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Determinants of Quality & Appropriability of Patentable Invention

Mark James Thompson

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Determinants of Quality & Appropriability of Patentable Invention

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presented by

Mark James Thompson

MA International Relations, Université de Genève
MA Comparative and International Studies, ETH Zürich
MA International Economics, The Graduate Institute, Geneva

born on
11.06.1980

citizen of
the Helvetic Confederation
&
the United States of America

accepted on the recommendation of

Prof. Dr. Martin Wörter
&
Prof. Dr. Peter Egger

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Contents

List of Figures

List of Tables

Dedication

I would like to dedicate this work to my wife, Elisabeth.

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First, Dr. Martin Wörter for his continued support of my PhD despite my professional work schedule, and Professor Egger for affording me the opportunity to study at the KOF.

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Summary

My thesis is a body of work that contributes to the some of the central topics in patent and innovation policy, specifically invention quality, cost-benefit aspects of the patent system, and the competitive dynamic that surrounds this legal régime that has been in place in industrialized countries for over a century. This thesis includes an analysis of newly collected Swiss litigation and cost data, refines and develops methods for assessing patent quality, and empirically tackles the value of patent rights while disentangling the interplay between competition and patent rights in determining innovation. It does this in the following chapters.

The first chapter deals with the litigation costs of the patent system in Switzerland. This process required a collection of original case data that was coded them with regard to procedural and damage awards.[1] There are three key policy design findings that may have wider implications for other jurisdictions: the first is that most of the action happens outside of the courts and thus out of the sight of the public. On the one hand this is good in the sense it saves the public from having to settle disputes that the parties themselves can solve, but it also greatly increases the opacity of using the patent system; the second, major finding is that many of the "patent troll" problems found in other jurisdictions are the product of the asymmetric cost of discovery in procedure and disproportionate damage awards. Adjusting these incentives might allay some of the recent policy concerns about patent trolls as a tax on the patent system. The last finding is the amount of collusion that is going on under the protection of invalid patents.

The second chapter is both a policy and methodological piece focused on the Swiss patent system, and assesses the quality of Switzerland's patent stock. One of the key issues surrounding the patent system is assessing the level of quality of the underlying inventions, and affording protection to only those that are novel and inventive. This is often only possible ex-post. Maintaining a level of quality in the system prevents spurious exclusionary rights from clogging the system, which avoids increasing the social costs of the patent system. To assess both the quality of the active patent stock, and predict the quality of patents during the grant procedure, this chapter presents a new quasi-realtime metric for assessing the novelty and inventiveness. It does this by leveraging patent search reports and examiner's intuition about the impact of adverse citations on the survival of the patent claim. The chapter then demonstrates this metric by evaluating the quality of Switzerland's national patent stock using a selection model, finding that between 84-96%[2] of the patent stock in the country is invalid – a key finding for reconsidering the value of the Swiss patent.

The third chapter, written with Martin Wörter, deals with the economic value of international markets in terms of the actual quality of the innovations that firms produce. By focusing on innovation, specifically inventions, we investigate the relationship between access to competitive international markets, invention quality, and firm performance. We compiled a unique time-series cross-section dataset combining patent and survey data covering the period 1990-2013 that allowed us to develop several measures of market structure, invention quality, and performance. We used international trade shocks as an instrument to identify invention quality and address selection issues utilising a Bayesian imputation approach. We found 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, we built a multi-criteria competitive index that is characterised by non-price factors (first-mover advantages, lead-time, and 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.

The fourth chapter looks examines patentee sensitivity to patent renewal fees, which likely suggests that renewal fees are low compared to the exclusionary value conferred within a jurisdiction. The low sensitivity may be explained by a decline in fees relative to GDP over the last 30 years. We also found that the patent family drives much of the renewal behavior at the jurisdictional level, and that estimates of patentee behavior at the jurisdictional level are likely to be biased or incomplete without

[1] The original judgment data are held by the Swiss Federal Institute of Intellectual Property and Federal Patent Court.

[2] Schankerman & Schuett (2016) using a completely different model finds similarly high rates of invalidity for the USA.

accounting for the family owner's global strategy. In doing so, we can infer the appropriability derived from the patent system.

The fifth chapter examines whether intellectual property rights (IPRs) foster or hinder innovation by estimating structural equations with instrumental variables for a large sample of Swiss firms. Our main findings are as follows: first, the effectiveness of IPRs increases the probability of own R&D. Second, better appropriability conditions at the industry level raise the number of competitors, presumably by allowing more companies to remain in the market. Third, individual firms face fewer competitors if they use IPRs. The further impact of fewer competitors is to raise R&D, when initial competition is strong, but to reduce it, when initial competition is weak ("inverted U").

Zusammenfassung

Meine Dissertation ist eine Arbeit, die zu einigen der zentralen Themen der Patent- und Innovationspolitik beiträgt. Im Speziellen sind das die Qualität von Erfindungen, das Kosten-Nutzen-Verhältnis des Patentsystems sowie die Wettbewerbsdynamik, die dieses seit über einem Jahrhundert in den Industrieländern existierende gesetzliche Regelwerk umgibt. Dazu sammelt sie neue Prozess- und Kostendaten, verfeinert und entwickelt Methoden zur Bewertung der Patentqualität und setzt sich empirisch mit dem Wert des Patentrechts auseinander. Zudem entflechtet sie des Zusammenspiel von Wettbewerb und Patentrechten bei der Bestimmung von Innovation.

Das erste Kapitel befasst sich mit den Prozesskosten des Patentsystems in der Schweiz. Der Autor sammelte originale Gerichtsfälle und kodierte sie hinsichtlich Verfahrens- und Schadenersatz.[3] Es lassen sich drei wesentliche Erkenntnisse zur Politikgestaltung finden, die weitere Auswirkungen auf andere Jurisdiktionen haben könnten: die erste besteht darin, dass die meisten Aktionen ausserhalb der Gerichte und ausserhalb der Öffentlichkeit stattfinden. Auf der einen Seite ist das gut in dem Sinne, dass es die Öffentlichkeit davor bewahrt, Streitigkeiten beilegen zu müssen, die die Parteien selbst lösen können, aber es erhöht auch die Undurchsichtigkeit der Nutzung des Patentsystems erheblich; die zweite, wichtige Erkenntnis ist, dass viele in anderen Rechtssystemen auftretenden "Patent-Troll"-Probleme, das Produkt der asymmetrischen Kosten der "Entdeckung im Verfahren" und der unverhältnismässigen Schadensersatzansprüche sind. Die Anpassung dieser Anreize könnten einige der jüngsten politischen Bedenken über Patent-Trolle als Steuer auf das Patentsystem ausräumen. Die letzte Erkenntnis ist das Ausmass der Kollusion, welches unter dem Schutz ungültiger Patente stattfindet.

Das zweite Kapitel ist sowohl eine wirtschaftspolitische als auch eine methodische Arbeit, die auch am Eidgenössischen Institut für Geistiges Eigentum, dem Schweizer Patentamt, verfasst wurde, und bewertet die Qualität des schweizerischen Patentbestandes. Eine der Schlüsselfragen im Zusammenhang mit dem Patentsystem ist die Bewertung des Qualitätsniveaus der zugrunde liegenden Erfindungen und der Schutz nur derjenigen, die neu und erfinderisch sind. Dies ist oft nur nachträglich möglich. Die Aufrechterhaltung des Qualitätsniveaus im System verhindert, dass falsche Ausschlussrechte das System verstopfen und die sozialen Kosten des Patentsystems erhöhen. Um sowohl die Qualität des aktiven Patentbestands als auch die Qualität des Patents während des Erteilungsverfahrens zu beurteilen, wird eine neue Quasi-Echtzeit-Metrik zur Beurteilung der Neuheit und der erfinderischen Tätigkeit vorgestellt. Dies geschieht durch die Nutzung von Patentrechercheberichten und der Intuition des Prüfers über die Auswirkungen von nichtigen Zitationen auf das Überleben von Patentansprüchen. Das Papier demonstriert dann die Metrik, indem es die Qualität des nationalen Patentbestands der Schweiz anhand eines Selektionsmodells bewertet und feststellt, dass zwischen 84 und 96% [4] des Patentbestandes im Land ungültig sind - ein Schlüsselergebnis für die Überprüfung des Wertes des Schweizer Patentbestandes.

Das dritte Kapitel, geschrieben zusammen mit Martin Wörter, beschäftigt sich mit dem Wert der internationalen Märkte hinsichtlich der Qualität der Innovationen, die Unternehmen produzierten. Indem wir uns auf Innovationen, insbesondere Erfindungen, konzentrieren, untersuchen wir den Zusammenhang zwischen dem Zugang zu kompetitiven internationalen Märkten, der Qualität der Erfindung und der Innovationsfähigkeit von Unternehmen. Wir haben einen einzigartigen Zeitreihenquerschnittsdatensatz aus Patent- und Umfragedaten für den Zeitraum von 1990 bis 2013 erstellt. Es ermöglichte uns, verschiedene Masse für Marktstruktur, Erfindungsqualität und Leistungsfähigkeit zu entwickeln. Wir nutzen internationale Handelsschocks als ein Instrument, um die Qualität der Erfindungen zu instrumentieren und wir adressieren Selektionsprobleme mit einem Bayesschen Imputationsansatz. Wir haben Belege dafür gefunden, dass der positive Effekt der Erfindungsqualität auf den Absatz innovativer Produkte positiv durch den Zugang zu internationalen Märkten und dem dort vorherrschenden Wettbewerbsumfeld verstärkt wird. Konkret erstellen wir einen multidimensionalen Wettbewerbsindex, der durch nicht-preisliche Faktoren gekennzeichnet ist (First-Mover-Vorteile, "Lead-time", zusätzliches Diensleistungsangebot) und den Zugang von Unternehmen zu internationalen Märkten positiv

[3] Die originalen Urteilsdaten sind beim Eidgenössischen Institut für Geistiges Eigentum und Bundespatentgericht.
[4] Schankerman & Schuett (2016) mit einem andren Model findet eine ähnliche höhe Nichtigkeitsrate in den USA.

beeinflusst. Dies hat wichtige politische Implikationen für die Handelspolitik und unterstreicht die Sinnhaftigkeit offener Märkte für die Erfindungsqualität, insbesondere in einer kleinen offenen Volkswirtschaft wie der Schweiz.

Das vierte Kapitel befasst sich mit der Sensibilität des Patentinhabers für die Patenterneuerungsgebühren. Die Resultate deuten wahrscheinlich darauf hin, dass die Jahresgebühren im Vergleich zu dem in einer Rechtsordnung geltenden Marktexklusivität niedrig sind. Die geringe Sensitivität ist möglicherweise auf einen Rückgang der Gebühren im Verhältnis zum BIP in den letzten 30 Jahren zurückzuführen. Wir stellen auch fest, dass die Patentfamilien einen grossen Teil des Erneuerungsverhaltens auf der Ebene der Jurisdiktion bestimmen und dass die Schätzungen des Patentinhaberverhaltens auf der Ebene der Jurisdiktion wahrscheinlich verzerrt oder unvollständig sind, ohne die globale Patentstrategie des Eigentümers der Patentfamilie zu berücksichtigen.

Im fünften Kapitel wird untersucht, ob geistige Eigentumsrechte (IPRs) Innovation fördern oder behindern, indem IV-Strukturgleichungen für eine grosse Anzahl von Schweizer Firmen geschätzt werden. Unsere wichtigsten Erkenntnisse sind: Erstens erhöht die Wirksamkeit von IPRs die Wahrscheinlichkeit von eigener Forschung und Entwicklung. Zweitens erhöhen bessere Bedingungen für das Amortisieren von Investitionen in Forschung und Entwicklung durch den Schutz geistigen Eigentums auf Branchenebene die Zahl der Wettbewerber, dennoch sind mehr Unternehmen, die auf dem Markt bleiben können – drittens sind einzelne Unternehmen mit weniger Konkurrenten konfrontiert, wenn sie geistige Eigentumsrechte nutzen. Die weitere Auswirkung von weniger Wettbewerbern besteht darin, dass wir hoehere FE Ausgaben beobachten, wenn der anfängliche Wettbewerb stark ist, aber sie sich reduzieren, wenn der anfängliche Wettbewerb relativ schwach ist und er sich dann anerhöht ("umgekehrtes U").

0.0 Introduction

The following gives a brief overview of the main themes of the thesis. The goals of the thesis were to explore patent quality and value the effect of competition on patent quality and value. The thesis deploys, *inter alia*, standard panel econometrics, multivariate dimension reduction techniques, a selection model, Bayesian imputation, instrumental variables, and system equations in order to measure and identify those relations.

In the two coauthored chapters, I am the primary investigator. In the case of Chapter 3, I collected and matched the patent data, investigated multivariate ways of measuring patent quality and market types, and developed a simple formal model for why international competition is important for fostering patent quality. I go on to extend my coauthor's idea of using firm export exposure as an instrument for patent quality, by using the 'boom-bust' of the international business cycle to identify patent quality. Martin Wörter, supervisor and coauthor, shaped how Chapter 3 fits into the wider competition literature, and guided me on which panel empirical techniques should be employed in order to best estimate the relation between competition and patent quality using the KoF innovation survey data. In Chapter 5, my coauthors provided me with a sketch for a research design based on the work they had done in Peneder & Wörter (2014). After extensively reviewing the literature and formalizing it in a causal graph, I then took that design and extended the model to incorporate intellectual property rights by developing a more accurate way of measuring IPRs based using the KoF innovation survey data. Martin Wörter advised on the econometrics to estimate the system of equations; Michael's previous work provided industry-level instruments, which, along with my causal attributions through firm-level instruments, allowed me to identify the system. After deriving the reduced form for the system and estimating the IV system, I go on to simulate the model. Michael Peneder formalized the draft text and model. The chapter represents to our knowledge one of the first papers to integrate and estimate the various piecewise theories and relationships of innovation, competition, and intellectual property rights.

