i + \omega_1 \tilde{O}_s + \rho_2 \tilde{K}_s + \rho_3 \tilde{K}_s + \rho_4 \tilde{K}_s + \chi_1 X_1 + \iota_1 + \epsilon_i \\
+\gamma_2^\prime C_i + \gamma_2^\prime \tilde{O}_s + \gamma_2^\prime \tilde{K}_s + \gamma_2^\prime \tilde{K}_s + \chi_2 X_2 + \iota_2 + \epsilon_i \\
+\gamma_3^\prime C_i + \gamma_3^\prime \tilde{O}_s + \gamma_3^\prime \tilde{K}_s + \gamma_3^\prime \tilde{K}_s + \chi_3 X_3 + \iota_3 + \epsilon_i \\
+\gamma_4^\prime C_i + \gamma_4^\prime \tilde{O}_s + \gamma_4^\prime \tilde{K}_s + \gamma_4^\prime \tilde{K}_s + \chi_4 X_4 + \iota_4 + \epsilon_i
\end{pmatrix}
$$

(5)

For better illustration, we partition the system. Following the vector of endogenous dependent variables, the matrix on the right hand side provides a full enumeration of all explanatory variables. Those in the first column represent the endogenous variables, followed by the exclusionary restrictions used for identification. Those in the second column represent exclusion restrictions at the firm- and sector-level, respectively. $X$ is the block of covariates followed by the error terms.

4 Data

Our empirical analysis is based on data from the Swiss Innovation Survey (SIS) observed across 7 waves of a comprehensive survey conducted between 1999 and 2015 and collected by the Swiss Economic Institute (KOF) at the ETH Zürich. Observations come from a stratified random sample of firms having at least five employees within all relevant industries in manufacturing, construction, and service sectors. The stratification covers approximately 28 industries and, within each industry, three size classes (with full coverage of the upper class of firms). The firm panel is highly unbalanced, but by pooling the data we

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6Available from www.kof.ethz.ch
can use a sample of ca. 10’900 observations for our final estimations.\textsuperscript{7} The SIS is similar in content and structure to the EUROSTAT Community Innovation Survey (CIS) in other European countries, which is the primary data source for measuring firm-level innovation activity in Europe. CIS surveys have been coordinated internationally to confirm validity across contexts and constitute a reliable source for innovation studies.

In the following, we briefly highlight the main characteristics of the variables used in the estimation. Table 1 provides further detail and Table 2 presents selected summary statistics.

Among the endogenous variables, \textit{competition} is measured by the number of principal competitors in the firm’s main product category as reported by the survey respondents. These had to fall into either of four mutually exclusive classes.\textsuperscript{8} The consequent \textit{innovation outcome} is again an ordinal variable, which distinguishes between firms that have not introduced any new technologies; those which merely adopted a new technology; firms that developed product or process innovations in-house, even if not considered new to the market; and attributed the highest score to firms introducing product innovations that were new to the market. Finally, \textit{IPR use} is computed as the non-linear binary combination of various IP rights (patents, copyrights, trademarks or designs) which the firm has actually applied.

The dependent variables are affected by a number of confounders, which we include as controls in each of the equations. We consider, in particular, the technological potential, human capital (proxied by the share of employees with higher education), foreign ownership, export status, firm size, firm age as well as time and industry dummies (see Table 1 for further details on the variables).

The exclusionary restrictions needed for identification of the system fall into two groups. First, we apply specific industry level taxonomies that characterize the prevalent technological regime in which firms operate (Peneder 2010). They were built from European CIS micro-data at the Eurostat safe centre. Statistical clustering algorithms were applied to the standardized distributions of heterogenous firm types. One is the typical sector distribution of \textit{opportunity conditions} among the EU countries. Another the \textit{cumulativeness}
of knowledge, which reflects the relative importance of external vs. internal knowledge for creative and adaptive firms. Finally, the sector-level appropriability conditions were clustered from differences in the distribution of EU firms applying patents or other formal and strategic means to protect their innovations. All of the three taxonomies have the advantage that they are strictly exogenous to the dependent firm variables: first, because firms are too small (or industries defined too broadly) for any plausible incidence of reverse causality; second, the Swiss firms studied here were not included in the EU micro-data used for the clustering of the technological regimes.

