Competition and Invention Quality: Evidence from Swiss Firms

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Abstract

The economic value of international markets are questioned by recent political decisions in several dimensions. Focusing on innovation we investigate the relationship between access to international markets, competition in those markets, invention quality, and firm performance. We compile a unique time-series cross-section dataset combining patent and survey data covering the period 1990-2013 that allows us to develop several measures of market structure, invention quality, and performance. We apply econometric procedures using international trade shocks as an instrument to identify invention quality and address selection issues with a Bayesian approach. We find evidence that the positive effect of invention quality on sales of innovative products is positively mediated by access to international markets and the type competitive environment found there. Specifically, competition that is characterised by non-price factors (first-mover advantages, lead-time, services) and firms' access to international markets positively leverages inventive quality. This has important policy implications for trade policy and underscores the meaningfulness of open markets for invention quality, especially in a small open economy such as Switzerland's.

Keywords: patents, innovation, competition

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1. Introduction

Moves such the U.K.'s Brexit vote and the United States' cancellation of the Trans-Pacific Partnership have politically called into question the value of international market access. We find international markets are important in ways that go beyond the static gains of neoclassic trade theory. Specifically, we provide evidence that access to the international market and exposure to international competition yields fruit in the form of quality invention. Based on Swiss data, a small open economy, this study investigates the importance of access to large globalized markets and international competition for the quality of inventions, and their effects on the market success of innovative products.

The role of competition and innovation has been a topic of debate within the innovation literature for a long time (cf. e.g., Scherer (1967), Aghion et al. (2005), Gilbert (2006)), be it in terms of the

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intensity or the type of competition. We contribute to this discussion by underscoring the role of market size and access to large markets (as proxied by exports) and the importance of the non-price aspect of competition. Our argument is more general than just exporting it would extend to all large markets, but since the Swiss domestic market is the size of a Chinese city, we believe that the export share is a good proxy for market size.

We investigate–in a first step–the meaning of access to international markets and the type of competition found in those markets for the inventive output (patent families) and the quality of the inventive output, respectively. In a second step we look at the relationship between invention quality and the market success of innovative products emphasizing the role of access to larger, international markets and the type of competition in those markets.

With this investigation, we add to the existing literature in several ways. First, we use a new measure for the quality of inventions based a principle component analysis on five quality indicators; these are forward citations, generality, family count, NPL counts and number of claims. Second, we can use a multi-criteria competition measure. Competition is frequently measured in terms of concentration ratios (C4, C5), the Herfindahl-Hirschman Index, relative cost measures (Boone (2000)), or by single types of competition, for instance, product obsolescence, product substitution, or barriers to entry (Vives (2008), Beneito et al. (2015)). We use principal component analysis on four competition indicators (export share, price competition, non-price competition, and number of principle competitors in the main sales market worldwide), resulting in two types of markets: 1. international oligopolistic like markets; 2 international markets that are characterized by non-price competition parameters, like first-mover advantages, customization, and services. Such an approach better mirrors the complex competitive reality of firms than single competition measures such as C4 ratio. Third, we identify the meaning of international market competition for invention quality, which has been largely overlooked by the empirical literature so far (cf. Table 2.1). Fourth, we investigate which market conditions allow inventive quality to boost innovative sales.

In analysing these relationships, we run into well-known problems of endogeneity. Inventive firms select into certain markets, and inventive quality cannot be perceived exogenous to innovation performance. Hence, we try to disentangle causality between quality and sales performance with an instrumental variable approach whereby exogenous change in Switzerland's international market regime, like the WTO, dot-com crash/euro and the financial crisis of 2008 are used as instruments for invention quality. Figure 1 plots the quality of patent output from Switzerland over time. Rather than being a static affair Figure 1 reveals some variance throughout time. We use this time variance in order to identify the quality effects, and we then build an exclusion restriction based on important changes in international market regimes. Figure 1 reveals that a change in international market regime was always related with a significant change in the quality of inventions on an aggregated level. We interact this information with the initial exposure of firms to such regime changes and use this variable as the instrument for invention quality.

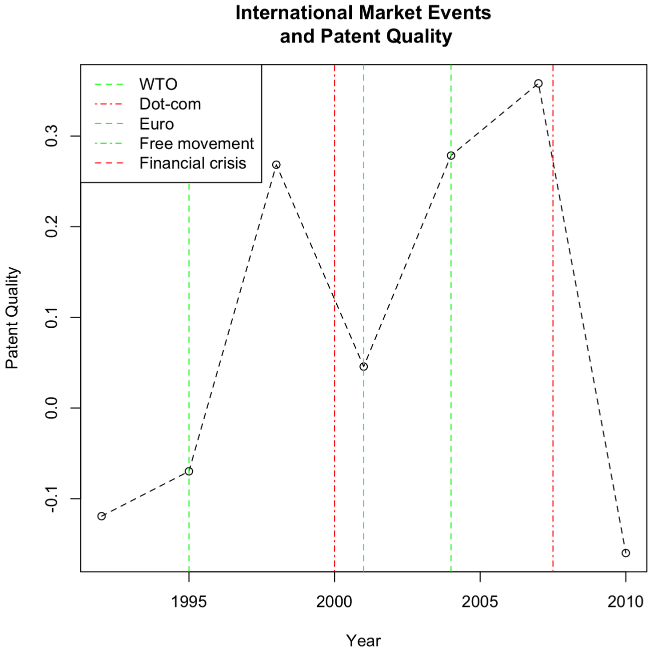

Figure 1: Patent quality may depend on international market conditions. This leads to asymmetric effects between exporters and non-exporters. We find evidence for three general phases: pre/post-WTO (1990+1993/1996+1999), pre/post-Euro (1996+1999/2002+2005), and pre/post global financial crisis (2005/2008). We find statistically significant difference in terms of the patent quality for exporters and non-exporters these three periods in terms of patent quality produced, with p-values (with n degrees of freedom) for each period: 1. p=0.109 (398); 2. p=0.04 (739) 3. p=0.035 (316) respectively.

Applying several econometric approaches including an instrumental variable regression and using a representative sample of Swiss firms over the period 1990 to 2013, we show that invention quality is positively related with innovative sales. Moreover, we learn that international competition and access to large markets are key elements for the quality of patented inventions and that the market success of firms with high quality inventions are significantly and positively associated to those markets. Access to international markets and non-price competition in those markets leverage invention quality. Consequently, political measures that shrink market size are likely to decrease inventive quality and the market performance of innovative firms accordingly. Small, technologically advanced countries would stand to loose competitiveness due to their small and more competitively sheltered markets. This implies that policy movements that reduce access to relevant markets is likely to decrease the quality of inventions. Moreover, there has been plenty of discussion about how to gain high quality inventions in policy circles. Often this discussion focuses on education, tax and regulation policy, but we find a relative dearth of emphasis on the types of markets and competitive environments that shape innovation and inventive output. In this study, we provide evidence that competition and access to international markets are key elements for patented invention. Being a small liberal and very open economy with highly innovative industries, Switzerland presents a unique case. Switzerland's openness is part of the puzzle for explaining the country's innovative performance, but one in which competition, rather than market access *ipso facto*, is an important proximate cause explaining some of that innovation. The simple policy implication is that trade barriers that limit access to large international markets might seriously dampen high quality inventions and might have negative growth effects in the medium term.

The paper is organized as follows. We first look at the literature surrounding patent quality, competition, and innovation. Next we present a basic model of how larger market and competition can affect patent quality and formulate the hypotheses. In section four we describe the data, show how we measure the quality of inventions, and how we address selection issues. In section five we explain the empirical specification. In section six we present the results and in section seven we conclude.

2. Literature

We place this paper in two main strands of the innovation literature. The first relates to the competition and innovation, the second deals with innovation and firm performance. As we shall see, measuring competition, innovation, and performance is a non-trivial task that the empirical literature has had to address. While we follow a slightly different approach, it is worth contextualizing the debate heretofore. Succinctly stated, our paper highlights the fact that market size and the type of competition in those markets leverages invention quality in terms of firm performance; invention quality only pays-off in competitive, bigger international markets. In terms of a contribution, we underscore the importance of international market size for patented inventions and the competition that comes along with it. We first take a look at the storied writings surrounding competition and innovation, market size and innovation, and how firm performance is related to inventive quality.

2.1. (International) Competition and Innovation

Observationally and theoretically, bigger markets generate more incentives to invent, but bigger markets also attract more players. These stylized facts have given rise to a long literature on competition and innovation emphasizing the meaning of concentration levels, number of competitors and their strategic interactions, non-price features, and access to international markets for the inventive activities of firms. They have their roots in Joseph Schumpeter's idea that firms innovate in order to escape from the tyranny of competition. Table 2.1 provides an overview of the key works.

Concentration

The basic concern centered around the level of concentration conducive to innovation. Theorists, like Reinganum (1983), took the focus away from the market and put it on the strategic interaction between few firms using an incumbent firm and challenger model. Writers on growth nibbled at the innovation question using more general growth models (e.g. Grossman and Helpman (1991)). However, it was Aghion et al. (2005) who revived theories about market structure and innovation, finding that innovation depends on the market concentration – highly concentrated markets are less innovative than oligopolistic ones; highly competitive environments are also less innovative. In contrast, Greenhalgh and Rogers (2006) shows that the market value for R&D depends on the level of competition – i.e. the payoff is more certain for investors; they suggest that the competitive science sector attracts lower R&D valuations. Boldrin and Levine (2008) reject the notion that innovation cannot take place in a competitive environment, and speak of transitory innovation rents that enable innovation despite the competition. In a detailed survey of the literature on the link between innovation and competition, Gilbert essentially says that there is no coherent picture for the relation; he concludes "[w]e remain far from a general theory of innovation competition, although the large body of theoretical and empirical evidence is beginning to yield conclusions, however meagre Gilbert (2006)."