The next sections go on to provide a bit more context on the nature of the contribution.

0.0.1 Patent System

Technological change is essential to the physical improvement of human welfare. In order to foster technological change, society has developed the institution of the patent. Patents aim to both reward an inventor's ingenuity and incentivize their contribution to the accumulation of technical knowledge, which, in the absence of a patent right, might otherwise be deprived of the value of the invention. The patent is by its very nature anti-competitive. In exchange for a reproducible description of a technical invention, an inventor is granted a patent, an exclusive commercial right to reap the fruits of the invention in the form of a rent derived from the exclusion of other competitors. Thus the patent replaces a competitive mechanism for the generation of new products and processes, with a legal one, which is imperfect in its ability to afford the inventor protection. The appropriability of the invention depends strongly on the type of invention and industry of the owner, and thus the private value of the patent right varies greatly. Hence, patents create a fundamental tension between protection and competition. Competition is thus a major theme throughout the thesis as an alternative mechanism to patents for the incentivization of innovation. Moreover, patent value and invention quality are key variables regarding the impact that the patent right. We have thus the social value of the patent in terms of quality of the invention given to society, the value of the patent right or appropriabilty which is an incentive to innovate, and an alternative incentive to innovate issuing from competition. However, the benefits of patents to inventors and society are contrasted with the drawbacks issuing from the very nature of the patent as an exclusionary right, which can have adverse effects on competition and impose social costs. Invention quality and society's gain are juxtaposed against the private appropriable value of the patent right, and then the mechanism by which this is done, i.e. market competition versus state legal protection, are themes that run throughout the thesis.

0.0.2 Appropriability of Value through Patents

Companies derive value from an invention in a myriad of ways (licensing, secrecy, lead time, etc.); patents are merely one method of appropriating that value. The mechanism is fairly well understood. For example, with regard to patents, Duguet & Kabla (1998) present detailed micro-data on both the impediments and reasons for patenting, which identify disclosure as the main impediment to patenting and preventing imitation as the principal rationale for patenting; other studies find similar results (Levin et al. 1987, 826). The results presented in Arora et al. (2008) would seem to indicate that the effectiveness of appropriability through patenting boosts R&D; their approach represents a state-of-the-art technique in identifying the incentive the patent right creates for R&D expenditures. The estimation techniques employed in Arora et al. (2008) have the potential to be quite brittle to both the variables employed and possibly the underlying data. Both the Arora et al. (2008) and Duguet & Kabla (1998) studies rely on detailed patent strategy survey data linked with firm-level data. Harabi (1992) and Duguet & Kabla (1998) find the effectiveness[5] of patents has no significant effect on the propensity to patent; this contrasts with the findings in Arora et al. (2008), where the effectiveness of patents in appropriating incremental value of innovation in spurring R&D has a statistically significant effect.

This thesis contributes to this literature on the appropriability of innovation through patents in a couple of different ways. The first way I look at appropriability is largely descriptive by examining court costs and damage awards for Swiss patentees, and how this affects some of their decisions on whether to collude with the technological competitors; *inter alia* I show how the Swiss legal regime alters the private value of a patent; this is done in Chapter 1. I consider appropriability again by exploring the propensity of a firm's willingness to pay for patents, and can draw inferences about the underlying value of the global patent family in Chapter 4. Finally, it looks at how the appropriability through intellectual property rights affects the competition at the industry level in Chapter 5.

0.0.3 Invention Quality and Value

The R&D process results in range of different innovative outcomes, including inventions, one of the key dimensions is the quality of those inventions. Invention quality, or as described in the empirical literature, patent quality has been measured in a wide variety of *ad hoc* ways, such as by counting forward citations. For example, a large patent family is often considered to be a sign of quality and value.[6] Measuring patent quality has become of interest as national policy-makers would like to compare both the level of innovation and patenting standards across countries. A key methodological insight for measuring patent quality can be found in Lanjouw & Schankerman (2004), who demonstrate the use of factor analysis to reduce the dimensionality of patent quality indicators to a single latent quality metric. This promising approach was picked up by the OECD (Squicciarini et al. 2013, 59), but van Zeebroeck & Graham (2011) raise some doubts as to whether the components chosen by Lanjouw & Schankerman (2004) were appropriate.

These quality metrics are wrought with theoretical ambiguity in certain cases. Measuring the "quality" of the inventive output seems to conflate: the quality of the invention, the invention's market value, and the value of the patent monopoly. Moreover, certain metrics, like the number of forward or backward citations, are tainted by for example the number of competitors in the technical domain who might cite another patent. In terms of patent family size, two patents of similar quality and/or economic value can vary drastically along this single dimension: a product patent with sales in a number of markets might have a large patent family, whereas a process patent might have a small one, which merely reflects a narrow geographic dispersion of the assignee's competitors. I address some of these theoretical ambiguities in two different ways: the first is to add a few refinements to an existing technique of extracting the latent quality information by normalizing with regard to technical field and time; the contribution to evaluating patent quality was to develop an entirely new quality metric based on the claims untainted by these observational selection effects.

[5]Effectiveness here is the prevention of imitation, which is cited in patent surveys as the most salient dimension of patents' effectiveness, see Cohen et al. (2000).

[6]van Zeebroeck & Graham (2011) represents a comprehensive survey on this topic.

This thesis then goes on to highlight the role of quality in determining firm behavior during the patent application process where quality enables protection from competition, and in the marketing stage, where inventive quality then affects sales. In Chapter 4, I consider the probability that the innovation meets the legal definition of novel and inventive – this is also one metric for innovation. This quality aspect of patents, and by definition, innovation then dictates both the revenue as seen in Chapter 3 and the value and likelihood of renewal of patents as seen in Chapter 4. Policy makers have been primarily concerned with patent quality for two reasons: the first is setting the bar at the optimum level to manage patent office load in terms of examination quality: a low bar may lead to backlogs, a higher bar may fail to capture the information in the patents for the wider public. The second, perhaps more important concern for the economy at large, surround patent quality has to do with the relatively low threshold that creates and the legal bar during proceedings. Appendix 6.1 presents some of the early work and much more detailed account on measuring quality, a simplified version of that metric was then adapted in Chapter 3. That preliminary work also shows how to improve on known quality metrics like forward citations by normalizing them for year and industry to better extract information from a collection of sub-metrics, like forward citations, claims, backward citations, etc.

0.0.4 Competition

Competition's role in determining and influencing the path of innovation has been a major topic in the literature since Joseph Schumpeter. The literature has been occupied with both how to measure the *intensity* of competition and the theory behind that intensity and innovative outcomes. This link was conceptualized by Schumpeter, and Scherer (1965*b*) ascertained the relation empirically. Building on Scherer's work, Kamien & Schwartz (1976*a*) present a model of that insight, which leads to an inverted-U shape relationship between competition innovation; Levin et al. (1985) likewise empirically demonstrated that there is an inverted U-shape relationship between competition and innovation using the revenue concentration of the top-four firms. Using a different model Aghion et al. (2005) results in a similar inverted-U shape using the price-cost margin.

From a theoretical perspective, Bondt & Vandekerckhove (2012) provide a good breakdown about the various models of competition and innovation. They develop a dichotomy between decision-theoretic models, centered around a manager's choice in the face of diffuse competition, and game-theoretic models more focused around the players in a particular industry. In the former, firms make inferences about the market "assume that the intensity of rivalry is exogenous and constant and is not affected by any firm's R&D investment decision." This type of model holds for much of the innovative and patenting industries, consumer electronics, furniture, machinery, or food producers.

Yet the universe of patenting firms is not homogenous and certain industries like pharmaceuticals where investment horizons are very long, and strategic interaction is necessary to not be competing in the same drug space, game theoretic models are more likely to apply. Using metrics like the C4 ratio or price-cost margins does not respect these empirical differences amongst types of competition with regard to innovation outcomes. Hence, in Chapter 3, we develop a typology of competitive international markets based around the notions of price and non-price competition. We go on to show how competition and access to international markets affects innovation, and how these types of competition relate to invention quality and innovative sales differently. Chapter 5 looks at competition in more general terms, and how it affects innovation through the R&D effort and subsequent innovation outcomes.

0.0.5 Objective and Outline of the Thesis

The purposes of the my thesis were to contribute to the literature on innovation economics with an eye on policy-relevance. While innovation is a major subfield in economics, too often there is a disconnect between the realities of government policy and the economic reality. This thesis looks at some of those policy preoccupations using theory, rigorous econometric technique, and novel data. Hence, my PhD provides new knowledge to address those basic questions, providing economic insight that would support society in striking an even better social bargain with its inventors through better policy. In this sense, many of the policy questions like patent litigation costs, maintaining a high level of inventive quality, intrinsic patent value, internationalization, and competition policy guide the topics of the thesis to keep it relevant to contemporary discussions surrounding intellectual property rights. Switzerland provided an interesting backdrop for this investigation because there has been no systematic economic study on the quantity or quality of firms' patented inventive output, the value of the patent incentive, nor is there much investigation on whether patents disincentivize subsequent invention. Understanding these might help explaining why the country has gone from an agrarian backwater nation to an innovation powerhouse since patents were introduced to Switzerland in 1801 under Napoleon.

Through the collection of four new datasets and use of econometric technique, the thesis investigated the additional economic costs that the system imposes on its users, revealing large incentives for competitors to form a cartel around an invalid patent (Chapter 1). This represents an empirical contribution to the broader literature on litigation costs and legal incentive, done mostly for US patent legal system, revealing that the nuances of the legal regime do matter for the aggregate costs of the patent system. One of the key issues surrounding the patent system is assessing the level of quality of the underlying inventions. This is often only possible ex-post. Maintaining a level of quality in the system prevents spurious exclusionary rights from clogging the system, lowering innovation efficiency. To assess both the quality of the active patent stock, and predict the quality of the patent and grant procedure. The thesis shows how patent quality can be better measured, and how this relates to the Swiss patent system showing most inventions to be invalid in the country (Chapter 4). This represents a methodological contribution to the broader literature on patent quality and the standard for obtaining the exclusionary right to an innovation in all jurisdictions. It presents major policy evidence informing the debate as to whether Switzerland should even maintain its current patent system at all.

The thesis then attempts to identify the amount of increased inventive output or patent quality attributable to the patent right along with the amount attributable to competition, and how policy variables such as access to competitive international markets play an essential role (Chapter 3). It then moves on to appraise patentees incentives using the economic value for firms on a global scale, revealing national jurisdictional considerations to be moot (Chapter 4). Chapter 5 then investigates whether patents actually undermine and disincentivize additional firm R&D by creating competitive hurdles. One common theme is addresses the appropriability of innovation by disentangling the economic value of patents from the underlying invention quality, and juxtaposing the role of the exclusionary patent right with the role of competition as being the primary cause of innovation rather than the patent right itself.

In doing so, this PhD addressed some of the current issues that are not entirely resolved in the literature on patent economics such as: how to best measure the quality of inventive output; how to measure the value of patents; how patents influence firm R&D expenditures; and whether patents inhibit innovation by stifling competition.

Chapter 1

Costs of Swiss Patent Litigation[0]

1.1 Introduction

1.1.1 Purpose

From an economist's perspective, the legal expenses of maintaining a patent right is a type of economic friction that serves no socially useful purpose—in a perfect world patents are unambiguously defined and enforcing their associated rights is costless and instantaneous. As our reader undoubtably knows, patents can be ambiguous, and take considerable time and expense to enforce. The legal costs associated with defending one's own patent and navigating others' are some of the key variables in evaluating both the expected value of a patent in particular and the performance of the patent system in general. Without a good idea of the costs, businesses cannot make good decisions about patenting and litigation; without a good idea of these costs policy-makers cannot eliminate the inefficiencies in the patent system.

By analysing legal actions in cantonal cases between 1991 and 2011, exploiting data in the Swiss patent registry, and conducting interviews with litigators and patent attorneys, this chapter provides: an initial estimate of the costs and number of patent disputes; develops a model of plaintiff behaviour in light of these costs[1]; and demonstrates how these costs influence the performance of the Swiss patent system in general. These should permit better insight into the efficiency of the patent system as a whole, allowing policy-makers to make more informed decisions about whether and how to reform it.

1.1.2 Data

This article draws on three principle sources of data: the full text decisions of cantonal judgments; interviews with litigators and patent attorneys; and legal events (e.g. title deletion) recorded in the Swiss patent registry.

Court Cases

The first and most important component of the information comes from Swiss cantonal judgments, which are well and similarly structured and have several convenient features for analysis:

1. the court usually defines the claim value (*Streitwert*) in the court record, which is an independently valued proxy for the economic significance of the patent;

2. judgments typically specify awarded lawyer's and attorney's fees; and

3. they usually state the court's costs, disaggregated into their constituents.

[0] Alternate version published in: *Sic!* 2013/6

[1] The costs come from both the damage awards and attorneys fees, and inferred from interviews

Given these advantages, the basic approach was to collect a comprehensive list of Swiss patent cases for at least one patent cycle of 20 years, 1991-2011. For cases filed before 2012, this meant drawing up a list of all known decisions using Swiss-Lex, Darts-IP, and Federal Court decisions. The Swiss Federal Institute of Intellectual Property (IPI) then asked the cantonal courts, under Art. 70a of the Patent Law, to fill in any missing entries and send the full text of the judgments for analysis.