The second set of exclusionary restrictions refer to firm-level responses about characteristics that should be unaffected by their own choices. Among them we use the past and expected growth of demand for the firm’s primary product, the effectiveness of IPRs, and a latent variable called hampering factors. The latter turns various self-reported technological factors that hamper innovation, i.e. lacking information on the latest technology and firms’ facing markets not willing to adopt new technology.

As a general caveat, we must assume that these exclusionary restrictions from the micro-data are not biased by the firms’ endogenous choices.
Table 1: List of variables

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>VARIABLE</th>
<th>DEFINITION</th>
</tr>
</thead>
</table>
| $E_i$  | R&D effort | 1 ... intramural R&D = 0  
|        |           | 2 ... R&D < 1.5% of total sales  
|        |           | 3 ... 1.5% < R&D ≤ 5%  
|        |           | 4 ... R&D > 5% of total sales |
| $I_i$  | Innovation | 1 ... Adaptive 1: pursuing opportunities other than from technological innovation (Non-innovators)  
|        |           | 2 ... Adaptive 2: introducing new products and/or processes new to their firm but not new to the market (Technology adopters)  
|        |           | 3 ... Creative 1: product/process innovator (new to the firm) developing innovation mostly on their own  
|        |           | 4 ... Creative 2: introducing products new to the market |
| $C_i$  | Competition | Number of principal competitors in the main product market worldwide; subjective firm assessment according to the following ordinal scale:  
|        |           | 1 ... Number of principal competitors ≤ 5  
|        |           | 2 ... Number of principal competitors > 5 & ≤ 15  
|        |           | 3 ... Number of principal competitors > 15 & ≤ 50  
|        |           | 4 ... Number of principal competitors > 50 |
| $P_i$  | IPR use | Non-linear binary combination of IP rights usage: ln\left[\left(\text{patents} + \text{copyrights} + \text{trademarks} + \text{designs}\right)^2 + 1\right] |

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>VARIABLE</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_i$</td>
<td>Hampering factors</td>
<td>Score of self-reported factors hampering innovation (or survey selection effect)</td>
</tr>
<tr>
<td>$P_i^a$</td>
<td>IPR effectiveness</td>
<td>Effectiveness of protection of innovation-based competitive advantages (Likert 1-5)</td>
</tr>
<tr>
<td>$P_i^b$</td>
<td>Expected demand</td>
<td>Expected demand in primary market (Likert 1-5)</td>
</tr>
</tbody>
</table>

Firm level exclusion restrictions are variables that are particular to a given equation in the system, but are not appropriate in all equations for theoretical reasons.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>VARIABLE</th>
<th>DEFINITION</th>
</tr>
</thead>
</table>
| $O_s$  | Opportunity | 1 ... neither intramural nor external R&D activities  
|        |           | 2 ... acquisition of external R&D, machinery, rights, etc.  
|        |           | 3 ... own R&D, but less or equal 5% of total sales  
|        |           | 4 ... own R&D, more than 5% of total sales |
| $A_s$  | Appropriability | 1 ... no appropriation measures  
|        |           | 2 ... appropriation only by secrecy, lead-time, or complexity of design  
|        |           | 3 ... appropriation by design patterns, trademarks, or copyright (with or without strategic methods)  
|        |           | 4 ... appropriation by patents (alone or with other strategic or other formal methods)  
|        |           | 5 ... appropriation by patents together with other formal and strategic methods |
| $K_s$  | Cumulativeness of knowledge | 1 ... reporting neither internal nor external knowledge sources of high importance  
|        |           | 2 ... creative firms with internal sources less important than external sources; adaptive firms with internal sources more or equally important  
|        |           | 3 ... creative firms with internal sources more or equally important than external sources; adaptive firms with external sources more important |

Sector level exclusion restrictions are variables that are particular to a given equation in the system, but are not appropriate in all equations for theoretical reasons.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>VARIABLE</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{i,0}$</td>
<td>Tech potential</td>
<td>Technological potential (Likert 1-5)</td>
</tr>
<tr>
<td>$X_{i,1}$</td>
<td>Higher education</td>
<td>Share of employees with higher education</td>
</tr>
<tr>
<td>$X_{i,2}$</td>
<td>Foreign owned</td>
<td>Whether the firm is owned by a non-Swiss entity</td>
</tr>
<tr>
<td>$X_{i,3}$</td>
<td>Export share</td>
<td>Share of firm sales coming from exports</td>
</tr>
<tr>
<td>$X_{i,4}$</td>
<td>Age</td>
<td>Firm age in years</td>
</tr>
<tr>
<td>$X_{i,5}$</td>
<td>Size</td>
<td>Firm size in number of full time employees</td>
</tr>
<tr>
<td>$X_{i,6}$</td>
<td>Intercept</td>
<td>Level of null model</td>
</tr>
</tbody>
</table>