Table 1: Statistical Studies of Innovation & Competition

Study	Dependent	Conclusions
Scherer (1965b)	patents	No correlation between R&D intensity and concentration
Scherer (1967)	R&D employment	Positive correlation with concentration, then falling after C4 of 50-55% after controlling for industry effects
Comanor (1967)	R&D expenditures	R&D intensity greatest in industries with barriers to entry
Mansfield (1977)	R&D expenditure,innovations	Some evidence of positive correlation at low levels of market concentration, but none above moderate levels
Mansfield et al. (1981)	R&D expenditures	Concentrated industries spent less on basic research; otherwise concentration had no significant effect on R&D
Scott (1984)	R&D expenditures	No correlation between concentration and R&D after controlling for fixed effects
Link and Lunn (1984)	Rate of return on R&D	Returns to process R&D increased with concentration. Returns to product R&D independent of concentration
Levin and Reiss (1984)	R&D expenditures	No statistically significant correlation with concentration
Culbertson and Mueller (1985)	R&D employment, expenditures, patents	Positive correlation with concentration in food manufacturing industries up to a threshold C4 of about 60%
Levin et al. (1985)	R&D expenditures, innovations	No effect of concentration on R&D after accounting for differences in appropriability
Angelmar (1985)	R&D expenditures	Concentration positively related to R&D intensity in industries with low barriers to imitation, negatively related to R&D in industries with high barriers to imitation.
Lunn (1986)	Patents	Process patents in low-tech industries positively related to concentration. No effect of concentration on product patents, or process patents in high-tech industries.
Lunn and Martin (1986)	R&D expenditures	R&D/sales increased with market share and C4 index in low-tech industries
Blundell et al. (1999)	Market value	High-market share firms leverage innovations the most
Aghion et al. (2005)	Citation-weighted patents	Finds an inverted U shape where medium levels of competition exhibit the most innovation
Greenhalgh and Rogers (2006)	Market value of R&D	Higher market share leverages R&D
Tang (2006)	Product/process innovation	Innovation negatively correlated with substitutability; faster product and production cycles associated with innovation
Artés (2009)	R&D intensity	Market structure dictates the long-term R&D decision, but not the short-run intensity
Bondt and Vandekerckhove (2012)	R&D investment	Dependent on product differentiation, Bertrand vs. Cournot competition, and spillovers

Adapted and extended from Gilbert (2006)

Number of competitors

Adjacent to this core empirical Schumpeterian literature, many papers exploring the link between competition and innovation focus on two very old ideas: Betrand and Cournot competition, extended to innovation. Exemplifying this, Negassi and Hung (2014) test the ideas of Bertrand and Cournot with respect to innovation using Community Innovation Survey data by comparing the effects of market competition amongst firms receiving public R&D grants (Cournot case) with those in the civil sector (Bertrand case). Using the Lerner index, Negassi and Hung (2014) finds competition to foster innovation, especially in the Bertrand case. Beyond studies of markets with "few vs. many" innovative competitors, Takahashi (1999) develops a more specific theoretical model where a duopoly leads to slower innovation than a monopolistic market structure. In contrast, Dana and Fong (2011) develop a model showing that oligopolistic market structure can lead to a high quality innovative output equilibrium, but is one of but many and is easiest to sustain in a duopoly: monopolists having less incentive to produce higher quality; competitive markets have a harder time maintaining a high quality equilibrium. Also taking the focus away from the polypolistic-oligopolistic distinction of classical competition theory, Vives (2008) consolidates various strands of the neo-classic competition literature into a coherent models based on market size, barriers to entry and product substitutability, finding that larger market size does not lead to more varieties because competing firms invest in quality. He essentially shows that firms are innovative in the face of free entry and more substitutability and generate new products when the fixed costs to introduce them are higher, creating a barrier to entry for that variety. His hypotheses were tested by Beneito et al. (2015), who, *inter alia* find, that firms facing larger markets and who are exporters tend to produce more process and product innovations. While these more mainstream aspects of competition might be most applicable to the "Mark II" situation (i.e. competition amongst big players), Cohen, in a nice overview of the subject, notes the difficulty of testing these theoretical notions of competition and innovation because the models require highly stylized situations not found in the wild (Cohen 2010, 155).

Non-price competition

Aside from the effects of market concentration and formal types of price and quantity dumping, there is a further "bucket" for competition, which do not fit within the classic paradigms. In our study, we call this "non-price competition", and it takes on various forms, such as competing on services, lead time, customization, or perhaps most relevant to this study, technological competition. Specifically with respect to innovation, He et al. (2006), for example, points out how the innovation of entrants can be used with its original capabilities to attack incumbent firms; they also show in great detail how forward and backward citations elucidate the competitive dynamic between companies (cf. Fig 3, p. 1156). Competition induces firms to take innovating competitors out through acquisition, this type of behaviour is documented in the patent record. Conversely, the market concentration in the field may belie the fact that technological firms are not necessarily in competition: inscribed in the patent record are both jointly held intellectual property rights and certain licensing deals. Adjacent citations within a IPC class are some indication of competition (Baudry and Dumont 2012, 892). Indeed, technological competition is real and the market reduces valuations when new firms enter into the same technological market as an incumbent firm.[1] Patenting firms by their nature compete with others directly in the legal space, and will ring-fence inventions with patents Schneider (2008). Tang (2006) deliberately tries to characterize competition within this "bucket" using survey data by characterizing competition in terms of substitution, new products, obsolescence, and cost pressure with the type of innovation inputs and outputs using Canadian innovation survey data.

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[1] Baudry and Patel's finding also shows that using forward citations as a pure quality metric can be misleading in that they can be proxy for competition within a given field or industry—one reason we use a synthetic metric (cf. infra).

Market size and international aspects

The last aspect of the innovation-competition link is market size, and there are few doubts that market size is important for innovation. Schmookler was perhaps the first to systematically investigate the demand-side to highlight its relevance in generating invention by relating sales and corporate patents; for him the "extent of the market" was the governing factor of firms' innovation. Scherer came to the same conclusion as Schmookler in a 1982 replication of that earlier 1966 study (Scherer 1982). The major empirical problem with market size has been disentangling the market's demand [pull] from the technology supply side [push] as these are typically jointly determined (albeit some exceptions exist like in pharmaceuticals where the demand is essentially fixed). Moreover, product innovations pose a particular conceptual problem for defining demand econometrically when they create an entirely new category of product, like the iPhone or iPod. How does one measure demand of a hitherto inexistent product? Godin and Lane (2013), in a survey of the literature, traces the long storied evolution of demand-driven innovation and points out that innovation is related to some sort of need rather than an extant market with defined demand. Firms do seem to be able to anticipate these "needs", Acemoglu and Linn (2004) show that pharmaceutical firms adjust their R&D program to their changing market size and composition with industry data.

A recurrent observation in the literature is the international aspect of patenting. Using Italian micro-data and exchange rate shocks, Basile (2001) finds that the export intensity of innovative firms is much higher than for non-innovative firms. Pla-Barber and Alegre (2007), using a panel of French biotechnology, show that innovation is related to export intensity. Cassiman and Golovko (2011) find for Spanish firms, consistent with the trade literature, that more productive firms enter the export market, but find that once productivity is conditioned on innovation, innovation becomes the export enabler. Evidence of similar phenomenon has been found amongst innovative German firms (cf. Becker and Egger (2013)). Deconstructed, there are three main phenomenon associated with an international market: 1. international markets are larger than domestic markets; 2. they are more competitive; 3. they have barriers to entry. So the international aspect of patenting might be better seen as one where the cost of quality can be averaged out, competition is inducing innovation, and productivity needs to be high enough to overcome the transport and beachhead costs. There is likely a common firm-specific productivity factor that drives both the patenting and the ability of the firm to export – meaning that patenting firms are likely drawn from the upper tail of a productivity distribution as would be the case in a Melitz (2003) style model.

Related to the scale aspect, Berry and Waldfogel (2010) asserts that product variety innovations tend to prevail in industries with large variable costs whereas average quality increases in industries with economies of scale; the idea here is that bigger firms can better leverage the quality. With regard to the competitive effect, Philippe et al. (2015) finds that product market reforms in the EU in conjunction with patent rights induce more R&D firm expenditure. The relation between market size and competition has been less investigated in international markets, and is where we make a contribution.

2.2. *Innovation and Firm Performance*

Hall and Mairesse (2007) provides probably the most succinct overview of the empirical literature on the topic of empirical findings on innovation; we refer readers there for a more general summary. We nestle our paper directly in a genre of the literature dealing with the performance of firms attributable to innovation. Scherer (1965a), the pioneer in the field, finds a link between patents, profits, and sales. His legacy is writ throughout the empirical literature. The notion of firm performance is polysemic however; various studies use it to refer to market valuation, profit, margin on exports, sales, internal returns, or even the number of patents themselves, and "innovation" is typically proxied by R&D employment, patents, or citation-weighted (i.e. quality-adjusted) patents, or product diversity. Trajtenberg (1990) is probably the best known paper, which relates innovation quality, as proxied by citation-weighted patents, with firm performance as measured by market valuation; Bronwyn Hall followed up on this with several studies (Trajtenberg (1990),Hall et al. (2010)). In contrast, growing sales represent an expanding market for new products and utility for the end-user. Firm sales measure performance and are related to the innovation productivity literature, where Lanjouw and Schankerman (2004) serves as a guiding reference for the innovation quality metric we use. Narrowing the focus from firm performance in general to sales specifically, Table 2 provides a selection of papers that investigate the relation between innovation inputs and sales outcomes. This is closely tied to the productivity literature related to innovation and productivity, but with a focus on the end market and not the firm's internal efficiency. This distinction is important and a market-centric view is predicated on the notion that innovation creates utility for the end-user, and is not simply an intermediate input to enhance firm productivity. Yet, there are four major empirical problems uncovering this link. The first is that there are industry effects to wrestle with that largely dictate the innovation of the firms; Mairesse and Mohnen (2002) highlights this structural aspect well. Secondly, firm's are persistent in their attributes, so even non-causal theories be used to characterize behavior, e.g. Holger (1995). Third, firms self-select into a patenting based on the quality/value of their inventions; studies of this genre capture the more valuable innovations. A body of literature surrounding patent strategy exists, as an example germane to our discussion, Brouwer and Kleinknecht (1999) shows using innovation survey data that while small firms are less likely to patent when they do they often patent *more* than large firms, possibly to compensate for missing appropriability mechanisms. Fourth, the endogenous feedback between better sales and more resources is a recurrent theme Crépon et al. (1998) is considered the reference structural model serving to inspire subsequent studies using similar approaches (e.g. Heshmati (2006), Benavente (2007), Agostini et al. (2015)).