Since the cantons had neither a strong incentive nor necessarily the resources to make an exhaustive search effort, we checked for under-reporting in two different ways. The first was by drawing on previous publications (from this very journal no less). Starting in 1995, Dr. Peter Heinrich conducted enquiries with the cantonal courts for how many patent-related cases they had seen between 1990-2000; the results for 1998-2000 were published in *sic!* in 2002 (C. Hilti, Ein Eidgenoessisches Patentgericht (EPG) 1. Instanz in Greifbarer Nähe? [A Confederal Patent Court (CPC): 1st Instance within Near Reach?], 288); compared with our sample, Heinrich's numbers reveal some likely under-reporting.[2]

The second technique was to use a simple *ad hoc* model to identify underreporting; that is statistically estimate the expected share of cases reported from a single canton by using the number of supposedly reported years, its GDP, whether it has a commercial court, its share of Swiss manufacturing, and share of EPO patents originating from the canton.[3] Here too, the evidence pointed to the missing cases from Zurich as a potential wild card, but relativises suspected underreporting in the other cantons because those cases are likely being tried in the over-reporting cantons. Despite Zurich's under-reporting, some of its cases are accounted for through references in other cantonal cases, Swiss-lex publications, or Federal Court records.

[2] The courts at that time reported 73 patent-related cases to Dr. Heinrich. Today, only 27 cases for the same period have been identified; even after eliminating double entries or known non-reporting, ca. 8 cases per year or 10% might be under-reported by the other cantons for these years.

[3] These factors are jointly significant with 98% confidence. For example, Berne with its commercial court, largish GDP, and manufacturing base should have seen about 37 actions, yet only 10 have been identified. This "missing" litigation is almost entirely compensated by cases in St. Gall, Zurich and Basle—whose "excess" litigation accounts for much of the "missing" litigation. Hence, there was likely some jurisdiction shopping with regard to patent litigation. Interestingly, these well-besought courts also seemed to have some of the smallest total legal costs proportional to the claim value, averaging 2% for Zurich vs. the national average of 18%.

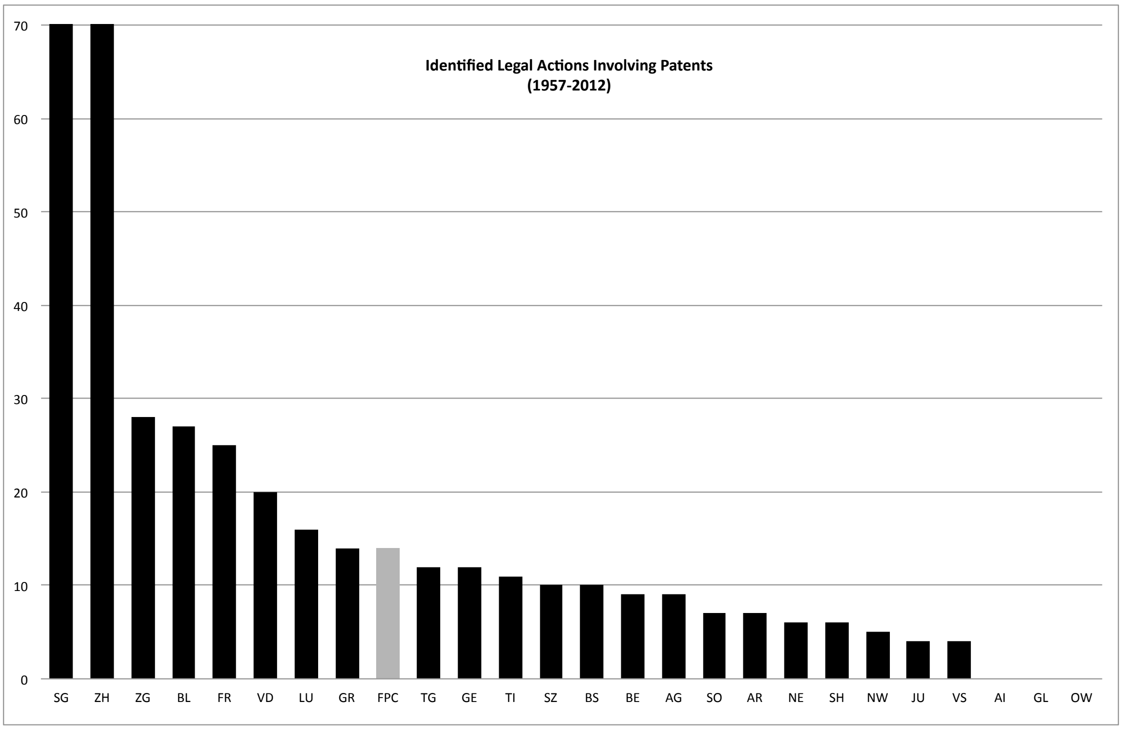

Figure 1.1: Along with superior record-keeping, St. Gall's renowned commercial court makes it the jurisdiction of choice for many businesses. Zurich, Switzerland's most economically powerful canton, is home to 14% of the country's patents; its non-reporting for years 1991-2007 means it likely has seen the most disputes involving patents. The universe of identified actions (currently about 580) is larger than the core years under investigation. Federal Patent Court is in grey.

Under-reporting notwithstanding, the sample is fairly representative of the types of action seen in the courts. Casting a wide net, the cantons provided a variety case types and actions, including writs of protection and confirmations of out-of-court dispute settlement. Almost half of the proceedings involve an element of infringement, but the exact legal strategy to obtain legal remedy varies. The same legal action, say a preliminary injunction, has a very wide range of "meanings": in some cases it is a simply judge's first glance at the merits of the case; in other cases, this supposedly 'procedural' action degenerates into full-fledged and protracted court battle, complete with supreme court appeal. In still other cases, an allegation of nullity induces a quick settlement without any technical assessment. In the face of this diversity, a robust and salient taxonomy was difficult to find based on the legal attributes alone. Table 1.1 shows some of the attributes examined in the core sample.

Table 1.1: Patent Action Attributes (1991-2012)

Attribute	Average
Settled out of court	28%
Nullity (counter-)claim involved	34%
Injunction requested	36%
Tort claim involved	42%
Contract law	14%
Penal law	4%
Trademark law	4%
Patent law	84%
Unfair competition	13%
Procedural or administrative	44%
Months until judgment	25
Years until suit after patenting	9.5
CH national patents	39%
N=256	

Beyond the core sample, about 580 patent-related legal actions going back to 1957 have been identified; some of the statistics presented draw on this bigger sample. Even though for the most part a systematic relation between costs and legal strategy could not be found. What is clear is that patent disputes with a contract (usually a licensing agreement) are much less likely to involve nullity claims, presumably because the parties have an interest in maintaining the patent right. Contract claims are about twice as likely to succeed, and patent violation claims about twice as likely to fail.[4]

Interviews

In order to understand any bias in the cantonal sample, ascertain the number of para-legal disputes, gain some qualitative grip on the judgment data, and estimate omitted costs in the award data, interviews were conducted between December 2012 and February 2013 with seasoned patent attorneys and litigators drawn from both the list of attorneys and judgments. These were done in a structured manner asking attorneys the same questions, and then letting the attorneys speak at liberty. Claim values handled by these professionals coincide with the case data. In terms proportion between extra-legal and legal disputes, about 43% of the incidents come into contact with the courts, though by and large they end outside of the court. Their responses also indicate the cantons have probably disproportionately under-reported settlement activity within the good offices of the courts.

Table 1.2: Key Interview Indicators

	Average	Variation
Years active in patent law	27	≈±11y
Disputes seen out of court	15.7	≈±20%
Disputes seen in court	11.7	≈±20%
Disputes going to full judgment	2.1	≈±28%
Highest *Streitwert* handled	CHF 25,000,000	≈±26%
Lowest *Streitwert* handled	CHF 294,000	≈±25%
Effective costs recovered in award (lawyers)	66%	≈±5.3%
N=17; % indicates relative standard error		

[4] Significant at the 10% level. cf. infra Table 8.

Swiss Patent Registry

Another important source of information is the Swiss patent registry. It records legal events about the patent. If a court strikes the patent down, or if a patent holder withdraw claims or even the patent itself, it gets recorded in the registry. These events, such as a patent modification, or voluntary withdrawal show up in the court records, allowing for some cross-checking. Due to a database migration around 1994-1995, the data before that point are not systematically captured. Events after 2006 taper off as the patents are "too young" to have been disputed.

Table 1.3: Registry Events

	CH	EP	Total
1996	10	1	11
1997	13	3	16
1998	10	7	17
1999	8	3	11
2000	11	6	17
2001	25	8	33
2002	28	15	43
2003	11	7	18
2004	7	15	22
2005	9	14	23
2006	18	14	32
Average	13	8	22
120+ events from Philips Electronics omitted			

A registry event either narrows or abolishes the patent right, so it is reasonable to assume such an action was induced by some sort of legal "incident". Such an "incident" can occur either in- or out-of-court. Partial nullity (*Teilnichtigkeit*) events should correspond 1:1 with a lawsuit. The relation between in- or out-of-court dispute, and a partial withdrawal is likewise believed to be 1:1. The correlation between disputes and full patent withdrawal events is believed to be less tight, owners occasionally pre-empt expiry by non-payment of annual maintenance fees; the IPI does not keep records on the reasons for withdrawal, so a 1:1 relation is assumed here as well.

Of course, not all legal incidents about patents result in a registry event. So the assumption here is that this proportion between observed settlements and withdrawals is equal to the number of recorded withdrawals and unobserved "incidents". For the 243 registry events presented in Table 1.3, it would imply about about 3,000 total "incidents". Now, an "incident" in this understanding may have almost no cost. It might be an angry telephone call to a competitor, an engineer studying the competitor's product for a few hours, getting a patent search report from the IPI, or consulting with a (patent) attorney. Each escalation is more costly, but increasingly less likely.[5] This assumption, admittedly a bit arbitrary, comes from both the observation of the costs and tendency for many economic variables (including patent values) to follow a power law as can be see in Figure 1.2 below.

Distribution of Costs

Before heading into the results, it is important to understand that we are trying to measure. Figure 1.2 shows the various cost stages, a large swathe of events are unobserved, but supposedly low cost.

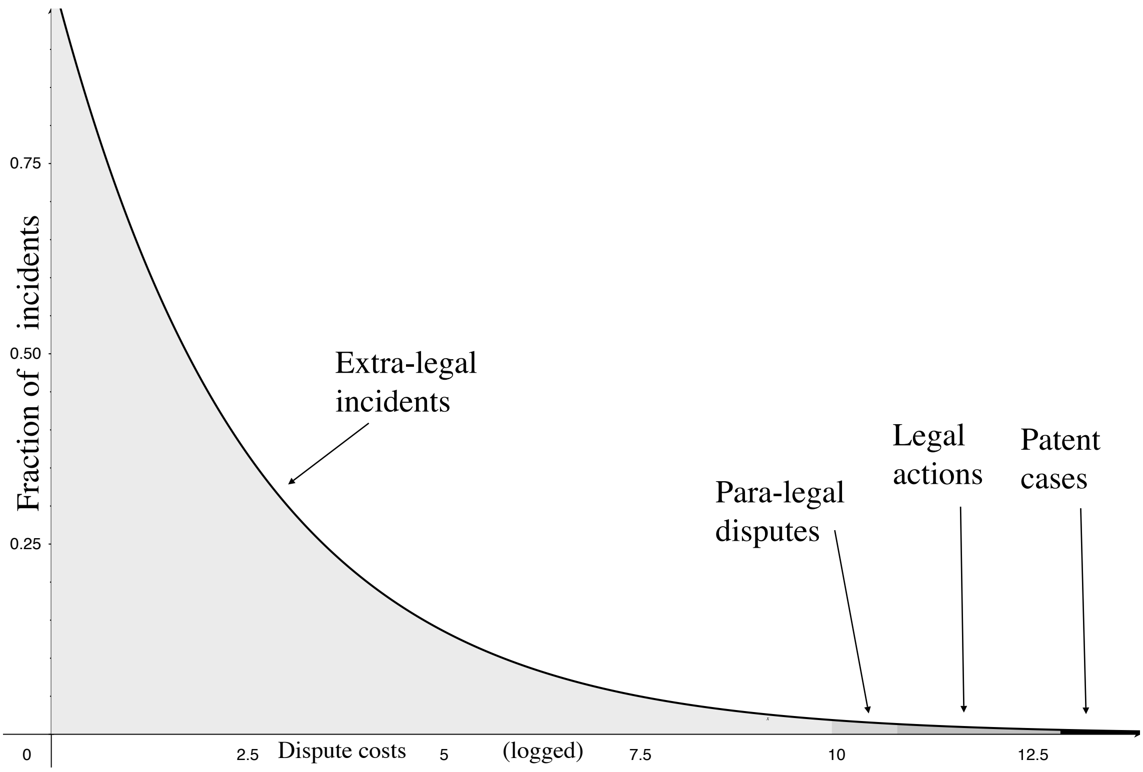

Figure 1.2: Costs of patent disputes are likely to follow some type of power law. Despite almost complete information about the tail in black, most information about the legal actions (dark grey), and some information about para-legal disputes, both the shape of the curve, and starting absolute number of events are essentially unknown.