IPRs are implied as this question is part of the IPR block in the survey.
Table 2: Summary Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D effort</td>
<td>1.67</td>
<td>0.965</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>innovation</td>
<td>1.73</td>
<td>0.773</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>IPR use</td>
<td>0.363</td>
<td>0.876</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>competition</td>
<td>2.21</td>
<td>1.04</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>competition²</td>
<td>5.97</td>
<td>5.266</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>hampering factors</td>
<td>0.013</td>
<td>1.22</td>
<td>-1.32</td>
<td>4.53</td>
</tr>
<tr>
<td>IPR effectiveness</td>
<td>1.08</td>
<td>1.18</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>demand past</td>
<td>3.15</td>
<td>1.03</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>demand expected</td>
<td>3.14</td>
<td>0.881</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>opportunity</td>
<td>2.19</td>
<td>1.08</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>cumulativeness</td>
<td>1.87</td>
<td>0.940</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>appropriability</td>
<td>2.59</td>
<td>1.67</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>techPotential</td>
<td>2.70</td>
<td>1.13</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>higher education</td>
<td>22.0</td>
<td>21.1</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>foreign owned</td>
<td>0.145</td>
<td>0.352</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>export share</td>
<td>22.98</td>
<td>33.9</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>ln[age]</td>
<td>3.98</td>
<td>0.668</td>
<td>0</td>
<td>6.36</td>
</tr>
<tr>
<td>ln[size]</td>
<td>4.01</td>
<td>1.37</td>
<td>0</td>
<td>10.57</td>
</tr>
</tbody>
</table>

N=10892
5 Empirical Estimation and Findings

The theory behind the system of equations in 5 requires a fair amount of consideration with regard to the type of estimation. So in order to efficiently estimate the system simultaneously, we use the three-stage least square estimator (3SLS) suggested by Zellner & Theil (1962); this estimator has several advantages compared to a 2SLS panel estimator, which is typically used in order to instrument endogenous dependent variables. The theoretical endogeneity implies that we must insert the estimated values of the dependent variables among the regressors in another equation, and hence expect their residuals to be correlated: the 3SLS approach uses generalized least squares to account for such a correlation structure. Taking advantage of the correlated error structure across equations, like seemingly unrelated regression (SUR), 3SLS is more efficient than 2SLS, and therefore gives more precise estimates in limited samples (Madansky 1964). There is an additional advantages if the system contains at least one over-identified equation, which is the case (cf. Table 4 for the over-ID tests). Otherwise, both methods are consistent and hence coefficients asymptotically equivalent. 10

In short, 3SLS gives us the instrumented values for the endogenous variables in the first stage. These are the predicted values resulting from regressing the endogenous variables on all exogenous variables in the model. In the second stage, the covariance matrix of the equation disturbances, which are based on the residuals of each in two-stage least square (2SLS) estimation in the system of equations, is computed. Finally, the third stage employs a GLS-type estimator using the covariance matrix from the second stage and the instrumented values from the first stage (Greene 2002, 405-407).

Since all coefficients and standard errors are estimated simultaneously, statistical tests involving coefficients can be performed conveniently. This makes it easier to test our hypotheses and to simulate the endogenous system, while also taking into account the indirect effects across different equations. For instance, we can quantify the indirect effects of a firm’s perception of IPR effectiveness on competition via a firm’s IPR use, thus accounting for indirect effects consistent with theory shown in our causal graph presented in Figure 1.

10Full information maximum likelihood would have been another choice, but that estimator is more sensitive to the underlying distributions. Green (2003, 409) states: “As always, the small properties remain ambiguous but by and large whereas systems estimators is used, 3SLS dominates FIML nonetheless (one reservation arises from the fact that the 3SLS estimator is robust to non-normality whereas, because of the term ln|Γ| in the log-likelihood, the FIML estimator is not. In fact the 3SLS and FIML estimators are usually quite different numerically”. 19
Table 5.0.1 reports the results for all four equations from the simultaneous system.