Table 2: Selected empirical studies on patents, patent quality and sales

Study	Sample	Variables	Method	Conclusion(s)
Scherer (1965a)	488 of Fortune's top 500 U.S. industrial firms in 1955	sales growth	regression	patents positively related to sales
Scherer and Comanor (1969)	57 pharma firms 1955 - 1960	Innovative product sales 2 years after market introduction	(partial) correlation	patents are related to subsequent sales
Brouwer and Kleinknecht (1999)	2,078 Dutch firms from CIS 1992	innovative sales, patents	probit	larger firms have a higher propensity to patent for a given level of innovative sales
Holger (1995)	50 German machine tool manufacturers between 1984-1992	a variety of sales metrics	ANOVA + factor analysis	int'l patentees perform best sales, profits
Holger (2001)	50 German machine tool manufacturers between 1984-1992	sales	panel fixed effects	patents (R&D) leads to higher sales
Crépon et al. (1998)	6150 firms from French CIS from 1990	innovative sales	structural equations	innovative sales increase with research effort
Mairesse and Mohnen (2002)	2500 firms from 7 CIS countries	share of innovative sales	generalized Tobit	structural effects need to be netted out before comparing country innovativeness
Heshmati (2006)	6222 Swedish firms from CIS 1996-1998	sales from new products	structural equations	innovation has bigger effect on value added than sales
Benavente (2007)	488 Chilean plants from 1995-98	sales from innovative products	structural equations	innovation does not boost sales
Frenz and Ietto-Gillies (2009)	786 enterprise from UK CIS	innovative sales per employee	Heckman selection	intra-firm collaboration is more salient for innovation
Klomp and Leeuwen (2010)	10,664 firms from Dutch CIS 1994-1996	sales; share of new or improved products	structural equations	feedback between innovation and sales
Agostini et al. (2015)	196 SME mechanical firms from N. Italy 2002-2010	sales	time-series panel	innovative quantity does not mean more sales; quality has bigger effect

Using a variety of techniques, all the studies find a positive relation between innovation/patents and sales, with the exception of Benavente (2007). One hypothesis explaining Benavente's finding for Chilean firms is the difference between a developed and undeveloped intellectual property régime. One of the main issues in all of the papers is the fact that patents are an exclusionary right, not just a measure of invention. It is not always clear that this conceptual distinction is made; for the academic authors tend to speak of patents as a synonym for invention. Since most of these studies use quantity rather than quality of invention, much of the returns from innovation come from diversifying the technological portfolio into areas where the internal returns to R&D are better (Lin and Chen 2005); high R&D in this situation is about expanding firm capability rather than staying at the technological frontier through invention quality. As with the market structure investigations, we see an international aspect where: [i]nternationally highly active patentees' [...] with a so-called 'ideal' patenting strategy are found to perform best on all variables, growth, profitability and performance trend (Holger (1995)). The theoretical trade literature would say this international link is both attributable to the productivity and product diversity effects.

2.3. Our Contribution

Betwixt these two large notions of competitive innovation and innovation-related firm performance we place our paper. That is to say we look at the competitive environment conducive to inventive quality, and then ascertain how that inventive quality benefits the firm emphasizing the mediating role of access to international markets and the type of competition in those markets. We focus on patent quality because patents themselves are more closely entwined with the legal strategy in competitive environment (cf. Lanjouw and Schankerman (2001)). Quality metrics such as forward citations are

contaminated with elements of market structure, distribution, and not untainted measures of quality — one reason we adopt a synthetic measure. Figure ... summarizes the main features of our investigation. In a first step we investigate the relationship between access to international markets and the type of competition in those markets based on a multi-criteria index comprising the degree of competitors, intensity of export activities, and price and non-price features for competition. This measure better mirrors the competitive reality of firms, which is never one-dimensional (e.g. concentration). Patented invention quality is also measured by multiple criteria following Squicciarini et al. (2013). In a second step we investigate the meaning of invention quality for the commercial success of innovative products considering unobserved heterogeneity that may drive both invention quality and commercial success. Competition might not only have a direct effect on invention quality it might also impact the commercial success of the related innovative products. Hence, access to international markets and the type of competition in those markets might positively mediate the relationship between invention quality and commercial success. We built interaction terms to investigate this important feature for policy making. These relationships have been hardly investigated so far, however, there are few papers that are closely related to the study at hand. Tang (2006) employs both micro data, uses the firms' perceptions of competition, and investigates the innovation behavior of firms, but looking primarily at the product aspects of competition (cycle time, competing products, obsolescence, substitutability). He found a strong connection between type of competition and product innovation activities. Referring to the performance side, Holger (1995) investigates 50 machine tool manufacturers where, using time-series cross-sectional data, he specifically tests *inter alia* whether "[h]igh quality patents lead to a greater subsequent improvement of firms' corporate performance than simple patent applications (Hagedoorn and Cloodt (2003))." We continue his research by testing this conjecture with a larger sample with a more direct measure of quality, and provide more color on the teleology of producing quality. In this context, he showed such companies with European (i.e. high quality) patents had higher subsequent sales than those with national patents[2].
Our contribution specifically shows how inventive quality fits into that competitive landscape.

3. Conceptual Framework

In what follows we want to synthesize the main features from the literature and illustrate them in a Cobb-Douglas framework. The literature reveals four stylized facts, which are part of our model.

1. the first is that invention quality is a normal good and tends to be associated with more demand;
2. there is a general observation that internationally oriented firms tend to produce more patents;
3. patents tend to be associated with firms with better sales performance;
4. competition fosters innovation.

We do this in four steps. First, we show how firms innovate with regard to quality by shifting consumer preferences; we do this by providing a justification for why competition in the quality space

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[2] National patents, at least for Switzerland, tend to be of lower quality Thompson (2016)

is different than in the price or quantity space of Bertrand and Cournot markets. Second, we show how international sales enlarge the customer base which is akin to shifting consumer budget constraint outward. Third, we relate that budget constraint to the incentive to innovate R&D. Fourth, we do this in a duopoly framework, illustrating how competition relates to innovation. It is important to understand that we ignore price competition, and focus solely on quality competition. Since firms use intellectual property rights, there is no copying – we assume the competitive firms expend R&D resources to develop a competitive product. We also ignore substitute goods beyond the duopolistic case presented.

For simplicity, we have a partial equilibrium model using the familiar Cobb-Douglas form. Our representative consumer maximizes her homothetic utility by consuming two varieties x from firm $i \in I$ of a good type $j \in J$ given her fixed budget $\bar{m}_j$ for the good. This means her utility U for that good is given by the consumption of $\{x_{1j}, x_{2j}\}$.

$$\begin{aligned} &\underset{U}{\text{argmax}} && U[\mathbf{x}_j] = x_{1j}^{\alpha_j} \cdot x_{2j}^{(1-\alpha_j)}, 0 \leq \alpha \leq 1 \\ &\text{subject to} && \sum_{i=1}^{I=2} p_{ij} x_{ij} \leq m_j,\ j = 1, \ldots, m \end{aligned}$$

The following solves for the direct demand of x_{j1} given that $\bar{m}$ is her budget constraint:

$$x_{1j} \quad \leq \quad \frac{\bar{m}_j \alpha_{1j}}{p_{1j}} \tag{1}$$

This leads to the intuitive conclusions that demand is: an increasing function of her preference α_{1j} for firm one's variety of the good x_{1j}; an increasing function of her fixed budget $\bar{m}_j$; and a decreasing function of price.

Going now beyond basic consumer theory, we postulate, based on the literature that there are three basic types of inventions:

- Firm-side cost/process innovations, which would lower p_{1j} and increase demand of x_{1j}.[3] An example would be the CRISPR technique which replaced zinc-finger nuclease techniques thereby lowering the cost of DNA manipulations.
- Innovations in a new product category, where a completely new good $x_{i,j=2} \in J$ is invented. For us, this would mean a different budget constraint is binding. An example would be Gilead's cure for hepatitis C.
- Quality product innovations shift consumers preference α_{1j} towards a variety within the same market. An example would be Apple's innovations on the iPhone, which improves the battery life.

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[3] e.g. Vives (2008) defines the innovations via a cost function $c(z) = \alpha z^{-\gamma}$

We ignore process and product innovations in other markets. Our conceptual framework for "patent quality" in this context can be thought of improvements for a product within the same market. Quality innovations in our mind alters the consumer's preference parameter α_{1j}. Classic economic theory holds that consumer's preference sets complete and hence defined even if the product does not exist. We model quality improvements as a shift in preferences (α) as a mathematical short hand for firm's initial good being replaced by a subsequent good which demands a new preference schedule. Since we are focusing on quality improvements in goods, we are implicitly presuming that a firm has only one type of good with a given quality level, replacing the obsoleted version. It turns out that this formulation is also convenient for making computable general equilibrium model tractable.
For simplicity, we use a logistic function, where the shift in the preference is a function of the cumulative knowledge stock r_{ijt} for the firm i product j at time t. Equation 2 is our putative firm's innovation function for quality shifts that preference α:

$$\alpha_{1j}[r_{ijt}] = \frac{1}{1+e^{-k_\alpha \sum_{t=0}^{T} r_{ijt}}} \tag{2}$$

k_α, the technological opportunity, can be thought of as the potential for the knowledge stock to alter the consumer's preferences, both are driving the increase in the quality of the invention. Substituting the firm's innovation function into the consumer's demand function, we can derive the consumer's expenditure function for x_{ij}.

$$x_{j1}p_{1j} = \bar{m}_j \alpha_{1j} \tag{3}$$

$$x_{j1}p_{1j} = \frac{\bar{m}_j}{1+e^{-k_\alpha \sum_{t=0}^{T} r_{ijt}}} \tag{4}$$

Assuming the market clears, a firm's sales s_{ij} equals consumer expenditure for the product $s_{ij} = x_{ij}p_{ij}$. Hence, we get the following marginal revenue equations for firm i in partial equilibrium:

$$s_{ij} = \frac{m_j}{1+e^{-k_\alpha \sum_{t=0}^{T} r_{ijt}}} \tag{5}$$

$$\frac{\partial s_{ij}}{\partial m_j} = \frac{1}{1+e^{-k_\alpha \sum_{t=0}^{T} r_{ijt}}} \tag{6}$$

$$\frac{\partial s_{ij}}{\partial r_{ijt}} = \frac{k e^{k_\alpha \sum_{t=0}^{T} r_{ijt}} m_j}{(1+e^{k_\alpha \sum_{t=0}^{T} r_{ijt}})^2} \tag{7}$$

Equation 6 simply states that firms get more sales from more consumer expenditures; that is the incentive to innovate is directly related to the budget m or market size. Equation 7 means that firms can increase their sales through cumulative knowledge and R&D, and that it would only make sense to do so in a competitive market structure (otherwise total expenditures on j equals firm sales and there would be no need to invest). We can also see that marginal R&D is multiplicative with the consumer's budget constraint m. In our context, this means access to larger international markets will generate a non-linear incentive to invest in R&D; larger markets lend every marginal R&D dollar greater sales potential. We should thus observe the most innovation in those markets with the largest expenditures. Since we consider a consumer preference for something *ceteris paribus* to be synonymous with "quality", which can be improved through R&D. We have shown that access to bigger markets, R&D, and competition lead to higher levels of innovation, and that bigger markets have an indirect effect on "quality" through a firm's quest for higher sales. Firms leverage their high quality inventions in terms of sales through access to larger international markets. Hence, the positive effect of invention quality on innovative sales increases with market size.

The relationship between quality and innovative sales is positively mediated by quality, which brings us to the following hypotheses:

H1: *If firms compete in larger markets, then they produce higher quality inventions.*

H2: *If firms produce higher quality inventions for larger markets, then they generate more sales.*

4. Data

Our empirical analysis is based on data from the Swiss Innovation Survey (SIS) collected by ETH Zürich/KOF Swiss Economic Institute joined with patent data from PATSTAT. The SIS is similar in content and structure to the well-established 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 (for examples, see Cassiman and Veugelers (2002); Laursen and Salter (2006); Leiponen and Helfat (2010)). PATSTAT is a comprehensive patent database from European Patent Office's that covers almost the entire global patent record. The panel survey captures a wide range of aspects related to innovation (e.g. R&D spending, competitive environment, knowledge acquisition, or cooperation) along with general firm characteristics and economic performance.