1.1.3 Results

Population of Disputes

One part of that is understanding the costs within the stages of disputes. Out of court settlements are a viable and common occurrence in Switzerland. The parties in the dispute can settle entirely out of court, or terminate proceedings with or without prejudice. Disputes can escalate into a judgment

[5] For simplicity, this is calculated from all legal actions for which the patent is known (221) minus any double-counts (22):

$$\frac{\text{observedEvents}_{\text{registry}}}{\text{observedActions}} \propto \frac{\text{recordedEvents}_{\text{registry}}}{\text{totalIncidents}} \tag{1.1}$$

$$\frac{16}{199} \propto \frac{243}{3037} \tag{1.2}$$

Assuming direct proportionality might be construed as conservative because incidents with a registry event are more likely to end up in court. For example all nullity decisions have a corresponding registry entry. Several partial withdrawals are observed in cases. As we shall see below an exponential proportionality might be more appropriate. Hence, this assumption aims at capturing most of the disputes that involve a patent attorney or lawyer, not the total effort expended in defence of a patent. Drawing samples with similar characteristics pointed at a much larger number of incidents and much higher costs. Survey data on firm costs surveilling their own patents might be able to fill in the blanks.

phase, which can have multiple legal actions during the main procedure. On average, each patent engenders about 1.3 legal actions.

The annual number of federal appeals and number of legal actions comes from the average number of annual appeals for the years 2008-2011. Total disputes in court include settlements during court proceedings. The inferred number of out-of court disputes is based on the ratio of in-court to out-of-court disputes deduced from the attorney reports of what fraction of their cases go to court. The number of "incidents" is inferred as indicated above based on registry data for the years 1996-2006 when the number of events is most representative. Table 1.4 pieces the data, interviews, and inferences together. Like in Figure 1.2, Table 1.4 shows the more costly the incident, the fewer of such incidents there are.

Table 1.4: Annual Patent-Related Incidents

	Number	Fraction
Patent-related "incidents"	276	1.00
— para-legal disputes	70	0.25
— — legal actions	40-??	0.15
— — — actions with judgments	33-??	0.12
— — — — federal appeals	7.25	0.02
— — — — — full patent lawsuits	4.6	0.01
?? = known underreporting; full suits avg. based on 2000-2011		

Number of para-legal disputes and legal actions are probably higher than presented in Table 1.4 because the interviews indicated only 18%[6] of cases in court go to judgement. This has to do with under-reporting, some of which is identified, for example, settlement proceedings in Basle-City can take place entirely orally without record. Weaknesses of this analysis notwithstanding, they do establish an initial baseline for a heretofore unquantified phenomena.

Patent Case Costs

From the cantonal court decisions, the court costs, awarded lawyer's and patent attorney fees were assessed across all the cases. Court records usually only contain the prevailing party's costs. The assumption is lawyers' costs are, on average, symmetric across parties. Some of the court records were often vague about number of patent attorneys involved, but it usually ranged from 1-3 depending on the case; 2 are presumed. Table 1.5 shows the average costs involved in a Swiss patent dispute.

Table 1.5: Cost Composition of Main Action

	Average [2011 CHF]	Relative Error
Court costs	18,900	≈±12%
Patent attorneys (x2)	61,400	≈±11%
Lawyers' fees (x2)	327,400	≈±59%
Average total per case:	408,000	
Bootstrapped mean & std. error; R=50,000.		

The large error with the lawyers' fees has to do with a myriad of factors. Whereas court costs are only partially tied to the claim value and patent attorneys' fees behave more like a fixed costs, lawyers' costs are related to: claim value, length and difficulty, court regulations, type of case, etc. Some awards seem to be on the actual amount the lawyer billed, costs being listed in great detail;

[6] Relative error: ≈ ±28%

other cantonal awards seem to be more "formulaic" relying on a defined set of rules. Many actions have no reported costs. One litigator said the court award for lawyers' fees varies from 20% to 100% of the actual costs billed to clients, elaborating that in injunction proceedings for example, the courts usually award less than it would for a full case, despite the former being expensive to prepare, so the observed court awards tend understate the true cost to a party (and by extension the implied value of a plaintiff's willingness to pay).

An interesting question is how these numbers stack up internationally. At first blush, Switzerland would seem to be an expensive legal jurisdiction in nominal terms (cf. Table 1.6). After adjusting the nominal amounts by the purchasing power implied by the costs, Switzerland does not look as quite so expensive in comparison.

Table 1.6: Litigation Costs for Patent Disputes

	Average [EUR]	
	Nominal	Effective
USA	5,000,000	8,140,000
Britain	825,000	1,238,000
Italy	300,000	441,000
Switzerland	**340,000**	**340,000**
Germany	150,000	219,000
France	125,000	203,000
Netherlands	130,000	181,000
Spain	75,000	122,000
Belgium	75,000	102,000

This study; Van Zeebroeck & Graham (2011)
OECD comparative prices for 2011 PPP.

The high estimates for the other jurisdictions are likely attributable to the fact that studies neglect the lower-valued extra-legal legal disputes; in this sense studies heretofore are more focused on the tail of the distribution rather than the mass of it.

Having established the general costs, it begs the question of what the general litigation costs for the entire patent system are.

Total Systemic Legal Costs

The general incidence of patent litigation in Switzerland is very low. There were a total of 15 legal actions involving patents of some 124,000 patents born during 1991-1992. Estimating system costs from 15 actions is not terribly robust, so total costs were estimated using the total costs for the years 2008-2011, i.e. the years for which the data is most complete. Aside from the 'hard' data, the interviewees information was incorporated in the form of unobserved billing and para-legal disputes. Because the costs appear to follow some sort of power law and the courts had a tendency to send the major cases in the long tail, the costs missing entries were imputed with the observed median[7] court costs (CHF 6,500) and lawyers' (CHF 21,000) fees.[8] Para-legal disputes were conservatively billed at one half of the median lawyers' fees (CHF 10,500) for each party. Half the posited "incidents" were billed at two times a quarter of the lawyer's median cost. This does not mean that a patent attorney might not be involved for the para-legal disputes and incidents; indeed, a threatening letter from patent attorney might be more credible, however the smaller the claim involved, the less likely both an patent attorney and lawyer jointly involved.

[7]For those not familiar with this metric, it is the mid point if all the observations are lined up in order of magnitude; it is often a much better representation of the average when data comprise extreme values.

[8]Bootstrapped and bias-adjusted; R=50,000.

Table 1.7: Patent-Related Legal Costs (2008-2011)

	Total [CHF]
Patent attorneys (x2)	1,680,000
Lawyers' fee awards (x2)	5,073,000
Unobserved lawyers' billing (+33%)	1,674,000
Court costs	1,968,000
Actions identified but undocumented (10)	650,000
Para-legal disputes (214)	4,543,000
"Incidents" (730)	7,724,000
Grand total	23,310,000
— annually	5,828,000
— —per active patent (95,000)	61

5.8 million francs in annual legal costs implied by the system looks like a bargain compared to a single US lawsuit. But is this reasonable? Possibly, the interviewees indicated the legal culture is more conciliatory–indeed the court records often indicate long negotiations within the court before the trial. Lack of punitive damages or even real damages for that matter decreases the incentive to litigate, as does the risk of paying the other party's legal fees. Furthermore, the Swiss market is small, meaning the stakes are lower.

Having examined the total cost, the next section is a preliminary attempt to formalize the Swiss legal battle.

1.2 A Model of Swiss Patent Suits

This section develops an economic model for the behaviour of the parties involved in patent dispute, which is typically a civil suit. It does this by taking the main features of the legal process, and expresses the behaviour of the actors as a function of their incentives. In doing so it reveals some of the institutional weaknesses of the Swiss civil suit, and also underpins some of the arguments further on in the article. The math and derivations have been left aside; their core logic being explained in words for the verbally inclined reader.

A Swiss patent suit has usually involves five types of actors:

1. the lawyers
2. the the court
3. the defendants
4. the plaintiffs
5. the patent attorneys

Each of these actors will be examined against their interests in light of the judgment data.

1.2.1 The Lawyers

The lawyers obviously want to win their case. Given that the cantons award lawyers' fees based on the *Streitwert*, and it is often correlated with the complexity of the case, this is modelled as some fraction (α) of *Streitwert* (W).

$$u_{\text{lawyers}} \equiv \alpha W \tag{1.3}$$

Depending on the canton, lawyers can also charge clients by taking a percentage of this *Streitwert*. Basle-Country, for example, allows lawyers to charge up to 2.5% of the *Streitwert* (BL-178.112 §4-5). The interviews with the lawyers revealed this is not necessarily a common practice. Another part of their fee is set at least in part by the court, again based the claim value. In some cantons like Geneva, contingency fees or case for a flat-fee are not allowed (LPAv Art. 35), so clients cannot induce optimal lawyer effort within the context of a single suit. No informant reported contingency as part of his or her billing.[9] This simplifies the model immensely because the case outcome is not determined as a function of fees paid for the lawyer's effort. The model essentially reduces to a decision made by the plaintiff.

1.2.2 The Court

While the court adjudicates the claim, less obvious is the fact that the cantonal courts placed a great deal of emphasis on arbitration. This is evidenced in the judgments by lengthy descriptions of various discussions between the parties and court in informal sessions; another indication is the fact that ca. 30% of the cases are settled during the lawsuit in court.

As far as economic incentives are concerned, the court is presumed to need revenue. To acquire it, it typically takes a fee that is some percentage (γ) of the *Streitwert* (W_c). [10] Courts also want to appear "fair" so as not get overruled on appeal, their utility is expressed in terms of fees and disutility from the divergence between claims and counterclaims presented. It is legally disinclined to deviate from the average *Streitwert* submitted by the parties.[11] The court gives some weight to the differing *Streitwerte* of the defendant (W_d), the plaintiff (W_p), and the court's own judgment (W_c) (γ, β, δ).

$$u_{\text{court}} \equiv \gamma W_c - \beta((W_c - W_d)^2 + (W_c - W_p)^2) - \delta(W_c - \frac{W_d + W_p}{2})^2 \tag{1.4}$$

The fact that court has discretion in awarding both attorneys' fees and setting the court's take of the *Streitwert* based on the difficulty of the case suggestions there could be upward bias on the *Streitwert*. Interviewee #3 indicated that some presiding judges would pressure parties to raise a low *Streitwert* submitted to the court. In our sample, the cantonal judges often characterised patent cases as "difficult" or "laborious". With exception of a few cantons (cf. Figure 1.1), most cantonal judges rarely saw a patent cases, which implies they would need read the doctrine, jurisprudence, and law thereabout in order to adjudicate the dispute. Merely reading a patent can take an even experienced examiner hours; determining novelty and inventiveness can take the better part of a week in certain cases. So "difficult" or "laborious" when compared to a rental dispute is not necessarily inaccurate.

Aside from increased revenue that may or not directly benefit the judge, judges can assign higher case value or attorneys fees that would benefit colleagues. This would be not much cause for concern if the composition of the judiciary were stable, but in Switzerland it is fairly permeable: lawyers and judges move between private practice and public service. Some of our informants mentioned current or past experience working in the courts. Economically, this means there is potential for a repeated game that would allow a judge to compensate a lawyer, who then would compensate the judge later in private practice via awards within the court's discretion. This does not mean that awards and setting claim values in the upper band indicate inter-case compensation. Our reader should not take this as an accusation of wrong doing. But it is not necessarily a first-best institutional design given judicial permeability or court funding pressures.

1.2.3 Patent Attorneys

While and entire case can hinge on a single patent attorney's opinion, the parties and courts essentially treat the patent attorneys like a passive technical resource. According to our interviews with

[9] To reduce moral hazard, they can induce more lawyer effort by forming long-term conditional contracts for repeat business or putting lawyers on staff with the option to terminate.

[10] While each canton has the right to set its own court costs under the Art. 96 uniform civil Procedure, many if not all, set these in proportion to the claim value.

[11] The burden is on the parties to determine the *Streitwert* K. Spähler / L. Tenchio / Dominik Infanger, Schweizerisches Zivilprozessordnung [Swiss Civil Suit Procedure], Basel 2010, 535.

patent attorneys, their fees are a function of difficulty and time involved, and unlike the lawyer's fees, not directly hinged to the *Streitwert*. The parties would occasionally agree to make the whole suit contingent on a single expert appraisal of the patent, which was a more cost-effective way of settling a dispute. Their utility is simply defined by the total amount billed (E). This means their can either be only one examiner or one for the plaintiff and defendant.

$$u_{\text{patent attorneys}} \equiv E \tag{1.5}$$

We assume the parties each have their own E_d and E_p respectively, and there can be even a third (albeit rare) if the court were to ask for its own opinion E_c.

1.2.4 The Defendant

If the plaintiff prevails, the defendant pays damages equal to the *Streitwert* of the case, his own patent attorney's fees, court costs, plus his opponent's and his own legal costs. Otherwise, the defendant walks away with nothing besides his costs covered. Here, we suppose the damages to be paid are equal to the value the plaintiff places on the case (W_p), which is then discounted by the probability that the action succeeds (p); should the plaintiff fail ($1-p$), the defendant walks away with nothing besides his costs covered for the defendant's attorney $\alpha_d W_d$ fee and court costs $\gamma_c W_c$:

$$E\{u_{\text{defendant}}\} \equiv (1-p)(E_d + \alpha_d W_d + \gamma_c W_c) - p(W_p + E_d + E_p + \gamma W_c + \alpha W_p + \alpha W_d) \tag{1.6}$$

Damages modelled as a function of *Streitwert*, this is *very* stylistic. If the plaintiff prevails, the defendant pays damages equal to the plaintiff's value of the case (W_p), his own patent attorney's fees and the other's fee ($E_d + E_p$), court costs based on the plaintiff's *Streitwert* (γW_p), plus his opponent's and his own legal costs ($\alpha W_d + \alpha W_p$). Most observed cases do not go past preliminary injunction, which indicates damages and payments are likely being made outside of the court. The interviews also support this conjecture; the lawyers indicated that settlements can be anything from a pure bargaining game to an accounting exercise based on standard licensing fees. For simplicity, and as a proxy for the patents value, this damage is assumed to be equal to the *Streitwert*. We have but 6 case out of 166 where the court has awarded actual monetary damages. Some of the implications are explored in Section 1.3.3.