Turning to the first equation, the results confirm the expected inverted-U shaped impact of competition on R&D effort. This finding is consistent with assumption A2 and the results reported in Levin et al. (1985), Aghion et al. (2005), and Woerter (2014). Among the exogenous variables, higher growth of demand in the past 3 years, higher expected demand growth in the coming 3 years, better opportunity conditions at the sector level, a higher technological potential, a higher share of personnel with tertiary education and exports all tend to increase the firms’ R&D effort. Conversely, the aforementioned positive impact does appear in to be relevant for R&D effort, which amounts to rejecting hypothesis H3b.

Consistent with assumption A3, equation 2 confirms that R&D effort buys a greater probability of successful innovations. In addition, the estimates show that firm size and a high technology potential tend to raise the productivity of R&D. In contrast, high cumulative knowledge appears to reduce the probability of success for the average firm.

Explaining the firm’s choice of using IPRs, successful innovation is a necessary precondition (H5). Consistent with our hypotheses H1 and H4, firms that operate in industries with favourable appropriability conditions and those which perceive IPRs to be effective, are more likely to use them. A higher expected growth of demand, technology potential, more employees with higher education, exports and firm size are further conducive factors to the use of IPRs. In contrast, foreign ownership appears to obstruct it (which may, however, be a particular feature of the Swiss situation).

With regard to the intensity of competition that is explained by equation four, intramural innovation has the expected negative impact of assumption A4. Among the exogenous variables, past and future demand growth, technology potential, highly educated employees, exports, age and size all tend to increase the number of competitors in the main product, whereas foreign ownership associates with fewer competitors.

Our main interest, however, culminates in the impact of IPRs on competition. Here the findings seem to fully reward our attention to both the sector and firm level as simultaneous locus of independent effects: consistent with hypothesis H2, better appropriability conditions at the sector level tend to increase the number of competitors, while for a given market structure and in accordance with hypothesis H6 the firm’s own use of IPRs is a means to reduce it.
5.0.1 3SLS IV System

Table 3: Full 3SLS System

<table>
<thead>
<tr>
<th></th>
<th>R&amp;Deffort</th>
<th>Innovation</th>
<th>IPRuse</th>
<th>competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endogenous System</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>competition</td>
<td>11.2***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.57)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>competition²</td>
<td>-2.18***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-3.59)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;Deffort</td>
<td></td>
<td>0.306***</td>
<td>-36.8***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9.60)</td>
<td>(-28.0)</td>
<td></td>
</tr>
<tr>
<td>Innovation</td>
<td></td>
<td>0.487***</td>
<td>-3.10***</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(3.13)</td>
<td>(-4.91)</td>
<td></td>
</tr>
<tr>
<td>IPRuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm Variables</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>haperingFactors</td>
<td>0.011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.73)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPReffectiveness</td>
<td>0.005</td>
<td>0.091***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-0.29)</td>
<td>(1.16)</td>
<td></td>
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</tr>
<tr>
<td>pastDemand</td>
<td>0.074***</td>
<td></td>
<td>0.294***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.99)</td>
<td></td>
<td>(6.28)</td>
<td></td>
</tr>
<tr>
<td>expectedDemand</td>
<td>0.091***</td>
<td>0.030***</td>
<td>1.28***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.01</td>
<td>2.62</td>
<td>(12.9)</td>
<td></td>
</tr>
<tr>
<td>Exogenous Sector Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opportunity</td>
<td>0.435***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.47)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative</td>
<td>-0.147</td>
<td>-0.026***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-1.113)</td>
<td>(-3.60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appropriability</td>
<td></td>
<td>0.063***</td>
<td>0.824***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.37)</td>
<td>(6.02)</td>
<td></td>
</tr>
<tr>
<td>Control Variables</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>techPotential</td>
<td>0.066***</td>
<td>0.022***</td>
<td>0.029***</td>
<td>2.04***</td>
</tr>
<tr>
<td></td>
<td>(3.92)</td>
<td>3.19</td>
<td>2.83</td>
<td>(12.5)</td>
</tr>
<tr>
<td>higher_education</td>
<td>0.008***</td>
<td>-0.000</td>
<td>0.002***</td>
<td>0.078***</td>
</tr>
<tr>
<td></td>
<td>(7.11)</td>
<td>(-0.797)</td>
<td>3.93</td>
<td>(8.514)</td>
</tr>
<tr>
<td>foreignOwned</td>
<td>-0.119</td>
<td>0.005</td>
<td>-0.067***</td>
<td>-2.34***</td>
</tr>
<tr>
<td></td>
<td>(-2.17)</td>
<td>(0.820)</td>
<td>(-2.86)</td>
<td>(-5.15)</td>
</tr>
<tr>
<td>exportShare</td>
<td>0.008***</td>
<td>-0.000</td>
<td>0.005***</td>
<td>0.076***</td>
</tr>
<tr>
<td></td>
<td>(9.54)</td>
<td>(-1.46)</td>
<td>15.5</td>
<td>(9.95)</td>
</tr>
<tr>
<td>ln[Age]</td>
<td>0.024</td>
<td>0.011</td>
<td>0.017</td>
<td>0.564***</td>
</tr>
<tr>
<td></td>
<td>(1.01)</td>
<td>(1.04)</td>
<td>(1.39)</td>
<td>(2.36)</td>
</tr>
<tr>
<td>ln[Size]</td>
<td>0.017</td>
<td>0.041***</td>
<td>0.078***</td>
<td>2.82***</td>
</tr>
<tr>
<td></td>
<td>(0.69)</td>
<td>(6.62)</td>
<td>(6.37)</td>
<td>(15.6)</td>
</tr>
<tr>
<td>intercept</td>
<td>-11.9***</td>
<td>0.838***</td>
<td>-1.40</td>
<td>30.9***</td>
</tr>
<tr>
<td></td>
<td>(-3.45)</td>
<td>(14.9)</td>
<td>(-9.99)</td>
<td>(20.1)</td>
</tr>
</tbody>
</table>