We make use of 9 waves of the survey (1990, 1993, 1996, 1999, 2002, 2005, 2008, 2011, 2013). Since we build our input and output patent portfolios around these cross-sections, we test our hypotheses in over 28-year period from 1987 to 2015. Given the study's motivation, we look at the patenting. In order to be included within our sample of firms, a firm must have produced at least one patent with the entire observational span. Since we do not observe the invention quality of firms that choose not to patent, we use multiple imputation to address selection and omitted response bias without invalidating our standard errors as would be the case with list-wise deletion or mean imputation. This means that the imputation of patent variables and quality creates a patent quality variable for non-patenters; for non-patenters, we thus have "virtual" invention score, which ideally corresponds to those inventions produced by firms, but which are not patented. Our final unimputed sample comprises about 3,600 observations with about 1800 patenting firms, which breaks down as shown in Table 3.

Table 3: Industry Breakdown

Industry	Count	Description
1	93	Food
2	75	Textiles
3	139	Stone, clay & wood
4	128	Printing/Paper
5	249	Chemistry
6	211	Plastics
7	468	Metals
8	385	Service sector
12	851	Machinery
13	214	Plastics
14	483	Electrical equipment
15	113	Electronics and instruments
16	72	Watches
17	98	Vehicles
18	26	Energy

Table 4 presents the summary statistics for that unimputed sample.

Table 4: Sample Summary Statistics

Innovative Output	Min	μ	Max	σ	Description
lnPatentOutput	0.00	0.87	7.75	1.27	Number of “docdb” patent families assigned to a firm in cross-section at $t \in \{0,+1,+2\}$
lnPatentQuality	-5.37	-0.10	7.06	1.50	Average first principal component of patent quality variables of the firms’ portfolio
lnInnoSales	0.00	6.33	22.58	5.01	Total annual sales made from innovative products
Competition					
priceCompet	1.00	4.07	5.00	0.94	Management’s assessment of the intensity of price competition (Likert scale)
nonPriceCompet	1.00	3.31	5.00	0.94	Management’s assessment of the intensity of non-price competition, e.g., the importance of quality, services, technological advancement (Likert scale)
degreeCompetition	1.00	2.39	5.00	1.33	Concentration measure: Number of principal competitors worldwide in the main product market (ordinal scale; less than 5, between 5 and 10, between 11 and 15, between 16 and 50, more than 50)
exportShare	0.00	0.52	1.00	0.37	Share of firm sales made by exporting
Markets					
intOligopolisticMarket	-2.97	0.00	3.19	1.11	1st principal component for competition variables
intNonPriceMarket	-4.14	0.00	2.83	1.04	2nd principal component for competition variables
Controls					
wagePercentileWithinInd	0.00	0.50	1.00	0.29	A time-varying proxy variable for managerial quality, as measured by the percentile of a firm’s per capita wage within an industry
industryWageLevel	0.00	0.50	1.00	0.29	A control variable percentile of firm’s relative per capita wage within Switzerland, typically clustering around an industry’s average
lnFirmSize	0.69	5.07	10.72	1.34	Number of employees (full-time equivalents)
lnPatentStock$_{t-1}$	0.00	2.48	11.34	2.01	Accumulated patent stock depreciated at 15% (perpetual inventory method)
shrEmplHiEduc	0.00	0.23	1.00	0.19	Share of employees with tertiary education
pastDemand	1.00	3.13	5.00	1.18	Management’s assessment of the demand development during the past 3 years on a five point Likert-scale (1 strong decline . . . 5 remarkable increase)
techPotential	1.00	0.41	5.00	1.05	Management’s assessment of technical potential (worldwide available knowledge to further the innovation activities of the firm) (Likert scale)

Imputed variables have tiny non-zero minimum bounds to ensure convergence.

The survey elicits information about single dimensions of competition from the participants directly from the survey responses. In our measure of competition, the survey asks the participants to rank from 1-5 their perception of price and non-price competition. While price competition is straightforward to comprehend, non-price competition is defined as: "product differentiation, new introduction of products, technical advancement, flexibility to meet customer requests, and additional services." Moreover, we have information for the number of principal competitors worldwide and in the main sales markets of the focal firm and its sales share of exports. [4] The single dimensions of competition does not necessary mirror the complex reality of markets where firms deal with several dimensions simultaneously. Those dimensions of competition however define the market environment of the firm. In other words, rather than defining competition in terms of number, or qualitatively as price/non-price, we try to capture the essential aspects of market. We use a principal component analysis (PCA) to identify the complex competitive situation of firms in their main sales market.
We can combine the survey competition variables into two types of "markets". We can then use the predicted scores as independent "market" variables without introducing too much additional collinearity into our regression.

Table 5: Principal Component Loadings of Market Attributes

	Int. Oligopolistic	Int. Non-Price	Market 2	Market 3
priceCompetition	-0.47	0.45	-0.66	-0.37
nonPriceCompetion	0.18	0.73	0.56	-0.34
degreeCompetition	-0.66	0.25	0.27	0.65
exportShare	0.56	0.45	-0.41	0.57
λ=	1.10	1.07	0.93	0.88

From Table 5 we infer two primary types of competitive environments (markets) for firms that can be characterized:

International Oligopolistic: the"market" (component) is characterized by a domestic-international dimension, a low number of principal competitors worldwide, and price-centric type of competition;

International non-price: this second type of "market" is more characterized by non-price competition (lead time, services, features, intellectual property, etc.) as evidenced by its high factor loading, but this market type also exhibits an international-domestic dimension, but one where the degree of competition, i.e. number of competitors is less salient than in the first market.

The first leads us to infer the existence of a polar dichotomy between a polypolistic domestic market with more price competition and an international oligopolistic market with less price competition. Table 6 summarizes these differences into a rough typology.

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[4] Link to questionnaire, pg. 2

Table 6: Rough Typology of Competitive Market Types

Int'l oligopolistic price-centric competition	Int'l oligopolistic non-price
Domestic polypolistic price-centric competition	Domestic oligopolistic non-price

In the first case, we would expect less innovation as the market goes from international and oligopolistic to domestic polypolistic. In line with H2, we would expect invention quality to be associated with non-price competition. This second market is perhaps the more trivial in that firms that patent are *ipso facto* employing intellectual property, a legalistic way to compete; it is a competitive environment, which is not based on price, and is independent of both price and the number of competitors in the market.

4.1. Patent Quality

"Patent quality" as a measure of invention is central to this paper. Since, we assume "high quality" patents map to a higher quality products and inventions, it is worth defining high patent quality with more precision here. This assumption is not unreasonable as high quality patents fetch higher prices at auctions; patent quality is associated with higher levels of market valuation. Patent quality in our conceptual model is a proxy variable for a type of independent innovative output distinct from the legal right of the patent itself. This means we need a metric divorced from the dirty legal realities of appropriation through the international intellectual property regime; furthermore, we need a metric divorced from the business logic, or organizational capacity. This is a tall order. Most patent quality metrics are polluted both empirically and conceptually. Forward citations, the most common metric, would be flawed in the context of this paper as a measure of patent quality: markets with more competitors have more citations and international patent families have more family members to cite. So what was once a measure of quality is now a proxy for competition. Another popular metric is the average family size of a companies portfolio: this is essentially synonymous with "export-oriented", and if we believe the trade literature, essentially synonymous with organizational productivity as well. In short, there is a massive amount of detritus mixed in with the information of any one bibliometric measure of patent quality. Van Zeebroek provides an excellent overview and discussion of the weaknesses of these metrics (van Zeebroeck 2010). There are additional selection effects when measuring patent quality, de Rassenfosse (2013), for example, finds a trade-off between both the quantity and quality. Patents with multiple owners tend to be of higher quality (Briggs and Wade (2014), Hottenrott and Lopes-Bento (2014)); the theory being that the transaction costs of working outside the firm need to be compensated by more profit from higher quality inventions. Such cooperations are also more likely to arise in a polypolistic environment, thus this particular quality metric thus reflects the market structure.

Rather than abandon our effort, we try to mitigate, but not entirely eliminate, these endemic methodological problems in two ways: 1. we normalize the variables by year and IPC4 class (i.e. industry) in order to purge some time variance and industry variance; 2. we compute the common "quality" factor amongst the constituent metrics using principal components (see Table 7). This is essentially the approach first taken by Lanjouw and Schankerman (2004) to assess research productivity and stock market valuation, who showed it reduces the amount of noise in the bibliometric proxies for invention quality.[5] Thompson (2014)[6] and Thoma (2014) both extended the idea by incorporating additional indicators and validating the metric against external data. Table 7 shows the components to our quality metric. The first constituent, forward citations, measures the scientific and commercial relevance (Fischer and Leidinger (2014), Hirschey and Richardson (2004), Trajtenberg (1990)). The second one, generality, has to do with how widely the patent can be used in other fields. Family count or number of family members has to do with the globalized nature of firm production. Patents with a larger number of non-patent literature (NPL) citations tend to have more scientific merit, and finally patents with more claims tend to have more legal purchase (Lanjouw and Schankerman (2004), Thoma (2014)). We compute these according to the OECD's handbook on measuring patent quality (cf. Squicciarini et al. (2013)).

Table 7: Factor Loadings of Quality Attributes

	PC1	PC2	PC3	PC4	PC5
ln[FWCitations]	0.439	-0.485	0.097	-0.748	0.052
ln[Generality]	0.397	-0.622	-0.315	0.597	0.025
ln[FamilyCount]	0.511	0.424	0.017	0.079	0.743
ln[NPLcount]	0.438	0.120	0.750	0.248	-0.413
ln[NumClaims]	0.444	0.429	-0.573	-0.129	-0.523
λ	1.52	0.94	0.90	0.76	0.66

Table 7 shows the principal components of these quality metrics. The bibliometric traits which are positively associated with patent quality all load positively on this component. Consistent with the idea that they are all manifestations of an underlying factor, we term "invention quality". This component describes roughly half of the variance, and so we also say that it is salient. While there is no guarantee that the first principal component represents "invention quality", theory and previous empirical studies make us believe something akin to "quality" underlies the notion.

Having highlighted some of the pitfalls of measuring patent quality, we turn to the more ubiquitous issue of selection effects and observation bias when it comes to quality. In our model, we are trying to measure the underlying quality of the firm's inventions not the quality of the patent right. All patents cover an invention by definition, but the converse is not necessarily true: not all high quality inventions are patented. What we know from the literature on appropriability is that firms selectively

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[5] We differ in that we make fewer assumptions by not choosing a particular oblique rotation, rather let the orthogonal eigenvalues be our guide. In our case, the first component aligns well with theory.