1.2.5 The Plaintiff

While the other actors are fairly passive, the plaintiff drives the legal action. The risk-neutral plaintiff wants to maximise expected value V of the claim upon prevailing, but will only take legal action if and only if she expects to benefit after subtracting all the expert costs E, court costs based on the court's *Streitwert* (γW_c), and both side's symmetric attorney's fees based on the court's final *Streitwert* ($2\alpha W_c$). The plaintiff will not file if the suit will cost more than the potential damages recovered—no doubt something any good lawyer would tell a client. The plaintiff's decision to go to court can be written as a function of all the legal costs, where $E_d + E_p + E_c$ cover up to paying three different examiners, and the payoff in terms of a lump sum award of the *Streitwert*:

$$\begin{aligned}
0 &\leq pV - (1-p)(E_d + E_p + E_c + \gamma W_c + 2\alpha W_c) && (1.7)\\
-pV &\leq (-1+p)(E_d + E_p + E_c + \gamma W_c + 2\alpha W_c) && (1.8)\\
pV &\geq (1-p)(E_d + E_p + E_c + \gamma W_c + 2\alpha W_c) && (1.9)\\
V &\geq p^{-1}(1-p)(E_d + E_p + E_c + \gamma W_c + 2\alpha W_c) && (1.10)\\
E\{u_p\} &\equiv \frac{1-p}{p}(2 \cdot (E_d + E_p + E_c) + \gamma W_c + 2\alpha W_c]), && (1.11)\\
& \quad \text{if } W_c \geq E\{u_p\} && (1.12)
\end{aligned}$$

The implied value of a claim changes with respect to the other cost factors and probability of prevailing in court. This idea is not new: one patent law commentary states that the implied costs of a case are used by the court to revise *Streitwert* upward (Christoph Bertschinger / Peter Münch / Thomas Geiser, Schweizerisches und europäisches Patentrecht [Swiss and European Patent Law] IV, Basel 2002, 842).

Not all decisions however are so rational. The informants made it clear that emotions and bad blood clouds clear judgement. Furthermore, plaintiffs might not have full information about legal proceedings and costs from the beginning, or be trying to deter future infringement. Informant 'C' mentioned that small businesses often underestimate the costs involved in court battles, and whereas corporate clients can be more ready to settle because they have a better picture of the true costs involved in a court battle. The dirtier managerial secret is that patent holders do always not have a grip on the value of their own patent let alone its legal embodiment in the form of a *Streitwert*. The legal literature on patent valuation in Switzerland makes it evident there is not a single accepted practice for valuation; the valuation experiences related by our informants indicated that managers do not really know what the value is, nor is there necessarily a real attempt at valuation, and even when valued, the court on average rarely awards anything approximating the value of right infringed.

Having set up all the actors' preferences, we now turn to the actual data to fill in the blanks. Given the centrality of the plaintiff in launching a suit, we shall largely focus on her decision and its implications in patent rights enforcement.

1.2.6 Parameters of a Swiss Civil Case

In addition to the general, case attributes presented in the first section, some of the key economic variables were coded so as to permit a parametrisation of the foregoing. These values are presented in Table 1.8 below.

Table 1.8: Parameters for Patent Violations

Parameter	Parameter	Error
Probability plaintiff wins (p)	41%	$\approx \pm 5.7\%$
Lawyers' take (observed)	8.1%	$\approx \pm 48\%$
Lawyers' take (effective) (α)	11%	-
Patent attorney's fee (E)	CHF 31,000	$\approx \pm 11\%$
Cantonal courts' fee =	18,900	$\approx \pm 12\%$
Cost federal patent court =	$20.2 \cdot \text{Streitwert}^{0.5715}$	

Bootstrapped relative standard errors; R=50,000.

Armed with and idea of how things work in a typical case, the chances of success, and costs, the implications we shall now explore the implications.

1.3 Some Implications of Litigation Costs

1.3.1 When (not) to go thermonuclear

Recall from that the average cost of a principle patent lawsuit is about CHF 408,000; this is also the amount a plaintiff would have to pay should she not prevail in her claim. Her historically determined probability of winning is 41%. Her probability of losing is 59%. Thus her expected costs of a suit becomes ca. CHF 240,000 ($0.59 \cdot 408,000$). She is indifferent between suing and being infringed if she will gain only CHF 587,000 in benefit (CHF 240,000/0.41). She will sue, if this will restore that more than that amount of benefit. Conversely, it becomes rational for others to infringe on her invention, if it is worth less than this amount. The policy implication is that many of the novel and inventive patents with low economic value will simply be infringed on anyway no matter how well examined.

The cost structure of the new patent court does hold out the possibility that the break even point will be lower, but it would require a radical new take on damage awards. Table 1.9 shows where a plaintiff might break even— at about 172,000 francs (*provided* damages are awarded as a lump sum equal to the *Streitwert*).

Table 1.9: Break-Even at the Federal Patent Court

Streitwert	E{recovery}	E{costs}	Net
160,000	65,600	68,577	-2977
172,370	70,672	70,671	0
180,000	73,800	71,955	1,845

Payout=*Streitwert*. See footnote.

However, this would require a major change in legal practice because plaintiffs up until now have, on average, only recovered a fraction of *Streitwert* in Swiss courts. The plaintiff's benefit using the empirically estimated parameters from Table 1.8 above is for the Federal Patent Court would be:

$$u_c[W] \quad = \quad 0.41W - (1 - 0.41)(2 \cdot 31000 + 20.2 \cdot \text{Streitwert}^{0.5715} + 2 \cdot 0.11 \cdot \text{Streitwert}) \quad (1.13)$$

However, suing only when breaking even is not always the best move. A patent owner can deter infringement by developing a reputation to litigate at a loss. Steve Jobs, Apple's founder, famously said, "I will spend my last dying breath if I need to, and I will spend every penny of Apple's $40 billion in the bank, to right this wrong. I'm going to destroy [Google's] Android, because it's a stolen product. I'm willing to go thermonuclear war on this (W. Izaacson, Steve Jobs, New York 2011, 1330)." Cooler heads seemed to have prevailed: Apple now has $137 billion in the bank as of Q1 of 2013, and Android is still around. In the Swiss court decisions, we did not see many suits conducted by the same litigant that would indicate such an aggressive strategy of deterrence.

Strategy aside, the private-value of the vast majority of Swiss patents probably falls well below even the new threshold value because of the Swiss market's small size. Furthermore, confrontational Jobsian megalomania is not a trait generally associated with Swiss managers. As stated above, both the court records and interviews hint at more conciliatory dispute resolution. High relative litigation costs no doubt also play a role. All this begs the question whether widespread infringement could be Switzerland's secret sauce for innovation?

With a concrete understanding of the plaintiff's decision, we now switch points of view to the competitor's perspective.

1.3.2 Why judicial examination is (micro-economically) broken

Patent Law Art. 26 allows a party with a proven interest to file a nullity suit, which would, upon success, permit a court to modify or strike the patent down. Despite the public good of having fewer bad patents in the system, Swiss legal procedure makes no special cost provisions for patent nullity actions. That is to say such cases are by and large subject to the same court costs as those presented above. The following is a sketch of why this cost constellation is problematic from a competitor's perspective.

Imagine a type of patented product whose cumulative countrywide profits are one million Swiss francs. Since only a single firm produces this product based on its monopoly right, that firm's profit would be the entire million. Enter our potential plaintiff, a firm that believes the patent is null. Upon winning, the firm will receive a portion of those monopoly profits, but since there will be two firms competing after the judgment, the firms' profits are given by the total value of the patent divided by the number of firms (i.e. profit/2). Now consider the most general case where there are n other competitors besides the patent holder and potential plaintiff. It becomes evident that the incentive to launch a nullity action evaporates when the number of firms is large because profit goes to zero. Of course the potential plaintiffs could coordinate a lawsuit, but as the number of firms grows so do the organisational costs amongst the potential plaintiffs. Moreover, some of them will have an incentive to free ride on the others' lawsuit. Around the time when the Swiss legislature was debating an unexamined patent in the early 1950's, imports were about 3.2% of GDP compared with 32% of GDP today.[12] A nullity action that might have been profitable in a duopolistic or oligopolistic situation of the post-war sheltered market has become a less attractive when the world's producers can compete alongside national firms.

The evidence for this hypothesis is admittedly limited, but we do know that nullity actions are quite rare which is consistent with the theory. From 1991 to 2011 the Swiss patent registry has seen only 13 patents that have been either modified or annulled. At the very least, the value of the case would have to be about double the value threshold before a nullity suit would be worth considering because post-suit profits are halved.

While judicial review could be micro-economically broken, this does not necessarily mean that it is broken. If there are no socially unjustified patents, there is no social cost. Even if there are unjustified patents, but they have little to no value, there is no socially deleterious monopoly rent. Furthermore, if all the unjustified patents have a value greater than about 1.2 million, judicial review should work when the number of firms is small, mitigating any economic damage. That is a quit a few "ifs"; so there is clearly some amount of social damage. Even then the amount damage still might be less than the costs of examination, which is a partial functional substitute to the nullity suit. Though there are ways to estimate these ill-gotten gains, explaining the rationale, methods, and assumptions in doing so would go far beyond the scope of this article, for this reason, we next search for an seemingly missing denizen of Swiss patent litigation landscape—the (too) much maligned "patent troll".

1.3.3 Hunting the elusive *Trollum privilegiorum helveticum*

The *trollum privilegiorum*, "patent troll", is typically a non-producing entity that does not directly use or implement the patented technology in question. They can play a useful role in the patent ecosystem by buying up and marketing technologies, which in the hands of the original proprietor, might have otherwise laid fallow. Aside from subsisting on courtage, trolls feed on settlements and damages. A patent troll thus has a different profit strategy than a producing entity in that it often allows the infringement to occur rather than prevent it as would a producing entity. Trolls will also be much less likely to strike a cooperative bargain (e.g. cross-licensing) with producing entities because they depend on licensing and damages rather than revenue from production. Trolls are a major source of legal costs in some systems: lawsuits from non-producing entities now comprise about 61% of the lawsuits in the US federal courts.[13] In stark contrast, of the some 160 Swiss judgments examined, there did not seem to be a single *prima facie* case of trolling. The argument advanced here is that both payoffs and costs are not conducive to trolling.

The first and most basic reason why the *trollum privilegiorum helveticum* seem to be an endangered species in Switzerland is that the Swiss market is small compared to other jurisdictions. This implies that both the likelihood of infringement and the size of possible damages are small compared to the United States or even Germany where trolls are known to dwell (M. Reitzig / J. Henkel / C. Health, On sharks, trolls, and their patent prey – Unrealistic damage awards and firms' strategies of 'being infringed', Research Policy 2007). Assuming courts award damages proportionally to relative market size, measured by GDP, a troll would be awarded about nine times more for a patent violation in Germany or 42 times more for a violation in the United States.[14] There is no doubt some critical jurisdiction/market size below which a patent troll's business model becomes unprofitable. Switzerland, as a small economy, seems to fit that general economic expectation. This basic economic expectation aside, there also are good legal reasons.

Andri Hess discusses some of the legal reasons for why typical cases of trolling in the United States would be difficult or impossible under Swiss law.[15] Reasons for which he cites: 1. the lack of penal damages; 2. the lack of submarine patents (patents that are not published quickly enough); 3. no patents on contentious and vague software and business processes; 4. more extensive compulsory

[12] WTO 2011 country profiles. 1948 imports from WTO over 1947 GDP based on F. Andrist / R. Anderson / M. Williams, Real Output in Switzerland: New Estimates for 1914-47, US Federal Reserve Review 2000

[13] S. McBride, US patent lawsuits now dominated by 'trolls' -study, Reuters 2010-12-10

[14] 2011 PPP GDP

[15] Patent Trolls: An Analysis according to Swiss Law, sic! 2009, 851-865

licensing; 5. compulsory licensing for a wide range of subfields; 6. a strong legal bar against abuse of right.

That last point is especially relevant. The tactic of waiting until an infringement has occurred or unrecoverable investments have been made in a product is common amongst trolls. In theoretical models of troll behaviour, both Shapiro 2010 and Henkel 2007 highlight that waiting until an infringer has incurred large sunk costs until before launching infringement proceedings can be an optimal strategy.

Hess points out that waiting is a questionable strategy under Swiss law given its strong principle of abuse of right; Swiss Civil Code Art. 2 par. 2 of the states that an "obvious abuse of a right receives no protection under the law." Common law has practically an opposite take: "If it was a lawful act, however ill the motive might be, he had a right to do it."[16] Hence the would-be viable strategy of waiting to maximise damages in some common law jurisdictions becomes at best dubious legal tactic under Swiss law, especially since the Federal Court strengthened the legal test for abuse of right in *i.S.I. Inc.* vs. *I.com Standard Inc.* (FCD 117 II 575). The results of this investigation largely support Hess's assertion that the Swiss legal environment is hostile troll habitat. But there are a few deficiencies in his analysis become apparent when we look at the court case data.