N=10'967; (t-stat); **10%, ***5%, ***1%. Industry and year dummies omitted for concision.
Instrumental variable tests conducted by 2SLS estimations for each pair of equations with a causal connection confirm that all of them are correlated with the endogenous variable (rejecting the Anderson canonical correlation test for under-identification), while the fact that they are predetermined guarantees (by assumption) that they are uncorrelated with the error terms (Table 4). Except for the first equation explaining R&D choice, the Sargan Test for over-identification has also been passed (see Table 4).\(^\text{11}\)

<table>
<thead>
<tr>
<th>Endogenous variable</th>
<th>Under-identification</th>
<th>Weak identification</th>
<th>Over-identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D effort</td>
<td>0.009***</td>
<td>3.10</td>
<td>0.960</td>
</tr>
<tr>
<td>Innovation</td>
<td>0.017**</td>
<td>3.78</td>
<td>0.345</td>
</tr>
<tr>
<td>IPRuse</td>
<td>0.009***</td>
<td>4.73</td>
<td>0.371</td>
</tr>
<tr>
<td>Competition</td>
<td>0.000***</td>
<td>4.90</td>
<td>0.113</td>
</tr>
</tbody>
</table>

*0.10, **0.05, ***0.01; stars for C-D test represent relative bias of S-Y critical values.

### 6 Simulation

In order to understand the implications of the model we compute the changes in the endogenous system by shocking select exogenous variables by two standard deviations, by moving from one standard deviation below the mean to one standard deviation above the mean. The algebra behind this system is presented in Appendix 8. Table 5 shows the equilibrium shift in percentage terms.

\(^\text{11}\)We test the instruments of the system in section, in a 2SLS framework by recursively inserted the predicted equation into another and then test whether the exclusion restrictions hold in a partial model. Exclusion restrictions are limited to those, which are exclusion restrictions in the full model. This means concretely that while ln[\text{Age}], for example, may be construed as an exogenous regressor in a 2SLS framework, it is a control in the 3SLS system, and thus cannot be used for identification in our 2SLS battery of IV tests.
<table>
<thead>
<tr>
<th>Exogenous Variable</th>
<th>R&amp;D effort</th>
<th>Innovation</th>
<th>IPR use</th>
<th>Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>3.9</td>
<td>-13.2</td>
<td>123.6</td>
<td>-0.4</td>
</tr>
<tr>
<td>IPR effectiveness</td>
<td>-0.8</td>
<td>1.4</td>
<td>54.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Appropriability</td>
<td>2.8</td>
<td>-4.6</td>
<td>71.5</td>
<td>-0.4</td>
</tr>
<tr>
<td>Demand</td>
<td>2.8</td>
<td>-4.5</td>
<td>21.4</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Simulated \( \frac{\partial y}{\partial x} \) of endogenous variables based on \(+2 \sigma\) around \( \mu_x \)