[6] In that study these were (for each docdb_family): number of inventors, forward citations, non-patent literature citations, backward citations, number of claims, grant count, family count, patent scope, oppositions, grant lag, total active life of the patent as measured by the last dates observed in the prs table, PCT status, number of applicants, patent generality, fraction of adverse citations

use patents for a myriad of reasons, some of which are unrelated to innovation, for example to shift profits. In this sense, even firms choosing not to patent have quality inventions. Rather than drop these observations, which might bias our Schumpeterian innovation model by tossing out the innovative weaklings, we opt to impute a virtual invention quality based on what we *do* know about the firm, which turns out to be quite a lot, much of which is extraneous to this particular investigation. Rather than discard that all that information we use some of it to make an educated guess about the firm's patent/innovation quality using Bayesian logic. This idea is elucidated in Section 5.3.2

5. Empirical Specification

In order to test our hypotheses, we pursue the following empirical strategy. In a first step, we investigate whether the quality of inventions and the quantity of inventions are driven by the same factors. We pay special attention to the effects of competition and market size. In a second step we investigate the relationship between quality of inventions mediated the commercial success of inventions as measured by innovative sales. The second step is also estimated as a reduced form 2SLS, whereby invention quality is endogenized using the international business climate as an exogenous shock.

5.1. Estimation of invention quality and invention quantity

Equation 8 shows the equations on invention quality and quantity. $y_{i,t}$ stands for the quality of inventions and the quantity of inventions, respectively. MSMC$_{i,t-1}$ is a multi-criteria measures for market structure (oligopolistic structures in international markets or non-price competition in international markets) issuing from the factor analysis and MS$_{i,t-1}$ represents various single measures for competition comprising proxies for price competition, non-price competition, number of principal competitors worldwide, and export share.[7] $\tilde{\pi}Z$ is the instrument which will be further explained in Section 5.3.1.

$$y_{i,t} = \mathbf{MS}_{i,t-1}\boldsymbol{\gamma} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + \tilde{\pi}Z + c_i + u_{i,t} \tag{8}$$

$$y_{i,t} = \mathbf{MSMC}_{i,t-1}\boldsymbol{\gamma} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + \tilde{\pi}Z + c_i + u_{i,t} \tag{9}$$

$$y_{i,t} \in \{ln[\text{patents}_{it}], ln[\text{patentQuality}]_{it}\} \tag{10}$$

$X_{i,t-1}$ are covariates controlling for important firm-specific characteristics. Following the theoretical notions of a Schumpeterian approach (see Cohen (2010)), we control for the firm size (log number of employees), the absorptive capacity of a firm (share of high educated employees and the knowledge stock), past demand, and the technological potential within the firm's industry. Past development of demand is a ordinal variable ranging from 1 to 5 (1=strong decline ... 5=strong increase), and also the technological potential is an ordinal variable ranging from 1(=low) to 5(=high) and indicates the

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[7] We also conducted a seemingly unrelated estimation procedure to consider the unobserved correlation between quality and quantity of inventions. The results are very similar. Estimations are not shown, however, available upon request.

worldwide available technological knowledge (private and public) that can be used to develop marketable new products in the firm's field of expertise; for instance, basic knowledge, knowledge about key technologies (nanotechnology), semiconductors, biotechnology, but also organizational knowledge relevant for the scope of business. This firm-specific time-varying effect we term "management quality", an often neglected variable in innovation equations.[8] We assume that "management quality" is positively correlated with the salary. Firms that pay-relatively to the industry-high salaries recruit the more talented workers and managers. Hence we inserted a variable that measures the relative position of the average salary paid by a firm (*wagePercentileWithinInd*). Since workers and managers can also switch from one industry to another we also control for the relative size of the focal industry salary compared to the average salaries paid in other industries (*wagePercentileWithinCH*) (see Table 4 for the description of the variables). c_i are firm-level fixed effects and $u_{i,t}$ is the stochastic error. We use a firm-level fixed effects estimators with lagged covariates and heteroscedasticity robust (clustered) standard errors. Hence, we control for unobserved, time-invariant heterogeneity and also address potential serial correlation.

Fixed effects are also a method to control for the appropriability of new knowledge generated by firms, a further important factor in an innovation equation (see Scherer (1967)). Since we lag the covariates by one period reverse causality should not be a big problem. Hence, the proposed empirical setting should provide us with consistent estimators, however, we cannot fully exclude that there is further unobserved heterogeneity that are correlated with the variables of interest. But given our empirical approach it would have to be one not absorbed in our firm-fixed effects nor absorbed in our time-varying covariates mirroring the theoretically important factors for innovation activities.

5.2. Estimation of the Firm Performance Attributable to Quality

In the second stage we investigate the relationship between invention quality and the innovation success of a firm considering market structure as a potentially mediating factor. We use an instrumental variable approach to endogenize the invention quality and estimate the reduced form. The dependent variable is the log of innovative sales. Equation 11 is estimated by a fixed effects estimator with heteroscedasticity robust (clustered) standard errors. In Equation 12 we endogenize invention quality and estimate the reduced form using an instrumental variable approach.

$$ln[\text{innoSales}]_{i,t} = \gamma_1 \mathbf{MSMC}_{i,t-1} + \gamma_2 ln[\text{patentQuality}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} \qquad (11)$$

$$ln[\text{innoSales}]_{i,t} = \gamma_1 \mathbf{MSMC}_{i,t-1} + \tilde{\pi} ln[\widehat{\text{patentQuality}}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} \qquad (12)$$

$$ln[\text{innoSales}]_{i,t} = \gamma_1 \mathbf{MSMC}_{i,t-1} \cdot \gamma_2 ln[\text{patentQuality}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} \qquad (13)$$

$$ln[\text{innoSales}]_{i,t} = \gamma_1 \mathbf{exportShare}_{i,t-1} \cdot \gamma_2 ln[\text{PatentQuality}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} \qquad (14)$$

We interact invention quality with the proxies for market structure and exportShare in Equations 13

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[8] "Management quality" is really a proxy for "personnel quality" based on firm i's wage level in time t vis-à-vis the industry and the industry's wage level vis-à-vis the country's wage level at time t. It means it absorbs time-varying effects.

and 14.[9] Again we use a fixed effects estimator with heteroskedasticity robust standard errors. Since the results for the instrumental equation (12) and the fixed effects equation (11) are rather similar, we suggest that unobserved time-varying heterogeneity is not a major problem in our setting and we proceed with the fixed effects approach in order to investigate the moderating effects with $exportShare$ and **MSMC** (see Equations 13 and 14). $\mathbf{X}_{i,t-1}$ is a set of control variables like in Equation 11 including the base variables for interaction effects in Equation 13 and 14.

5.3. Endogeneity Issues

Endogeneity is an issue in our setting. Hence, we made several attempts to address this problem. First, we used fixed effects estimator. Second we use lagged independent variables. Third, we pursued an instrumental variable approach to address endogeneity of our most important variable, the quality of inventions. Fourth, we imputed missing values in order to take care about potential selection issues, since firms self-select into the patenting régime.

5.3.1. Endogeneity of Patent Quality

As mentioned above we use an instrumental variable approach to address the endogeneity of our variable for invention quality. We use various policy shocks to the Swiss economy to instrument for it. A descriptive analyses about the relationship between external economic crises and the quality of invention suggests a significant relationship in a sense that every time when the economic shock suggests an increase in potential market size, inventions quality reacts positively and conversely, when the economic shock engenders a decrease in market size, invention quality tends to decrease, too (see Figure 1). Hence, it is suggested that invention quality is related to economic shocks which are beyond the influence of a single firm and external shocks (positive or negative) also limit or expand the sales opportunities of firms, and that this effect is independent of quality's contribution to innovative sales. The 2008 crisis exemplifies an external shock to the Swiss economy in order to identify the effects of patent quality on innovative sales. In order to create our instrument, we take the export share of firms during the initial state in 2005, we then interact their total initial exports with a 0/-1 dummy variable for pre/post crisis. The expectation being that the crisis affects exporting firms more than domestically oriented firms. This effect would be different with respect to a firm's exposure to the international markets, which we measure using the initial export share. For a similar instrumental approach using an initial export condition and macroeconomic shock (Kaiser and Siegenthaler (2016)). For the 2001 negative shocks due to the meltdown of the .com bubble and the Iraq war, we construct the same type of instrument for our 1999/2002 cross-sections. Jointly we term these scenarios "bust".
Conversely, we would expect a positive external shock to boosts quality for firms with a high initial export share. Switzerland has undergone two recent rounds of liberalization: the first in 1995 with the advent of the WTO, and the second 2002 when the labor market was liberalised in exchange for better access to the EU market. Again, we construct an instrument by interacting the exports of the companies pre-WTO with a 0/1 variable for pre/post liberalization. Our expectation is that

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[9] In this equation the remaining proxies for MS are included in $\mathbf{X}_{i,t-1}\boldsymbol{\beta}$ and MSMC.

liberalization affects patent quality along the firm's degree of exposure to international markets due to increased demand. For the 2002, liberalization of the Swiss economy to the EU, we construct the same type of instrument for our 2002/2005 cross-sections. Jointly we term these scenarios "boom". We pool these scenarios in a boom-bust model whereby we have the pre-shock export share (initial exports), i.e. $1 \cdot \text{initialExports}$ for the "boom" scenarios, $-1 \cdot \text{initialExports}$ for the "bust" scenarios, and $0 \cdot \text{initialExports}$ for the other periods. The exogenous world economic cycle then has varied implications with regard to the inventive quality of the firm.

Formally, we can write this construction as follows:

$$\mathrm{Z} = [\text{exportShare}_{t=0} \cdot \{\text{boom} = 1 \wedge \text{bust} = -1\}] \tag{15}$$

In Equation 15, Z represents the instrument for quality. We believe this instrument is reasonable and it is statistically valid (F-test = 8.4) because the international business environment is exogenous — the Swiss firms in the survey make up less than 1% of the total world GDP. Second, there is no reason to believe that the innovative sales at t+3 are driven by the export share in the past once we condition on past demand. In other words, any additional resources that a firm might have gotten from patent quality in the past is gets absorbed by our past demand variable. The results of this IV estimation are shown in the appendix Table 13.

The 2008 crisis by far the strongest effect as evidence by the largest coefficient on the instrumental variable which is much higher than during our boom period — doubling the quality of the inventions leads to a 186% increase in innovative sales during a severe crisis. This effect is much smaller during boom times where the marginal contribution to sales is a mere doubling. Our conjecture is that the firms at the technological frontier have an easier time selling during times of crisis, leading to more downward deviation for those firms with lower quality inventions. Assuming that all companies have the same marginal cost to produce, but those with differentiated products can grab market share by cutting prices – those firms with little innovation prowess have little in the way of margin to trim. Coming back to our original quality model in Section 3, firms competing on quality have already incurred the sunk costs of research, any price competition on their part further market share away from competitors.