First, Hess underplays the role of preliminary injunctions in trolling. The economic literature on patent trolls shows how potent an injunction can be in negotiations because it has the potential to cut off the entire revenue stream of a given product line (cf. Shapiro 2010; Henkel 2007). As one defendant put it, a preliminary injunction in the United States "create[s] the financial equivalent of nuclear winter (M. Armond, Introducing the Defense of Independent Invention to Motions for Preliminary Injunctions in Patent Infringement Lawsuits, California Law Review 2003, 120);" it can force even a large company with deep pockets quickly to the negotiating table. Swiss law also provides for temporary injunctive measures, but it is a mere shadow of the legal cudgel that makes companies cower in fear in the United States. Whereas US federal courts are wont to grant an injunction, the opposite holds true in Switzerland. When reading the tone of the cantonal judgements, one gathers that Swiss courts seem very disinclined to issue injunctions. Our sample statistics also bear this out: (pre-)preliminary actions only succeed about 26% of the time. Under Switzerland's current uniform civil procedure of 2011, a plaintiff typically must show that:

1. she actually has a right that has been or will be very likely to be violated or vitiated;
2. a disadvantage therefrom that cannot be easily repaired; and
3. (if pre-preliminary, an element of urgency.)

These current cumulative conditions largely codify the previous practice of the cantons, which theretofore was only to allow injunctions when necessary to secure the legal interest of the plaintiff that might otherwise be irreparably prejudiced (secure evidence from destruction, freeze bankrupt assets, etc.).

VS-2007-10-04[17] is a concrete example of this judicial conservatism with respect to injunctions. Therein is described an owner of a patent, which passively mixes mash during fermentation, requesting an injunction against a wine producer who had purchased fermenters from a former distributer. That distributor had lost its right to distribute in Switzerland implying the fermenters were extremely likely to be counterfeits from the grey market. The judge ruled against the injunction, not on material grounds of a plausible interest, the judge even hints at a possible criminal violation, but that examination of the fermenters just was not urgent enough, and that even if the evidence were moved or destroyed, the damage of using the patented fermenters could be repaired. In other words, even where there is a likely blatant violation and evidence could be destroyed, urgency and the fact monetary compensation are available militate strongly against the other requisite factors in the Swiss legal test for an injunction. In other cases, the courts allowed a security deposit to be put up in order to forestall a writ—an option not typically seen in patent cases before US federal courts.[18] There is also some

[16] *The Mayor of Bradford* v. *Pickles*, House of Lords, 1895.

[17] This refers to the canton and date of judgment; regular citations are unavailable because the cases were provided on condition of anonymity.

[18] e.g. *BL-2001-09-26*

real legal risk involved in obtaining an Swiss injunction because if it is overturned, the plaintiff can be made liable for the lost-profits arising from the issuance of the injunction itself (*LU-2011-06-27*)! This again stems from a strong idea of abuse of right, but stands in stark contrast to common law jurisdictions, where "there is no general principle of restitution available to a party harmed by a 'wrong' court order."[19]

This case would have likely merited an injunction because the US Federal Court "has indicated that an injunction should be issued once infringement has been established unless there is a sufficient reason for denying it."[20] Assuming that the winemaker is typical, (s)he could have lost out on a whole season's worth of income of about CHF 87,000[21] because the case had been (strategically?) introduced right around harvest time. Had the injunction been issued, the winemaker might have been willing to settle for any amount less than this income despite obvious and cheap substitutes for the patented fermentation tanks (e.g. pumps, mechanical or even manual stirring). (Could the judge's real reason for denying the injunction have been a balancing of hardships as required by equity in common law?)

Lastly, while HESS rightly points out the lack of treble damages works to the disadvantage of patent trolls, but he misses the fact that *all* civil damages are nigh impossible to recover in Switzerland. Plaintiffs do not pursue damages in the courts, and even when they do, the judgments reveal that the courts were also reluctant to assign direct damages. In fact, we saw monetary damage awards in only eight cases, which represents 5% of the legal actions evaluated. Our informants, including a president of a commercial court, stated that this is the case because Swiss jurisprudence on the matter is inconsistent. To recover, a Swiss plaintiff has to choose between requesting damages or disgorgement of unjust profits; both remedies expire after a year. Even where harm is quantifiable, a claim can easily stumble on proving causality, plaintiffs in our sample seemed to opt for seizure of illicit profit, indicating relief is more likely to be found. Interviewee B, a litigator, stated this is his preferred avenue for recovery. Even then it is hard for plaintiffs to quantify their expected value in case of recovery. Since there is no general principle of discovery, only after wrongfulness has been determined does the judges order the books be examined. In more than one case in our sample did a plaintiff obtain a Pyrrhic victory, winning on the merits, but either not recovering damages, or at a legal cost in excess of what was recovered. No doubt the relatively weak damage remedies induce settlement prematurely on valid claims, revealing a source of legal inefficiency.

This is all not say that the fabled *trollum privilegiorum helveticum* does not exist; 4 of the 16 informants interviewed reported sightings. But the lack of automatic injunctions, small Swiss market, lack of penal damages, and legal difficulty in recovering damages or lost profits, all imply that the Swiss species of patent troll is likely to be an especially hardy breed able to subsist on a relatively sparse diet of pre-trial settlement awards.

1.4 Conclusion

We might conclude that individual suit costs are higher than in other countries, but this does not necessarily imply high systemic costs. Furthermore, judicial inefficiency caused by uncertain damage awards and low probability of plaintiff success, is probably displacing those visible costs in the form of increased infringement and para-legal dispute activity. The more tempered approach Swiss judges also take to injunctions and damages has distributional implications. Since, trolls disproportionately prey on small companies and start-ups, this judicial stance aids small companies, whilst at the same time lowering the value of patents in general due to diminished enforceability.

A research priority should be narrowing the error in estimating the costs para-legal disputes through survey data. Two policy recommendations would be standardise damages in patent suits to reduce uncertainty for plaintiffs and eliminate the current prisoner's dilemma for challenging bad patents by incentivising successful nullity challenges to bad patents in some manner.

[19] *SmithKline* v. *Apotex Europe Ltd.*, Supreme Court of Judicature of Appeal, UK, 2006-05-23.

[20] *W.L. Gore & Associates, Inc.* v. *Garlock, Inc.*, 842 F.2d 1275, 1988. This blanket injunction practice was recently overturned in *Robert Bosch LLC* v. *Pylon Manufacturing Corp.*, 659 F.3d 1142, 2011

[21] Swiss Federal Office of Agriculture survey for its farm accountancy data network

Chapter 2

Measuring Patent Quality: A claim and search report approach[0]

2.1 Introduction

Statistical ways of assessing the quality of patents "appear indispensable in order to provide a firm basis for decisions on matters such as whether and to what extent the abandonment of an old system in favor of a new one is justified (Editorial Board 1982, 148)." As patent statistics have become more readily available to economic researchers through new data sets like PATSTAT and the general standardization and expanding collection of bibliographic information on patents, have allowed us to make good on what was a relatively distant proposition in 1982. With the strong growth in patenting and corresponding documentation, assessing quality statistically becomes an important approach for policy-makers to find the balance between externalities of the patent right and the system's incentive to innovate.

In this paper, "patent quality" is understood to be the novelty and inventiveness of the patent application's claims, as opposed to the legal defensibility, technical merit, or clarity and disclosure. However, one of the major problems of traditional quality metrics for assessing novelty and inventiveness, such as forward citation counts or oppositions, is their timeliness. There is usually a considerable lag between the first application and these observed bibliographic traits. One challenge is thus to find a prospective metric of patent quality. This paper develops such a metric using the citations of prior art found in the initial search reports issued for the patent applications filed via Switzerland's Institute for Intellectual Property (IPI).

The metric presented here is based on the examiner's claim-by-claim assessment in a patent application's initial search report. The strong and intuitive assumption behind this approach is that the citation categorization found in the search report correspond to the underlying quality of the invention and have subsequent patent grant. The notion of using backward citations is not new, but the literature on their use has led to some mixed results in terms of their theoretical interpretation for patent quality and value.

Harhoff et al. rightly note that "[b]ackward citations reflect broad scope as well as the existence of subject matter that may restrict the scope of the patent [...] it is therefore not clear whether the coefficient should be positive or negative [for a patent's value] (Harhoff et al. 2003, 1350)."[1] Lanjouw & Schankerman find that backward citations are not salient in patent litigation. In more recent unpublished work for the OECD presented in Milan, Harhoff, Hoisl, and Webb find that the share of the X-citations is a very weak,[2] but statistically significant predictor of both the likelihood of opposition during examination and subsequent negative outcome. This finding stands in somewhat

[0]Published *World Patent Information*

[1]OECD (2009) provides a recent overview on the use of backward citations to evaluate quality.

[2]They report that raising the share of X-citations from 0% a 100% increases the likelihood that the patent will be challenged by 1.3% (t = 8.7; N = 594,647) (Harhoff et al. 2006, 34).

contradistinction to Harhoff et al. where: "[b]ackward citations either to the patent or to non-patent literature (e.g. scientific papers) have been found to be positively related to the value of a patent (Squicciarini et al. 2013, 22)." A small but positive association between backward citations and the value of a patent was found to be statistically significant by Gambardella et al. (2005). We see the search report as a measure of the novelty and inventiveness of a patented invention, which may or may not engender economic value or incite litigiousness. Yet, part of the ambiguity in the literature about the interpretation of backward citations is also likely attributable to the measurement error when the metric is operationalized as a mere count, count/claim ratio, or citation-code weighted fraction. Careful examination of the typical search reports reveals that each of these approaches is an inadequate approximation. A pure backward citation count typically does not respect the fact that patents with more claims will have more citations because a typical search procedure is a best-effort attempt of the examiner to find prior-art for each claim. Indeed omitting the number of claims likely led to the spurious conclusion that "[b]ackward citations are positively correlated with the patent's value in our study, and that the coefficient is again estimated with high precision Lanjouw & Schankerman (1997)."[3] Lanjouw & Schankerman (1997) correctly fix this correlation by normalizing the backward citations against the number of claims, but unsurprisingly find a null result on infringement and patent challenges [3]. Here, it would be important to note that backward citations are not homogenous in their implications for technical innovation (nor legal assailability). Furthermore backward references to non-patent literature (NPL) and the number of "A" citations, which merely reference the state of the art, usually bode well for a patent grant and underlying quality. Hence patents, which have NPL and "A" citations mixed with "X" & "Y" citations that have negative implications for novelty and innovation, jointly lead to an ambiguously defined variable. Even where citations are adjusted for these attributes, such as by Harhoff et al., the authors implicitly neglect the fact that many of the adverse citations often load on just a couple of claims, which often get shed during examination Lanjouw & Schankerman (1997). This is probably why they are also a weak predictor of a grant because the patent attorney files broadly and narrows the patent during procedure. Not all studies conflate the types of backward citations. Schneider uses a trivariate probit model, which controls for claims, to show that both "X" & "Y" citation types lead to application withdrawal Schneider (2007). More recently, Schettino & Sterlacchini (2009) show, using a probit model, that the combined number of "X" & "Y" citations leads to premature application withdrawal, supporting Schneider's findings.

The tact taken in this study is to look at the patent as a composite of claims, and a particular citation as addressing a given claim rather than the patent as a whole. That is to say we assign a citation value to each claim of a patent. The type and number of citations in aggregate will induce the applicant to proceed or withdraw from prosecution, and govern the patent grant.

Since Switzerland has a dual patent system where applicants can either obtain a national patent from the IPI, which is not examined for novelty and inventiveness, or a European patent, which is examined for novelty and inventiveness, investigating the most recent quality of the Swiss national population in the face of applicant filing strategy and choice of search report presents an empirical challenge, which is addressed using Heckman's selection model and the applicants' characteristics (Heckman 1979).

The plan of the paper is as follows: the nuts and bolts of the metric and data are discussed in Section 2.2. Section 2.3 then tests the measure for plausibility. Finally, after having accounted for quality using the search reports and the selection effects, the paper moves on to infer the unobserved novelty and inventiveness of the Swiss national patent stock.

2.2 The Metric and Data

Aside from the applicant and application characteristics, the core of the data is derived from both the EPO and IPI search reports that are obtained during the early period of the application process. EPO

[3]In that study, Harhoff et al. did not have access to the "[t]he number of claims in our data is due to the fact that PATDPA did not include claims in their database in 1977 (pg. 1350)."

and IPI search reports were chosen for reasons of data availability for our Swiss population.[4] Given that IPI policy is essentially to apply the EPO's search standard, the reports are largely comparable, boosting the sample size.

2.2.1 Search Reports

Typically during examination, patent offices do prior art searches, and summarize their findings in the form of a search report. A search report attempts to find documents that would either destroy novelty, inventiveness, or otherwise pose a legal threat to the patent application. These documents are typically very well structured, and the patent examiner uses citation codes (X, Y, A, E, P) to qualify the type of threat a citation poses to a specific patent claim.[5] Aside from these qualifications, a citation can refer to a wide range of documents, including patents and scientific journal articles. These citations have a number of other attributes, which convey a fair amount of information, hence citations often provide a rich basis for studying a wide variety of phenomenon such as geographic flows of information, speed of technological innovation, or a patent's worth. Here, we shall be using the citation codes as an assessment of inventive quality.

In the context of the Swiss patent system, where there is no obligatory examination for novelty and inventiveness, rather applicants can choose: to have their patent researched for novelty and inventiveness, either by the IPI for a fee that at the time of writing was CHF 500 or the EPO for approximately CHF 1400; or dispense entirely with a search. As of this writing, about 17% of the sampled applications had some type of search report, either done by the EPO (N 890) or by the IPI (N 1150). The IPI search report is cross-subsidized through renewal fees, and represents about 3000 francs worth of search services, i.e. it is cheaper and broader than the EPO's quicker and narrower search.[6] Hence the search fees, patent quality, and applicant filing strategy engender possible selection effects with regard to choosing where to obtain a search report. Both the report and its mere existence contain information about the patented invention's novelty and inventiveness. How the information in the report itself is exploited is discussed in the next section.