Larger firms exhibit higher levels of R&D, presumably because the marginal effect is larger.\(^{12}\) Competition is a fairly invariant response in the level of competition in our sample; this could be mirroring fairly static industry dynamics and industrial organization. In contrast, IPR usage is responsive to the business cycle, and exhibits more variability in our sample. As firms grow larger, IPR usage increases dramatically, which is consistent with our observation that large companies have bigger portfolios. IP is more valuable to a larger company in that a single global trademark can boost global sales; a single patent can be licensed worldwide. A single trademark for a local firm does not have the same marginal benefit. The effectiveness of the IPR in the firm’s particular business case (IPR effectiveness) plays a lesser role than does the structural effect of the industry (appropriability) on IP rights usage. What is especially important to note is that these values capture the indirect effects. This is why IPR effectiveness, a variable which is not included in 2/4 equations can still have an (indirect) impact on the endogenous outcome variables in those equations where it is excluded. So for example, higher levels of appropriability encourage more competition as new entrants seek to profit as well, raising competition, which in turn lowers the funds available to perform R&D, negatively affecting innovation. The net affect of any one change must therefore be seen through the lens of these sometimes competing direct and indirect effects.

7 Summary and Conclusions

IPRs are a popular policy tool to foster innovation. But their actual impact can be more ambiguous than is generally perceived. In short, the pro-IPR rationale originates in the problem of appropriability, or missing markets for new knowledge. When it bears characteristics of a public good with non-rival and non-excludable use, the fact that producers cannot fully appropriate the social returns undermines their incentives to invest own effort and resources. Thus the situation will typically provoke an under-supply of innovation.\(^{12}\)

\(^{12}\)Thompson & Wörter (2017) presents a simple model for this effect.
When IPRs are effective, however, firms can use them to appropriate the economic benefits of own innovations. IPRs thus transform public goods into club goods, where consumption is excludable but still would be non-rival. The consequence is a tendency towards under-consumption, since the individual price to pay becomes larger than the social cost of use.

There is clearly a trade-off between legal provisions that render new knowledge public or a club good. Two crucial intermediating factors are the impact of IPRs on competition on the one hand, and the mutual relationship between competition and innovation on the other. Both add considerable complexity to the problem. For example, the actual choice to use IPRs may successfully and independently reduce competition for the individual firm. At the same time, the widespread usability of IPRs in an industry may protect small and innovative firms against the dominance of large competitors. Or to put it differently, diminished appropriability may raise the strategic advantages of a few large firms and thereby hinder competition. We thus must expect independent and potentially opposite effects of IPRs at the meso-level of industries and the micro-level of individual firms (for a given “technological regime”).

The second complication arises from the endogeneity of competition and innovation. Largely undisputed is the expected negative impact of innovation on competition. But the question how competition affects R&D incentives has been highly controversial, repeatedly shifting between theoretical and empirical claims for a negative or positive impact. More recently, the hypothesis of an inverted-U relationship has attracted much research and distinctively adds further complexity by conditioning the impact on the initial level of competition.

In this paper, we aimed to test whether IPRs foster or hinder innovation and developed a small structural model, which is designed to comprehensively address the above relationships. We estimated a simultaneous system of four equations for a large sample of Swiss firms. Our main findings confirm the above concerns and identify various mechanism of how IPRs affect competition and the incentives to innovate:

- Treated as a purely exogenous variable, which reflects technological characteristics of an enterprise’s narrower knowledge domain, a higher effectiveness of IPRs significantly increases the probability that it invests in own R&D.

- Also treated as a purely exogenous variable but at the industry level, better appropriability conditions significantly raise the number of competitors, presumably by allowing more innovative companies to stay in the market.

- Being part of the endogenous core of the system, an individual firm’s actual use of IPRs significantly reduces the number of competitors for its principal product.

\[13\] The well known and more specific problems, such as strategic hold-up of competitors, are easily understood as particular instances of this general tension.
Confirming an inverted-U relationship between competition and innovation effort, the full endogenous system further implies that fewer competitors (e.g., due to the above use of IPRs) tends to raise R&D, when initial competition has been strong, and tends to further reduce it, if initial competition has been weak.