5.3.2. Selection Issues

There are numerous selection issue to deal with in such a research design. There is naturally some attrition bias over the course of the panel due to the fact that the sample is not regenerated entirely anew for each cross-section. Certain data are missing for firms between years. More importantly, patenting firms by definition are self-selected into an intellectual property protection regime, which implicitly states something about the type of innovation, legal capacity of the organization, market and export activity of the company. Firms that do not patent often do not think it is worth while to patent. Hence, a sample attempting to cover *invention* quality, must deal with the fact that non-patentable/unpatented inventions are missing.

Addressing this innovation vs. patenting selection issue has been a perennial problem in the innovation literature. Either being ignored entirely or all results bearing the caveat "amongst patenting

firms", dealt with using instrumental variables (de Rassenfosse (2013)), or using a sophisticated selection model with detailed micro-data, exemplified by Arora et al. (2008). Our approach is a more generalizable to datasets without a valid instrument or a way to estimate an endogenous system.
To address this we use multiple imputation following the methodology outlined in King et al. (2001). The logic applied to our patent quality problem is as follows. If more innovative firms are more likely to patent, then the selection process is missing at random (MAR) provided that the patenting status of some firms is known. In our case, we have the complete patent record for every firm so this condition is met. Moreover, if fewer innovative firms do not patent as often as those firms, which are innovative, then the generative process would also be MAR, if we can predict the patent-propensity with other variables in the data set. This condition is met: with knowledge of the firm size, labor quality, industry, the patenting status can very easily be guessed. Having knowledge that a company has 10'000 employees, produces pharmaceuticals, and has 100 billion in sales makes it almost certainly a patenting firm. Unlike other selection models, the predicted patenting status need not be causal. By including more variables amongst our predictive covariates, the MAR assumption becomes more accurate. The selection would be non-ignorable if fewer innovative firms are less likely to patent and the dataset cannot predict which firms are highly innovative. Indeed, the entire purpose of the survey is to identify innovators, and our Schumpetarian model is specifically designed for this purpose. This condition too is met. Furthermore, we have no clear picture of how to formally model the selection effects in that the causes of the selection are not well defined. We try mitigate these selection effects through the use of Bayesian multiple imputation for those firms with no patents.
This is to say we assume that the unobserved random invention quality variable (Y) is a partitioned matrix where cells M are the missing quality scores and cells O are the observed invention quality of the firms based on the patents.

$$\begin{aligned}(Pr\{Y = y_i \perp O\}) \vee (Pr\{Y = y_i \in M|X\} \\ \approx Pr\{Y = y_i \in O|X\})\end{aligned} \tag{16}$$

Either the value is completely independent of its missingness or the probability of its value conditional on the covariates is equivalent to the probability of the quality of conditional on the observed variables. If it is orthogonal to its missingness we do not need to worry; our quality variable would be simply less precisely measured with any estimator. In the other case, we are assuming we can make a very educated guess about the quality given everything else we know about the firm. This is to say Y and X come from a joint distribution parametrized by $\boldsymbol{\theta}$. Considering our ignorance of the mean and variance, we use the maximum entropy distribution as a diffuse generative prior for our data matrix T:

$$Y \wedge X \in \mathbf{T} \sim f(\boldsymbol{\theta} = \mathcal{N}_k(\boldsymbol{\mu}, \boldsymbol{\Sigma})) \tag{17}$$

The likelihood of the parameters is thus given by the full data:

$$\mathcal{L}(\boldsymbol{\theta}|T) \propto Pr\{T|\boldsymbol{\theta}\} \tag{18}$$

We can derive the probability of the full data by summing the marginal probability of all constellations of missingness conditional on a set of postulated parameters:

$$Pr\{T|\boldsymbol{\theta}\} = \sum_{\mathbf{m}=i}^{M} Pr\{T|\mathbf{m}, \boldsymbol{\theta}\} Pr\{\mathbf{m}|\boldsymbol{\theta}\} \tag{19}$$

It follows that posterior for $\boldsymbol{\theta}$ is $\underset{\boldsymbol{\theta}}{argmax}\{\mathcal{L}(\boldsymbol{\theta}|T)\}$. Obviously, testing all possible generative constellations of $\boldsymbol{\theta}$ makes for a great deal of computational effort. To reduce this computational effort, we employed Amelia II for R, which can robustly make inferences about $\boldsymbol{\theta}$ and T using a bootstrapped expectation maximization algorithm.[10] The basic intuition here is that if we observe several characteristics about a firm, we are able make a very educated guess about the inventive quality and patenting status of that firm based on all the observations.

6. Results

In this section, we present the empirical results of our investigation. First, we look at the relationship between the proxies for market structure and the quantity and quality of inventions, respectively. Second, we will present the estimation results for the relationship between invention quality and the commercial success of innovative products considering market structure as a mediating factor.

6.1. Market Structure and Innovation Output

Table 8 shows the influence of our competition variables on both invention quantity and quality. The sample here is only patenting firms – clearly we see in Column Ia that firms exposed to larger markets (as proxied by *exportShare*) conditional on the levels of competition tend to produce more patents as evidence by a 1.3 patents [11] increase in patent families (inventions) as firm moves from totally domestic (exportShare=0) to totally international (exportShare=1). The increased market size would appear even more salient to the level of invention quality. A totally internationally oriented firm's invention quality improves by about 54% over its domestic counterpart conditional on the level of competition. The independent effect of larger markets is not inconsistent with Schmookler's original conjecture that market size governs the degree of invention.

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[10] See King (2010) for a bit more color on the technique.

[11] $e^{0.3} = 1.30$

Table 8: Competition and Innovation Output (FE)

	Patents$_{i,t}$ (Ia)	lnQuality$_{i,t}$ (IIa)	Patents$_{i,t}$ (Ib)	lnQuality$_{i,t}$ (IIb)
priceCompet$_{t-1}$	-0.055^{***}	0.02		
	(0.006)	(0.04)		
nonPriceCompet$_{t-1}$	0.070^{***}	0.05		
	(0.007)	(0.04)		
degreeCompetition$_{t-1}$	0.017^{***}	0.02		
	(0.004)	(0.03)		
exportShare$_{t-1}$	0.301^{***}	0.43^{***}		
	(0.037)	(0.10)		
intOligopolisticMarket$_{t-1}$			0.059^{***}	0.08^{**}
			(0.005)	(0.03)
intNonPriceMarket$_{t-1}$			0.040^{***}	0.11^{***}
			(0.006)	(0.03)
ln[firmSize$_{t-1}$]	0.170^{***}	0.11^{***}	0.226^{***}	0.11^{***}
	(0.013)	(0.03)	(0.013)	(0.03)
ln[knowledgeStock$_{t-1}$]	0.922^{***}	0.26^{***}	0.815^{***}	0.26^{***}
	(0.035)	(0.09)	(0.03)	(0.09)
ln[knowledgeStock$^2_{t-1}$]	-0.031^{***}	-0.01	-0.02^{***}	-0.01
	(0.002)	(0.01)	(0.002)	(0.01)
shrEmplHiEduc$_{t-1}$	-0.402^{***}	0.61^{***}	-0.408^{***}	0.64^{***}
	(0.03)	(0.20)	(0.03)	(0.20)
pastDemand$_{t-1}$	0.038^{***}	0.07^{**}	0.044^{***}	0.07^{**}
	(0.004)	(0.03)	(0.005)	(0.03)
techPotential$_{t-1}$	0.064^{***}	0.07^{**}	0.060^{***}	0.08^{**}
	(0.009)	(0.03)	(0.009)	(0.03)
wagePercentileWithinIndustry$_{t-1}$	-19.9	-1.90^{***}	11.41	-1.87^{***}
	(31.9)	(0.33)	(31.8)	(0.33)
wagePercentileWithinCH$_{t-1}$	0.476^{***}	2.27^{***}	0.646^{***}	2.23^{***}
	(0.113)	(0.35)	(0.113)	(0.35)
Firm fixed effects	*yes*	*yes*	*yes*	*yes*
Time fixed effects	*yes*	*yes*	*yes*	*yes*
R^2		0.14		0.14
F		674^{***}		38.3^{***}
Log-Likelihood	-6619	674^{***}	-6613	38.3^{***}
N	1796	1796	1796	1796

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Patent modeled as Poisson count.

In addition, invention quality and invention quantity are driven by different factors. We see that the number of patents produced "knowledge stock" tends to have a linear effect in that the simple and quadratic terms are not significant at the same time, hinting at equivalent monotonic transformations, indicating a linear effect of the "knowledge stock" on invention quality and quantity [12], indicating that firms with more patents tend to produce inventions in a non-linear fashion, perhaps indicative of a deliberate patenting strategy. We also see that market structure matters for inventions. Both invention quantity and invention quality have a common cause in market structure. We find evidence that international oligopolistic type markets boost the quantity and the quality of inventions: going from a domestic and polypolistic market to an international oligopolistic market boosts patenting by about 6%. Going from a domestic price competitive market to an international non-price market raises the use of patents by about 7%. Those same market structure effects on invention quality are slightly higher at about 8% and 11%. This again in the context of only patenting firms. Both market types seem to be of similar importance when it comes to producing quality. A two-tailed test reveals that export share has a differential effect with respect to both the invention quantity and quality, significant at about the 1% level, indicating two different aspects of competition's effect on innovation and the marginal response in quality.

It needs to be pointed out that the results for the patent output are for the "within" fixed effects estimator. We show the fixed effects estimates in Table 8 despite the fact that Hausmann test between the fixed-effects and random effects models does not exceed the critical value (0.001 vs. 95% ^{2} with 13 df of 5.89). The coefficients are very close, e.g. the effects for non-price competition in the Poisson regression (Ia) are within about a 1000th of a patent of each other. But we would like to mention the fact that the coefficient on the share of educated employees changes from negative (-0.4) to positive (0.75) when switching from estimators based on deviations from the firms' averages vs. estimators that compare between variance where going from no employees with tertiary education to a labor force of only university education employees implies about 2 additional patents. The only conjecture we have for this "switch" at the moment is that as share changes within the firm it might represent a shift in business model away from producing physical things that require patent protection, whereas when the educated share of a workforce is observed between firms we clearly see that firms that produce inventions, on average, have more educated workforces.