Table 2.1: Mapping Report Codes into Claim Rejections

	Citation Code				
	X	Y	A	E	P
"1st guess"	1	0.75	0.5	-	-
"2nd measure"	0.94	0.81	0.18	0.47	0.33
s.e.	0.01	0.03	0.04	0.10	0.09
Responses	39	38	26	16	18

N=41

2.2.2 Backward Citations as a Metric

One of the difficulties of using backward citations as a metric is translating between citation codes and their implications for the quality of the patent (application). Table 2.1 shows how the individual

[4] No doubt some applicants request search from other offices, but these are likely to be very untypical applications and unrepresentative.

[5] To wit: X = Particularly relevant documents when taken alone; Y = Particularly relevant if combined with another document of the same category." A Documents defining the general state of the art; P Documents published between the date of filing and the priority date; E Potentially conflicting patent documents published on or after the filing date of the underlying invention (Squicciarini et al. 2013, 120).

[6] The IPI's former EPO personnel report that they are afforded much more time to evaluate the merits of a patent application than at the EPO. Because the EPO has more specialized personnel their reports tend to find more specific prior art, whereas the IPI's more general personnel tend to find pertinent prior art outside a narrow technological domain. But, even when an IPI search report is of good quality in that it cites relevant prior art, the lack of obligatory examination for novelty and inventiveness of Swiss patents can lead to invalid claims being granted because the claims have not been amended in the light of the cited prior art.

report codes were mapped into a (subjective) probability that the associated claim, as drafted in the application,[7] would be rejected. Again, each value of the code applies to the invalidity of given claim, not the entire patent. An assumption in our study is that the patent examiner will usually apply the correct citation code (X, Y, A, E, P) to the claims, with the understanding that the aggregate of those claim assessments predict the outcome with error.

Not knowing whether the approach would work, a “first guess” served as the baseline for the major codes. The “first guess” having proved fruitful was replaced by a “second measure” based on a survey that was designed to better capture the differences in the codes. The operating assumption is that the IPI's searchers' interpretation is similar to those of the EPO's examiners; indeed, IPI search report guidelines lean heavily on the EPO's guidelines and some of the IPI's searchers are former EPO staff. Control variables in our study absorb most of the remaining difference in practice between the offices.

It is possible to compare the values in Table 2.1 despite the number of responses not being the same for each citation code because the comparison is being made on the basis of the average of the responses. For example, there is a 95% chance the X citation invalidity lies between 0.92 and 0.96, but for the P-type the range is much wider, i.e. between 0.24 and 0.42. The “second measure” was constructed by asking the IPI's patent search personnel their opinion on the meaning of a given document code by asking:

“When you assign an < X, Y, A, E, P> to a claim what percentage of the time do you think that that document kills the corresponding claim; how threatening do you think a <X, Y, A, E, P> code is for a patent claim.”

An initial trial of a written questionnaire proved too difficult for the survey recipients to understand as to what was being sought (i.e. translating a legal assessment into a probability). Hence, short interviews were conducted individually with the patent experts on how they use the codes, eliciting a response to the question above. Naturally, a face-to-face interview runs the risk of introducing some bias, but additional qualitative details were gleaned from the encounter. Some respondents answered directly without hesitation in terms of a percentage. When the interviewee appeared unclear or hesitant, the interviewer (i.e. the author) asked a series of questions to develop at least a rank-order between the “X”, “Y”, and “A” citation codes, if not the precise distance between them relative to “X”, which had a very clear definition in most of the searchers minds as Table 2.1 attests. Some respondents gave qualitative answers like “always” or “sometimes” kills the claim, for which a numerical translation was given by the interviewer, who then had the interviewee confirm his or her answers, which would tend to reduce the variance of those responses and introduce an additional source of error from bias in the final measure.

The small standard errors in Table 2.1 show that X documents are strongly mentally typed; Y documents for the most part also, but were said to be more subjective according to the interviewees. The variance associated with the subjectivity of the inventive step has been observed in other studies as well (Schryvers et al. 1994). The variance is much larger for “A” documents because according to the IPI patent search personnel these can be used to: signal potential infringement, i.e. a quasi “X”/“Y”, or simply as a citation of last resort for defining the state of the art, which has no adverse impact on the claim. The responses about “E” and “P” documents exhibit large standard errors and many non-responses, telltale signs of an invalid survey instrument. Given the IPI's comparatively low application volume, many of the IPI examiners had never seen an “E” or “P” document. Most of the documents they cite have been published, and if they did happen to find one during a search, they had a stated preference to cite “X” and “Y” documents instead. Many of the IPI patent search personnel stated that because precise legal effects of “E” and “P” documents differ depending on jurisdiction (e.g. co-inventorship, ownership and/or validity), such citations' legal effect was hard to quantify *in abstracto*.

For each claim in a report, the maximum value from amongst the cited documents was assigned to the claim (one claim can have any number and combination of “X”, “Y”, “A”, “E”, “P” citations. The report score is then computed as the average score across all the claims. That is to say if claim #1 received an “X”; claim #2 a “Y”, then the report score is the average of the (maximum) claim

[7] While the patent claims can be revised depending on the examiners comments, the idea here is that if too many of the claims are rejected, the probability that the patent can be revised in a reasonable way declines fatally.

value 0.94 and 0.81=0.875.

Having explained the metric, we now turn to testing it by comparing the quality of granted Swiss patents with granted European patents.

2.2.3 Data

The dataset comprises around 10,000 patent applications filed between 2008-07-01 and 2013-03-08, effectively the number of applications filed via the IPI for the period. The sample includes two types of reports: those search reports done by the EPO, and search reports done by the IPI. The EPO reports, only available in PDF were coded manually, and the IPI report scores were preprocessed with KNIME from the IPI's internal citation database. For certain firms, this core report data was augmented with commercial information from Dun&Bradstreet, a credit-rating service, about the number of employees and capitalization of each firm. These firms were cross-checked against stock market listing; firms controlled by a stock market firm were classified as being publicly listed as well. The names, and the occasional Internet search, were used to determine whether the applicant was an educational institution or individual inventor.

2.3 Testing the Metric

The first step is to test whether the search report score as defined above is correlated with analytically interesting aspects of patent applications and outcomes. We present a few unconditional tests to assess the metric, and then use it to predict the novelty and inventiveness of a patent, and then ultimately a grant.

Before turning to the instruments validity let us take a brief look at the two types of search report in the sample. Many of the IPI examiners noted during the interviews that that EPO search reports tend to cite too many novelty-invalidating documents, indicating the two types of reports are different. Two of the Institute's former European Office examiners stated that a European search report is a prelude to an examination, and citation codes are used strategically by the examiner to communicate something to the applicants. In contrast to the EPO's process, IPI patent search reports are a single-shot affair based on a three-day best-effort search with no real subsequent grant procedure/negotiations to consider.

H1: If EPO and IPI search reports and populations are equivalent, EPO search reports should reject the same number of claims as IPI search reports do.

The two-sample two-tailed t-test p-value at the foot of Table 2.3 resoundingly rejects the hypothesis that the two reports and/or populations are equivalent, which means we ought to at least control for the report types in our empirical design (Table 2.4).

Now we turn to the simple question of whether patents granted by the EPO are more novel and inventive than those that have not (yet) been granted.

H2: If the report score is an invalid indicator of patent quality, then Swiss applications with granted EPO siblings should have at least no fewer rejected claims than others without an EPO sibling, *ceteris paribus.*

On average granted EP patents exhibit lower report scores (i.e. few rejected claims) than "un-granted" patents, which are either in administrative limbo, or which have been withdrawn or rejected.

One of the most salient and common observations about patent quality is that companies and research institutions tend to produce more novel and inventive patents than individuals. We ought to see this reflected in their respective patent search report scores.

H3: If the report score is a valid indicator of patent quality, then applications from individual inventors will have a higher fraction of rejected claims than organizations do.

Indeed, we reject the hypothesis that individuals' application quality is superior to those of organizations: there is four-thousandths in one chance they are equivalent. This stands in contrast to individual inventors, who opt for the IPI's (cheaper) report by a 3:1 margin; because the IPI's reports tend to reject fewer claims (cf. Table 2.3), it also implies their observed average is downward biased.

Now that we have seen that this new measure captures some of the known stylized facts about patent quality, we put the new metric to work in a fuller model that will allow us to infer the quality of the Swiss national patent stock, and be able to predict European patent grants (Table 2.5).

2.3.1 Expert Appraisal vs. Report Score

Parallel to this study, the IPI's patent search personnel independently conducted an accelerated assessment, i.e. searched for 2 – 3 hours, on a random sample of 50 granted Swiss national patents from the same time frame (2008-07-01 to 2013-03-08) and found prior art that in their opinion either rendered 84% (s.e. ± 5.49%) of the independent claims (i.e. the core of the patent) as either anticipated or lacking an inventive step. An excerpt of the results of that search are presented in Table 2.2.

Table 2.2: Comparison between Metric and Human Appraisal

Claims rejected	New & inventive? Ind.	Dep.	Examiner's Note
100%	0	0	[Another] document shows that 1 mm3 as typical of microfile systems, and basically has the same drawing as that presented [in final patent]
95%	0	0	according to WO search report, X for 1, 3-11; 2. X-doc also Y-doc for 12-15 possible; [Search report] has X for claim 2
85%	0	0	#13-15 seem obvious & not listed in [Search report]; according to [Search report] & comparison with EP A-doc
75%	0	1	X: # 1, 2, 8; Y: #6, 7; further claims likely not inventive
64%	0	0	EP report X for #1-14; possibly different and new is #6, nevertheless there are several X & Y docs (cf. CT in CH patent)
55%	0	1	[Search report] has Y's for #1, 2, 4, 6, 9; claims in patent prct claims in B-doc practically identical: 1- 10; 12, 13 basically new #13-16; Characteristics of #3, 10 weren't found in [Search report]; #11-16 weren't examined, but seem obvious

Table 2.2 compares this new metric with that human appraisal of the patent's independent and dependent claims. They found also that 52% (s.e. ± 7.14%) of the patents probably would not survive a reformulation based on the content of their independent claims. Since the number of adverse citations found is an increasing function in the time spent searching for prior art, their investigation probably understates the number of "bad" patents. Since less novel and inventive pants (i.e. the granted Swiss patents) tend to not have a search report, only a few patents overlap in the two samples. Table 2.2 indicates that report score does roughly correspond to an examiner's appraisal.

Table 2.3: EPO vs. IPI Report Scores

	EPO	IPI
μ	0.683	0.596
σ	0.293	0.273
N	891	1151
Pr{EPO≡IPI}=0.000		

Table 2.3 shows the difference between EPO search report scores and those issued by the IPI.

Table 2.4: Granted EP Scores vs. "Un-Granted" Report Scores

	Granted	"Un-granted"
μ	0.529	0.657
σ	0.324	0.277
N	141	1897
Pr{Granted≡ "Un-granted"}=0.000		

Table 2.5 shows the difference between search report scores from organizations and those of patents from individuals.

Table 2.5: Organizations vs. Individual Inventor Report Scores

	Org.	Ind.
μ	0.633	0.685
σ	0.292	0.261
N	1698	343
Pr{Org.≡ Ind.}=0.004		

2.4 Results and Discussion on Using the Metric

We have now seen that an application's initial search report score very likely indicates something "real" about the novelty and inventiveness of a patented invention. Hence, we will now look at a statistically appropriate way of using claim score, then show how to account for applicant strategy, and finally demonstrate the claim score's ability to ascertain the novelty and inventiveness of the Swiss national patent stock.

2.4.1 Finding an Appropriate Estimator for the Report Score

Since the patent report score is a fraction, an elementary econometric caution when predicting a limited dependent variable using ordinary least squares (OLS) leads to consistent but inefficient estimation. That is to say, if we use OLS, we would obtain the correct marginal effect, but be more likely to find a null result. In order to correct for the known source of the heteroskedasticity in the linear model issuing from bounded 0-1 interval of a fraction, we present both feasible generalized least squares (FGLS),[8] the fractional logistic model pioneered by Papke & Woolridge (1996), and the most

[8] With $\omega = \frac{1}{\hat{p}(1-\hat{p})}$

appropriate β-distribution model.[9] Table 2.6 presents a comparison of these estimators.[10]

Table 2.6: Percentage of Patent Claims Rejected

	OLS	FGLS	f-Logit	β-GLM
Intercept	0.334	-10.29***	-2.14	-17.6
Applicant=represented	-0.056**	-0.036*	-0.248	-0.187*
Applicant=inventor	0.081***	0.060***	0.364'	0.280**
Applicant=edu. institution	-0.039	-0.011	-0.165	-0.081
ln[trend]	1.967	1.04	0.205	1.68
PCT	-0.099*	-0.067'	-0.436	-0.311'
∃ CH grant	0.049'	0.043*	0.221	0.150
∃ EPO grant	-0.114***	-0.068***	-0.485*	-0.394***
Report type=EPO	0.117***	0.133***	0.513***	0.471***
∃ sibling application at EPO	0.034	-0.043*	0.181	0.116
ln[citedDocs]	0.079***	0.057***	0.350**	0.252***
ln[numClaims]	0.013	-0.025*	0.058	-0.007
ln[familySize]	-0.039	-0.038	-0.200	-0.150
MSE	0.0765	0.0867	0.1717	0.0772
N=1242; significance codes: ***0.001, **0.01, *0.05, '0.1				

The models in Table 2.6 indicate that granted EPO patents have about $7 - 12\%$ lower rejected claim score, with the FGLS on the low side, and the fractional logit at the upper end of that interval.[11] Swiss national patents tend to have slightly more rejected claims. Unsurprisingly, we see final score depends largely on the number of cited documents. Applicants represented by a patent attorney would seem to lower the amount of prior art found, either because the attorney helps draft a better application and/or applicants with better inventions tend to be represented.