We believe that the added complexity of simultaneously solving for IPR use, competition and innovation can explain some of the ambiguity of previous research as to why the link between innovation and IPRs has been mixed. In short, the final impacts of IPRs depend on a non-linear second order effect of decreasing competition on the firm’s innovative behavior. As a consequence, IP regulations may require closer integration with competition policy. Moreover, since the market for technology is international, these complex interdependencies may not be well addressed by the competition authority in any one jurisdiction.

Further research is certainly warranted. This study covered but Switzerland – a small country – with lots of unobserved competition. Future research would attempt to implement this in one or several markets where all the competitors can be observed. Moreover, our key outcome variable, IPRuse could be improved by matching with the patent, trademark, and design databases.

References


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8 Appendix

8.1 Reduced Form

The foregoing exposition describes the economic rationale and identification strategy for our endogenous system. We can also solve the system to obtain a reduced form of the model, which is then written in terms of exogenous variables and coefficients. We drop the error terms from the system for conciseness of exposition. First, we substitute the firm’s effort identity into the innovation Equation 2 to yield the innovation identity:

\[ I_i = \epsilon_2^2 \gamma_1^2 C_i + \gamma_1^2 C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta R_i + \delta_i + \omega_i O_s + \xi_1 K_s + X_1 X_{1,i} + v_{1,i} + \xi_2 K_s + x_2 X_{2,i} + v_{2,i} \]  

(6)

We substitute this now into the IPR strategy Equation 4

\[ P_i = \nu_3 (\nu_2^2 \gamma_1 C_i + \gamma_1^2 C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta R_i + \delta_i + \omega_i O_s + \xi_1 K_s + X_1 X_{1,i} + v_{1,i}) \\
+ \epsilon_3 e_i + \delta_i d_i + \delta_3 \Delta_s + \chi_3 X_{3,i} + v_{3,i} \]  

(7)

We substitute that identity into the competition Equation 4

\[ C_i = 4_4 (\nu_2^2 \gamma_1 C_i + \gamma_1^2 C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta R_i + \delta_i + \omega_i O_s + \xi_1 K_s + X_1 X_{1,i} + v_{1,i}) \\
+ \epsilon_2 \xi_2 K_s + X_2 X_{2,i} + v_{2,i}) + 4_4 (\nu_3^2 (\nu_2 \gamma_1 C_i + \gamma_1^2 C_i^2 + \\
+ \epsilon_3 e_i + \delta_i d_i + \delta_3 \Delta_s + \chi_3 X_{3,i} + v_{3,i}) \\
+ \epsilon_3 e_i + \delta_i d_i + \delta_3 \Delta_s + \chi_3 X_{3,i} + v_{3,i}) \]  

(8)

In Equation 11, next we group the competition terms outside of the inner expression:

\[ 0 = 4_4 (\nu_2^2 \gamma_1 C_i - C_i + \epsilon_4^2 \gamma_1^2 C_i^2 + \epsilon_4^2 \gamma_1^2 C_i^2 + \\
+ \epsilon_4 (\nu_2^2 \gamma_1 C_i + \gamma_1^2 C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta R_i + \delta_i + \omega_i O_s + \xi_1 K_s + X_1 X_{1,i} + v_{1,i}) + \\
+ \epsilon_2 \xi_2 K_s + X_2 X_{2,i} + v_{2,i}) + \\
+ \epsilon_4 (\nu_3^2 (\nu_2 \gamma_1 C_i + \gamma_1^2 C_i^2 + \\
+ \epsilon_3 e_i + \delta_i d_i + \delta_3 \Delta_s + \chi_3 X_{3,i} + v_{3,i}) + \\
+ \epsilon_3 e_i + \delta_i d_i + \delta_3 \Delta_s + \chi_3 X_{3,i} + v_{3,i}) + \\
+ \delta_4 d_i + \delta_4 d_i + \delta_3 \Delta_s + \chi_3 X_{3,i} + v_{3,i}) \]  

(9)

Recall that for a 2nd degree polynomial of the form \( ax^2 + bx + c = 0 \), the quadratic formula gives its roots:

\[ C_i = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]  