6.2. Innovation Performance, Competition, and Invention Quality

In a second step we investigate the relationships between invention quality, market structure and innovation performance, measured by the share of innovative sales, which is to say the amount of revenue issuing from products which the firm deems to be new to the firm or new to the market. Since we already had good reason to believe the sample to be heavily selected in that patenting firms are likely to be very different, we tried to account for that fact by imputing unto those firms a "virtual" *invention quality* score based on the attributes of those firms that did not patent (cf. *supra* Section 5.3.2). This allows us to better contrast between innovative and non-innovative firms because the

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[12] Following the innovation literature, this is the patent stock depreciated at 15% using the perpetual inventory method.

sample no longer conditions on patenting firms which are by definition innovators and exhibit less intra-class variance. Consequently, this significantly increases our sample and the variance.

Table 9: Innovation Sales Performance and Competition

	$\ln[\text{innoSales}]_{i,t}$			
	(V)	(VI)	(VII)	Boom-Bust
(Intercept)				3.07^{***}
				(0.81)
lnFirmSize_{t-1}	0.06^{*}	0.06^{*}	0.06	0.16
	(0.03)	(0.03)	(0.03)	(0.34)
$\text{lnPatentStock}_{t-1}$	0.46^{***}	0.45^{***}	0.48^{***}	0.16^{***}
	(0.04)	(0.04)	(0.04)	(0.06)
wagePercentileWithinIndustry	2.83^{***}	2.83^{***}	2.86^{***}	1.33
	(0.60)	(0.60)	(0.60)	(1.56)
wagePercentileWithinCH	-3.09^{***}	-3.09^{***}	-3.14^{***}	-1.73
	(0.62)	(0.62)	(0.62)	(1.65)
shrEmplHiEduc	2.32^{***}	2.32^{***}	2.41^{***}	2.68^{***}
	(0.25)	(0.25)	(0.25)	(0.77)
pastDemand_{t-1}	0.20^{***}	0.20^{***}	0.20^{***}	0.20^{**}
	(0.04)	(0.04)	(0.04)	(0.10)
$\text{techPotential}_{t-1}$	0.49^{***}	0.49^{***}	0.49^{***}	0.49^{***}
	(0.04)	(0.04)	(0.04)	(0.12)
$\text{inventionQuality}_{t-1}$	0.07^{**}	0.01	0.07^{**}	**0.79*****
	(0.03)	(0.04)	(0.03)	**(0.34)**
priceCompet_{t-1}	0.04	0.04		
	(0.04)	(0.04)		
$\text{nonPriceCompet}_{t-1}$	0.32^{***}	0.32^{***}		
	(0.05)	(0.05)		
$\text{degreeCompetition}_{t-1}$	-0.15^{***}	-0.15^{***}		
	(0.03)	(0.03)		
exportShare_{t-1}	2.35^{***}	2.40^{***}		
	(0.15)	(0.16)		
$\ln[\text{inventionQuality}_{t-1}]{*}\text{exportShare}_{t-1}$		0.25^{***}		
		(0.09)		
$\text{intOligopolisticMarket}_{t-1}$			0.17^{***}	0.31^{***}
			(0.04)	(0.11)
$\text{intNonPriceMarket}_{t-1}$			0.83^{***}	0.54^{***}
			(0.05)	(0.12)
$\text{intOligopolisticMarket}_{t-1}{*}\ln[\text{inventionQuality}_{t-1}]$			0.04	
			(0.03)	
$\ln[\text{inventionQuality}_{t-1}]{*}\text{intNonPriceMarket}_{t-1}$			0.05^{*}	
			(0.03)	
R^2	0.18	0.18	0.18	0.07
Firm fixed effects	yes	yes	yes	yes
Time fixed effects	yes	yes	yes	yes
Imputation	yes	yes	yes	no
F				8.4^{***}
N	7852	7852	7852	1989

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. **Instrumented** sample is not imputed.

In Table 9, presents the main results. Table 9 presents fixed-effects estimates. The instrumental variable regressions are presented in the Appendix (Table 12) and the regressions without imputed values are presented in the Appendix (Table 13).

We see that entirely exporting firms have about 28% more innovative sales than completely domestic firms (Table 9; column V). Higher levels of competition measured by the number of principal competitors lead to fewer innovative sales, consistent with economic theory (cf. (Kraft 1989)). However, higher levels of non-price competition increases the benefits from invention activities. This results confirms the findings of Tang and Vives, emphasising the importance of the type of competition for innovation. Invention quality has the expected positive and significant effects on the commercial success of innovations. The patent stock is also positively related to further sales implied by both the legal exclusivity which the patents afford and the quantity of inventions, which a firm has produced in the past.

One of the key results of this table is presented in column (VI). Here we investigate the mediating effect of market size (measured by export share) for the invention quality. We see the invention quality only exerts a significant positive effect, if the firm's has access to larger markets. This implies that firms can only leverage those high quality products with a sufficiently large market where access to large markets is necessary to make the development of high quality patents profitable. This is an important finding for a small, open economy that operates at the technological frontier and owns great parts of its economic wealth to its innovativeness. Moreover, we see that the international non-price competitive environments leverage patent quality, whereas the oligopolistic market type does not. This would seem to challenge our Schumpeterian Mark II vision of the world, a world in which the number of principal competitors worldwide is the determining factor rather than than the mode of competition. It is not very surprising that the number of principal competitors do not show any significant effects. By definition, successful technological inventions limits the number of competitors. Consequently it is plausible that the *type* of competition amongst patent firms is more decisive than the number of competitors. Non-price competition on international markets rather than price related competition significantly leverages invention quality in terms of innovative sales. However, the type of competition in international markets is less important than the sheer access to those markets.

We perform several robustness tests. First we run instrumental variable regressions for the extended base model (column VII in Table 8). Table 12 in the appendix presents the estimations. We see that the boom-bust estimation in Table 12 gives qualitative identical results compared to the extended base model. Hence, we think that the time-varying unobserved heterogeneity does not significantly bias our results. In further robustness tests, we perform analogous regressions for patenting firms only (i.e. without imputation). Amongst patenting firms, we find again that invention quality alone does not contribute to innovative sales (cf. Table 14 Column VII), but is activated by access to an international market. Since all patenting firms are non-price competitors to a certain degree, we see little variance along this dimension amongst patenting firms, whereas this price/non-price distinction is important between patentees and non-patenting firms where quality becomes salient.

If we restrict the sample to patenting firms, the number of principal competitors[13] does not show any effect (cf. 14 Column VII). This is because there are few patenting firms in the sample and the variance amongst those patenting firms is low. Patents segment the market by definition, lowering the number of principle competitors we might expect. This within-group variance leads to a null effect within the patenting-only sample.

In Column Boom-Bust of Table 9 shows the IV estimation for a similarly specified model. Our instrumental variable for patent quality (Z), in bold, is significant and positively related with invention quality, showing that an economic shock that increases the market size also increases invention quality and conversely, if the shock suggests decreasing market sizes or trade obstacles, invention quality

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[13] In our survey, this means the number of principal in the firm's main sales markets worldwide.

decreases, too. The effect size standard panel estimates are downward biased towards zero. [14].

7. Conclusion, Research Outlook & Policy Implications

In this paper, we provide a basic theoretical explanation based on consumer preferences for the empirical observation of the literature that exporting to international markets is conducive both to patenting and producing higher quality inventions. We then measured both the contribution of market size and international competition on innovative outcomes, namely, inventive quantity (i.e. patenting), inventive quality (i.e. patent quality), and innovation performance (i.e. sales issuing from new products). We also saw that both non-price and oligopolistic markets are conducive to producing patents.

Coming back to our original hypotheses: 1. we find that firms competing in larger markets produce higher quality inventions as evidenced by the increase in patent quality conditional on the export share of the companies in our sample. 2. We also saw that firms in a price-competitive environment tend to produce lower quality inventions; 3. higher quality inventions translate directly into sales, if and only if the firm has a large market, which in our study means internationally active; Figure 2 shows those relations.

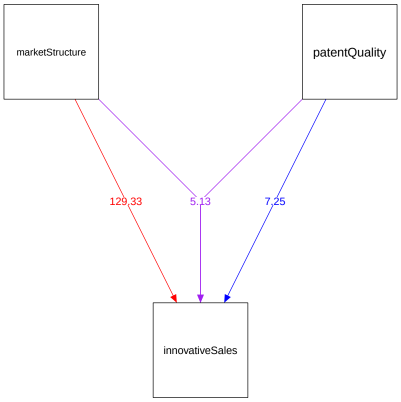

Figure 2: Basic structure and results of our investigation. Coefficients are in percent change of our variables and change in innovative sales. Selling into international non-price markets explains much of the performance relation. Doubling patent quality raises sales by about 7%, and the interaction between quality and the market raises sales by about 5%.

This means that firms may only leverage being at the cutting edge of technology if there is a sufficiently large market to support the invention. Inventions of high quality are unlikely to be developed in firms operating in too small markets, the sales perspectives are too low inhibiting

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[14] Table 13 in the Annex presents both the boom and bust separately. The effect sizes are of a similar magnitude

considerable investments into high risk and potentially high return projects. In Figure 2 we give an overview of the quantitative dimension of the results.

The major policy implications are twofold. The first is that larger markets contribute to patent quality, and for small countries like Switzerland, free trade seems to be one route to directly providing a larger market. Here free trade has a dynamic effect beyond the static gains. The dynamic effects from trade are that firms can further specialize and gain the research scale needed to compete globally because there is demand for their products. The second major policy implication is that competition and market structure, i.e. external factors, are just as important to innovation as firm-intrinsic factors such as labor quality – increasing competition and reducing barriers to international trade are important not just for the static gains they provide consumers with, but also conducive to competition which stimulates innovation. The last major policy implication is that firms' understanding and usage of IP rights is important for accessing foreign markets where traditional methods of appropriation such as lead time or customer service are more difficult to use transnationally. In terms of future research, we would like to see if our results hold for more countries and whether "non-price" competition amongst inventive firms can be predominantly characterized by technological competition.