(10)
For concision we write polynomial in terms of the exogenous variables:

\[ a = \epsilon_4\gamma^\phi_1 + \epsilon_4^\phi_1 \gamma^\phi_1 \]
\[ b = (\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1) \]
\[ c = \epsilon_4^\phi_3 (\rho_1 \gamma^\phi_2 + \epsilon_1 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \delta_1^\phi_2 \delta_1^\phi_2 + \tilde{\omega}_1 \bar{O}_1 + \bar{K}_1 \bar{X}_1 + \bar{r}_1 \bar{X}_1 + \nu_1, \nu_1) + \]
\[ \bar{K}_2 \bar{X}_2 + \gamma_2 \bar{X}_2, \nu_2, \nu_2) + \]
\[ \epsilon_4^\phi_3 (\rho_1 \gamma^\phi_2 + \epsilon_1 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \delta_1^\phi_2 \delta_1^\phi_2 + \tilde{\omega}_1 \bar{O}_1 + \bar{K}_1 \bar{X}_1 + \bar{r}_1 \bar{X}_1 + \nu_1, \nu_1) + \]
\[ \bar{K}_2 \bar{X}_2 + \gamma_2 \bar{X}_2, \nu_2, \nu_2) + \]
\[ \epsilon_2 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \delta_2 \bar{X}_2 + \nu_3 \bar{X}_3, \nu_3, \nu_3) + \]
\[ \delta_1^\phi_2 \delta_1^\phi_2 + \delta_2 \bar{X}_2 + \nu_4 \bar{X}_4, \nu_4 \]

(11)

This leads to the following substitution in Equation 4 for competition:

\[ C_i = \frac{-((\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1) \pm \sqrt{(\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1)^2 - 4ac}}{2(\epsilon_4^\phi_1 + \epsilon_4^\phi_1 \gamma^\phi_1)} \]

(12)

We can now substitute back into the R&D effort in Equation 1 to get the value in terms of the exogenous variables:

\[ \ell_i = \gamma_1 (\frac{-((\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1) \pm \sqrt{(\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1)^2 - 4ac}}{2(\epsilon_4^\phi_1 + \epsilon_4^\phi_1 \gamma^\phi_1)} + \gamma_1^\phi (\frac{-((\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1) \pm \sqrt{(\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1)^2 - 4ac}}{2(\epsilon_4^\phi_1 + \epsilon_4^\phi_1 \gamma^\phi_1)} + \rho_1 \gamma^\phi_2 + \epsilon_1 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \tilde{\omega}_1 \bar{O}_1 + \bar{r}_1 \bar{X}_1, \nu_1, \nu_1) + \]
\[ \bar{K}_2 \bar{X}_2 + \gamma_2 \bar{X}_2, \nu_2, \nu_2) + \]
\[ \epsilon_2 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \delta_2 \bar{X}_2 + \nu_3 \bar{X}_3, \nu_3, \nu_3) + \]
\[ \delta_1^\phi_2 \delta_1^\phi_2 + \delta_2 \bar{X}_2 + \nu_4 \bar{X}_4, \nu_4 \]

(13)

And now the innovation equation:

\[ t_i = \epsilon_2 \gamma_1 (\frac{-((\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1) \pm \sqrt{(\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1)^2 - 4ac}}{2(\epsilon_4^\phi_1 + \epsilon_4^\phi_1 \gamma^\phi_1)} + \gamma_1^\phi (\frac{-((\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1) \pm \sqrt{(\epsilon_4^\phi_2 + \epsilon_4^\phi_2 \gamma^\phi_1 - 1)^2 - 4ac}}{2(\epsilon_4^\phi_1 + \epsilon_4^\phi_1 \gamma^\phi_1)} + \rho_1 \gamma^\phi_2 + \epsilon_1 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \tilde{\omega}_1 \bar{O}_1 + \bar{r}_1 \bar{X}_1, \nu_1, \nu_1) + \]
\[ \bar{K}_2 \bar{X}_2 + \gamma_2 \bar{X}_2, \nu_2, \nu_2) + \]
\[ \epsilon_2 \epsilon_1 + \delta_1^\phi_2 \delta_1^\phi_2 + \delta_2 \bar{X}_2 + \nu_3 \bar{X}_3, \nu_3, \nu_3) + \]
\[ \delta_1^\phi_2 \delta_1^\phi_2 + \delta_2 \bar{X}_2 + \nu_4 \bar{X}_4, \nu_4 \]

(14)