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8. Appendix

Table 10: Industry Breakdown

branch	uba	Industry
1	752	Food
2	399	Textiles
3	769	Stone, clay, & wood
4	802	Printing/Paper
5	642	Chemistry
6	430	Plastics
7	1500	Metals
8	7896	Service sector
12	1487	Machinery
13	449	Plastics
14	904	Electrical equipment
15	333	Electronics and instruments
16	177	Watches
17	346	Vehicles
18	274	Energy

Table 11: Raw Correlations

	ln Patent Output	ln Patent Quality	ln Inno Sales	wage Percentile Within Ind	wage Percentile Within CH	ln Firm Size	ln Know Stock	empl shr higher	demand past	tech Potential	compet price	compet non-price	degree Competition	export share	int Oligopolistic Market	int Non Price Market
lnPatentOutput	1.00	0.02	0.21	0.12	0.15	0.45	0.75	0.20	0.10	0.19	0.03	0.11	-0.01	0.23	0.13	0.19
lnPatentQuality	0.02	1.00	0.02	-0.03	-0.03	-0.05	0.01	-0.00	-0.03	-0.01	0.00	0.00	0.01	-0.04	-0.03	-0.01
lnInnoSales	0.21	0.02	1.00	0.02	0.02	0.14	0.19	0.17	0.07	0.21	0.01	0.13	-0.00	0.23	0.13	0.20
wage Percentile Within Ind	0.12	-0.03	0.02	1.00	0.95	0.11	0.06	0.27	0.13	0.07	-0.02	0.07	-0.14	0.13	0.17	0.06
wage Percentile Within CH	0.15	-0.03	0.02	0.95	1.00	0.12	0.09	0.35	0.13	0.10	-0.04	0.08	-0.14	0.13	0.18	0.06
lnFirmSize	0.45	-0.05	0.14	0.11	0.12	1.00	0.37	0.03	0.02	0.17	0.10	0.10	0.03	0.15	0.02	0.18
lnPatentStock$_{t-1}$	0.75	0.01	0.19	0.06	0.09	0.37	1.00	0.14	0.04	0.15	0.02	0.08	0.00	0.18	0.09	0.14
shrEmplHiEduc	0.20	-0.00	0.17	0.27	0.35	0.03	0.14	1.00	0.14	0.23	-0.10	0.10	-0.10	0.23	0.23	0.11
pastDemand	0.10	-0.03	0.07	0.13	0.13	0.02	0.04	0.14	1.00	0.09	-0.15	0.04	-0.13	0.09	0.19	-0.03
techPotential	0.19	-0.01	0.21	0.07	0.10	0.17	0.15	0.23	0.09	1.00	0.02	0.10	-0.03	0.22	0.13	0.17
priceCompet	0.03	0.00	0.01	-0.02	-0.04	0.10	0.02	-0.10	-0.15	0.02	1.00	0.01	0.15	-0.01	-0.52	0.47
nonPriceCompet	0.11	0.00	0.13	0.07	0.08	0.10	0.08	0.10	0.04	0.10	0.01	1.00	0.03	0.11	0.20	0.76
degreeCompetition	-0.01	0.01	-0.00	-0.14	-0.14	0.03	0.00	-0.10	-0.13	-0.03	0.15	0.03	1.00	-0.15	-0.73	0.26
exportShare	0.23	-0.04	0.23	0.13	0.13	0.15	0.18	0.23	0.09	0.22	-0.01	0.11	-0.15	1.00	0.62	0.46
intOligopolisticMarket	0.13	-0.03	0.13	0.17	0.18	0.02	0.09	0.23	0.19	0.13	-0.52	0.20	-0.73	0.62	1.00	-0.00
intNonPriceMarket	0.19	-0.01	0.20	0.06	0.06	0.18	0.14	0.11	-0.03	0.17	0.47	0.76	0.26	0.46	-0.00	1.00

8.1. Derivation of Utility

$$
\begin{aligned}
\mathcal{L} &= \alpha_{1j} ln[x_{j1}] \cdot (1-\alpha_{1j}) ln[x_{2j}] - \lambda(\sum_{i}^{I} p_{ij} x_{ij} - m_j) && (20) \\
\frac{\partial \mathcal{L}}{x_{1j}} : 0 &= \frac{\alpha_{1j}}{x_{1j}} - p_{1j}\lambda && (21) \\
\frac{\partial \mathcal{L}}{x_{2j}} : 0 &= \frac{1-\alpha_{1j}}{x_{2j}} - p_{2j}\lambda && (22) \\
p_{1j}\lambda &= \frac{\alpha_{1j}}{x_{1j}} && (23) \\
p_{2j}\lambda &= \frac{1-\alpha_{1j}}{x_{2j}} && (24) \\
\lambda &= \frac{\alpha_{1j}}{p_{1j} x_{j1}} && (25) \\
\lambda &= \frac{1-\alpha_{1j}}{p_{2j} x_{2j}} && (26) \\
\frac{1-\alpha_{1j}}{p_{2j} x_{2j}} &= \frac{\alpha_{1j}}{p_{1j} x_{j1}} && (27) \\
\frac{p_{2j} x_{2j}}{1-\alpha_{1j}} &= \frac{p_{1j} x_{1j}}{\alpha_{1j}} && (28) \\
p_{1j} x_{j1} &= \frac{\alpha_{1j} p_{2j} x_{2j}}{1-\alpha_{1j}} && (29) \\
p_{2j} x_{j2} &= \frac{(1-\alpha_{1j}) p_{1j} x_{1j}}{\alpha_{1j}} && (30) \\
\bar{m}_j &\geq p_{1j} x_{j1} + p_{2j} x_{2j} && (31) \\
\bar{m}_j &\geq p_{1j} x_{j1} + \frac{(1-\alpha_{1j}) p_{1j} x_{j1}}{\alpha_{1j}} && (32) \\
\bar{m}_j &\geq p_{1j} x_{j1} + (1-\alpha_{1j}) \frac{p_{1j} x_{j1}}{\alpha_{1j}} && (33) \\
\bar{m}_j &\geq p_{1j} x_{j1} + \frac{p_{1j} x_{1j}}{\alpha_{1j}} - \alpha_{1j} \frac{p_{1j} x_{j1}}{\alpha_{1j}} && (34) \\
\bar{m}_j &\geq p_{1j} x_{j1} + \frac{p_{1j} x_{1j}}{\alpha_{1j}} - p_{1j} x_{j1} && (35) \\
\bar{m}_i &\geq \frac{p_{1j} x_{j1}}{\alpha_{1j}} && (36) \\
\bar{m}_j \alpha_{1j} &\geq p_{1j} x_{j1} && (37) \\
x_{j1} &\leq \frac{\bar{m}_j \alpha_{1j}}{p_{1j}} && (38)
\end{aligned}
$$

Table 12: First Stage IV for 2008 Crisis Shock

lnPatentQuality	
	2008 Crisis
(Intercept)	-1.18^{***}
	(0.34)
initialExports*bust	-0.02^{**}
	(0.01)
lnFirmSize	0.11^{***}
	(0.03)
lnPatentStock$_{t-1}$	0.02
	(0.02)
market1	0.04
	(0.04)
market2	0.12^{***}
	(0.04)
empl_shr_higher	0.61^{***}
	(0.23)
R^2	0.13
Adj. R^2	0.11
Num. obs.	1259
RMSE	1.37

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 13: IV for Patent Quality through Boom and Bust

	ln[InnoSales]				
	WTO	’08 Crisis	Boom	Bust	Boom-Bust
(Intercept)	3.45^{***}	2.03	2.64^{***}	2.75^{***}	3.07^{***}
	(1.08)	(1.63)	(0.75)	(0.81)	(0.81)
IV[patentQuality]	0.34	1.70^{***}	0.70^{**}	1.05^{***}	0.79^{**}
	(0.42)	(0.53)	(0.30)	(0.40)	(0.34)
lnFirmSize	0.33^{*}	0.59^{**}	0.16	0.05	0.16
	(0.18)	(0.28)	(0.10)	(0.12)	(0.12)
lnPatentStock$_{t-1}$	0.10	0.15	0.20^{***}	0.18^{***}	0.16^{***}
	(0.08)	(0.10)	(0.06)	(0.07)	(0.06)
emplShrHigher	2.90^{***}	1.78^{*}	2.99^{***}	2.46^{***}	2.68^{***}
	(1.00)	(1.08)	(0.74)	(0.76)	(0.77)
demandPast	-0.00	0.00	0.22^{**}	0.28^{***}	0.20^{**}
	(0.12)	(0.13)	(0.10)	(0.10)	(0.10)
techPotential	0.45^{***}	0.38^{***}	0.53^{***}	0.45^{***}	0.49^{***}
	(0.14)	(0.14)	(0.12)	(0.11)	(0.12)
intOligopolisticMarket	0.40^{***}	0.03	0.30^{***}	0.30^{**}	0.31^{***}
	(0.15)	(0.18)	(0.11)	(0.12)	(0.11)
intNonPriceMarket	0.10	-0.02	0.65^{***}	0.35^{**}	0.54^{***}
	(0.15)	(0.17)	(0.12)	(0.14)	(0.12)
wagePercentileWithinCH	4.62^{*}	-5.84^{**}	-1.74	-5.90^{***}	-1.73
	(2.71)	(2.84)	(1.55)	(1.68)	(1.65)
wagePercentileWithinIndustry	-3.89	4.08	1.42	5.14^{***}	1.33
	(2.56)	(2.72)	(1.47)	(1.62)	(1.56)
R^2	0.08	0.01	0.13	0.05	0.07
F (p-value)	0.08	0.01	0.13	0.05	0.07
Num. obs.	1209	1259	1989	1675	1989

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Random G2SLS with errors clustered on individual; time-effects not shown. Industry effects absorbed in the wage percentile variable. scenario*exports instruments for patent quality, cf. text.

Table 14: Innovation Sales Performance and Competition (Patenting Firms Only)

	(V)	(VI)	(VII)
lnFirmSize$_{t-1}$	0.14	0.14	0.13
	(0.09)	(0.09)	(0.09)
lnPatentStock$_{t-1}$	0.27***	0.26***	0.27***
	(0.06)	(0.06)	(0.06)
wagePercentileWithinInd	0.89	0.80	0.96
	(1.18)	(1.18)	(1.18)
wagePercentileWithinCH	-1.04	-0.96	-1.17
	(1.23)	(1.23)	(1.23)
shrEmplHiEduc$_{t-1}$	4.49***	4.51***	4.65***
	(0.69)	(0.68)	(0.68)
pastDemand$_{t-1}$	0.07	0.06	0.06
	(0.10)	(0.10)	(0.10)
techPotential$_{t-1}$	0.49***	0.47***	0.50***
	(0.11)	(0.11)	(0.11)
portQuality$_{t-1}$	-0.04	-0.30^{**}	-0.03
	(0.07)	(0.12)	(0.07)
priceCompet$_{t-1}$	0.08	0.08	
	(0.12)	(0.12)	
nonPriceCompet$_{t-1}$	0.31***	0.32***	
	(0.12)	(0.12)	
degreeCompetition$_{t-1}$	0.02	0.01	
	(0.09)	(0.09)	
exportShare$_{t-1}$	2.15***	2.12***	
	(0.31)	(0.31)	
portQuality$_{t-1}$*exportShare$_{t-1}$		0.51***	
		(0.19)	
intOligopolisticMarket$_{t-1}$			0.45***
			(0.11)
intNonPriceMarket$_{t-1}$			0.60***
			(0.11)
intOligopolisticMarket$_{t-1}$*portQuality$_{t-1}$			0.13**
			(0.06)
portQuality$_{t-1}$*intNonPriceMarket$_{t-1}$			0.11
			(0.07)
R^2	0.13	0.14	0.13
F (p-value)	24.3 (0.000)	22.7 (0.000)	23.4 (0.000)
Num. obs.	1900	1900	1900

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$