Contra theorem, OLS has the smallest mean squared error. While both the fractional logit and b-GLM might be theoretically more appropriate for modeling the underlying distribution of the dependent variable, their numerical implementations would occasionally give spurious coefficients and errors and b-GLM proved insoluble for certain constellations of covariates.[12] The f-logit model also exhibits a substantially larger mean square error than the other three models. None of the models is terribly predictive, describing only around 10% of the overall variance.[13] Including the four-digit IPC class eliminates the observed heteroskedasticity in the residuals: the Breusch-Pagan test goes from strongly rejecting homo-skedasticity to null.[14] This fact is likely picking on three factors known to play a role: 1. different approaches to examination within a technological field; 2. different patenting strategies based on the technical field; 3. heterogenous inventive capacity amongst applicants within a field. Yet, given the smallish sample, incorporating some 264 additional dummy variables makes the model much worse in terms of concision.

One of the major issues with the patent report dataset is dealing with self-selection. The IPI's patent search personnel have consistently noticed that applicants with higher quality patents tend to request a search report whereas applicants with weaker patents choose to register a national patent without examination for novelty or inventiveness, and thus the sample is likely strongly selected. To what extent the sample is selected is difficult to know precisely as applicant behaviors are heterogeneous and their motives obscure. According to an internal IPI study, we know that applicants requesting an

[9]Since a β-distribution is only defined within the unit interval, those patents with either no claim rejections or all claim rejections were assigned a value of 0.001 and 0.999 respectively. The same transformed dependent variable was also used for benchmarking the other models.

[10]Robust OLS and iterated weighted least squares were also estimated without much qualitative difference.

[11]Similar to logit models, β-GLM coefficients are interpreted as odds ratios.

[12]R v. 2.15.1 Mac OS X Leopard build 64-bit; packages stats v. 2.15.1 and betareg v. 3.0e2.

[13]The four-digit IPC class raises the coefficient of determination from about 0.09 to about 0.32. Prediction was substantially better when the sample was limited to firms, and additional firm attributes, such as number of employees could be included.

[14]p-values of 0.000 and 0.381 respectively.

initial search report tend to go onto file an EP or PCT application. As a second choice, applicants must decide whether to obtain a search report via the IPI or EPO. Based on experience, we believe that applicants use the priority period and the inexpensive initial search report to make a decision whether to invest more in the process, and about 50% subsequently appear to use the feedback to modify the patent's claims. Applicants with a European strategy can defray some of their future search costs by choosing the EPO search report directly.

Given this, we model the applicant's decision to file via Switzerland as one conditional on a putative filing with the EPO, with the applicant determining whether to obtain an initial search report via the IPI in a second step. Conditional on those choices, along with the firm attributes, we estimate the latent quality of the invention in using a 3-stage Heckit-type model using the successive inverse Mill's ratio at each stage in the process, whereby the applicant's origin acts as the exclusion restriction; presumably applicants That 3-stage model is presented in Table 2.7.

Table 2.7: 3-stage Selection Model for Applicant Firms

	1st probit stage: EPO filing	2nd probit stage: Report via IPI	3rd OLS stage: Fraction of claims rejected	Simple OLS: Fraction of claims rejected
(Intercept)	959*** (207)	5.06 (76.5)	-7.65 (15.7)	- 7.61 (15.8)
PCT	8.62*** (1.05)	0.49 (0.476)	-0.060' (0.033)	-0.057* (0.026)
Ln[trend]	-91.4** (19.5)	-0.102 (7.04)	0.763 (1.48)	0.076 (1.48)
Ln[familySize]	2.93*** (0.422)	-0.370** (0.143)	-0.045 (0.032)	-0.041 (0.030)
Ln[laborForce]	-0.0820' (0.043)	0.0964*** (0.022)	-0.008 (0.005)	-0.0080 (0.005)
Ln[kapitalStock]	0.091** (0.029)	0.040** (0.016)	0.008* (0.004)	-0.008* (0.004)
publicListed	1.205** (0.408)	-0.493** (0.183)	-0.039 (0.043)	-0.033 (0.043)
origin=CHLI	0.18 (0.667)	1.24*** (0.206)	–	0.065 (0.091)
origin=EPOstate	-2.02 (1.58)	–	–	0.006 (0.127)
Represented	0.23 (0.22)	-0.099 (0.166)	-0.084* (0.035)	-0.08* (0.035)
ln[patentStock]	-0.234*** (0.059)	0.0570 (0.031)	-0.001 (0.006)	-0.002 (0.006)
ln[citedDocs + 1]	0.232 (0.189)	1.89*** (0.093)	0.105** (0.035)	0.099** (0.02)
searchOffice = EPO		–	0.135*** (0.020)	0.135*** (0.020)
CH member granted	0.420 (0.456)	-0.054 (0.143)	0.053 (0.030)	0.054 (0.033)
EP member granted	4.59 (225)	0.103 (0.128)	-0.126*** (0.030)	-0.125*** (0.030)
No EPO application ($lambda_1$)		0.147* (0.069)	–	–
No search report ($lambda_2$)		–	0.015 (0.068)	–
N	21'382	21'382	949	2'950
R^2	0.88	0.28	0.11	0.11

Significance codes: ***0.001,**0.01,*0.05, 00.1; 1-digit IPC dummies not shown.

Amongst the firms, the selection effects are basically non-existent as evidenced by the insignificant report selection hazard variable, and the fact that the coefficients remain essentially unchanged when compared with a simple linear model. We can see applications with a granted EP patent family member have about 13% fewer claims rejected, indicate a quality difference between those patents with a granted member.

Table 2.8 presents a similar selection model based on a sample of the entire population of applicants alongside a comparatively specified OLS model. PCT and organizational status act as good exclusion restrictions in that they predict the choice to request a report, but have little bearing on the quality of the final report except mediated through that choice. In our dataset, we observe that patents with large families often originate from outside of Europe, and thus are less likely to have an initial search report with either the IPI or EPO, but commensurate with the applicant's investment in multiple filings, doubling the family size lowers the number of rejected claims by about 7% (Table 2.8).

Table 2.8: Heckman Selection and Linear Models Compared

	1^{st} Stage		Full Model	
	Probit	s.e.	OLS	s.e.
(Intercept)	27.2	(35.3)	10.9	(16.8)
PCT	1.20***	(0.052)	0.255	(0.379)
Applicant=organization	0.362***	(0.055)	0.076	(0.126)
ln[familySize]	-0.601***	(0.059)	—	
ln[trend]	-2.61	(3.33)	-1.02	(1.62)
N=3,997	2^{nd} Stage OLS			
(Intercept)	0.469***	(0.016)	—	
Report type=EPO	0.122***	(0.024)	0.122***	(0.017)
ln[citedDocs]	0.081***	(0.016)	0.081***	(0.016)
∃ EPO grant	-0.115***	(0.027)	-0.115***	(0.027)
∃ CH grant	0.053*	(0.027)	0.049'	(0.028)
Applicant=represented	-0.054**	(0.023)	-0.054*	(0.023)
ln[familySize]	-0.067**	(0.022)	-0.192	(0.186)
Applicant≠ organization	0.060*	(0.060)	0.056	(0.049)
Report not chosen (λ)	0.079*	(0.028)	—	
N=1,242; Significance codes: ***0.001, **0.01, *0.05, '0.1				
One-digit IPC control dummies not shown				

Patent families with an IPI application, which then receive a subsequent EPO grant exhibit a statistically higher quality than patents granted by the IPI in fact, a Swiss grant is a statistically significant indicator of weakness. Moreover, there is also a sizeable selection effect, whereby applicants not opting for a search tend to have weaker patents as measured by the 8% increase in their claim rejection score. This stands in contrast to the firm-only sample, where the choice to obtain a report via the IPI has no quality implications, possibly indicating the choice says less about the adverse selection quality and more about firm routines as to how applications get filed and where reports are obtained.

Comparing the standard error on the family size coefficient in both the selection and full OLS models reveals that not incorporating the selection effects introduces considerable measurement error, as evidenced by the much larger standard errors. It indicates the size of the patent family would seem to be tied closely to an applicant's strategy related to the patent's quality. We also see the strong consistency in the estimates independent of the applicant's strategy, such as the EPO's grant standard and the search report's findings.[15]

2.4.2 Novelty and Inventiveness of National Patent Population

Since not all applications have a search report, we predicted their "virtual" score based on the selection model presented in Table 2.8. Table 2.9 reveals the average difference between the fractions of claims rejected in each population.

[15] The Heckman model typically includes all the regressors from the equation of interest, but even then identification can be weak unless there is an exclusion restriction. The strong assumption here is I presume to know the factors governing both the selection choice and the factors claim quality in the two-part model. The findings in the table are consistent with the notion that the coefficient is downward biased; there are a number of cases, given truncation, where simple OLS is superior (cf. Puhani (2000), *Journal of Economic Surveys* 14:1, for a meta-review of Monte Carlo studies) .

Table 2.9: Predicted Report Scores of Granted Patents

	CH	EP
Mean (μ)	0.639	0.494
N	572	142
$\Pr\{\mu_{CH} = \mu_{EP}\} =$		0.000

As expected, the search report scores for those patents with a granted EPO sibling exhibit a lower score, i.e. fewer rejected claims. The corresponding two-sample t-test strongly rejects the assertion that the average quality of the patents is equal.[16]

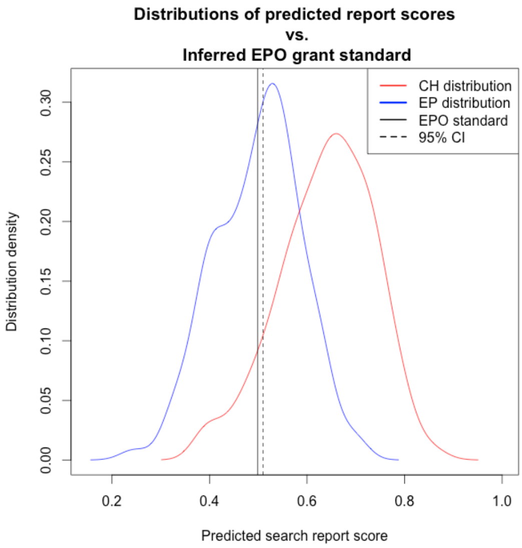

Figure 2.1: Here we see the implied distribution density of predicted report scores based on the selection model. The vertical line is the average for the report scores of patents granted at the EPO and its one-tailed 95% confidence interval along with the distribution of scores for granted Swiss patents. The EPO patents have slightly more mass in the left-hand part of the distribution—likely because more novel and inventive innovations tend to be granted as a European patent.

Figure 2.1 shows the bigger picture by comparing the average fraction of rejected claims amongst European patents with the fraction within the Swiss national patent population.

Defining an inferred EPO grant standard in terms of the mean report scores is a simplification, which omits other aspects of the grant (unity, clarity, disclosure, etc.), but it does allow for a comparison with the granted Swiss national patent population. If we take the EPO grant standard to be the quantile that contains 95% of the lowest distribution scores from the granted EP population, i.e. a report score of less than 0.631, the fraction of granted Swiss national patents likely to meet the EPO's examination standard is only about 16%. If the EPO grant standard were defined as national patents whose report scores lie within the 95% confidence interval around the mean shown in Fig. 1, corresponding to a report score of about 0.51, the fraction of recently granted Swiss national patents that would likely meet the EPO's examination standard drops to about 4%. (Un)coincidentally, only about 3.3% of the sample investigated here have a granted European sister.

Differences in the number of claims surviving from application to grant could be biasing the results in that the standard shown in Figure 2.1 is computed against the sample score. The 2012 EP grant population experienced about 12.7% claim attrition from application to grant; our grant

[16]Since the imputed report scores are likely under-dispersed, we experimented with added various types of normal and β-distributions only to find the tests robustly rejects the null hypothesis that the populations are the same.

sample experienced an average of 2.3% claim attrition. Since we have not observed all grants to-date, this difference in attrition may be simply a transient artefact in the data. The natural claim attrition would mean the implied grant standard in Figure 2.1 could be set too high as the EPs in our sample lose fewer claims than those in the general EP population. Claim attrition is also a function of the number of claims, whereby each additional claim increases attrition by about 1.3% and time in procedure (0.0000625 claims/day). The 2012 EP grant population had a median of about 13 claims; our EP grant sample had median of 12 claims, hinting at simpler and better inventions getting through procedure quicker. Accounting for the difference in averages and claim effects, we get an estimated bias of about 9.1% $(0.127 - 0.023 - 0.013 * (13 - 12))$ for the implied grant standard on the high end. We then looked at the relation between the fraction of claims rejected in the report and the fraction of claims lost in procedure (attrition)—the correlation of 3.79%, was positive as one might expect, but nigh zero. Accounting for that weak correlation, the implied bias would be only about 0.34% $(0.091 \cdot 0.0379)$. Given this slight expected bias, the fraction of Swiss national patents, which would not survive examination, is thus more likely in the lower part of the predicted confidence interval, i.e. 84% − 90%.

One last consideration worth mentioning, but likely not a factor in this context, is the number of fee-free claims included in the application fee: patents of identical quality would be more likely to have 15 claims if only filed via the EPO and 10 claims if filed via the IPI. Because our sample is based on IPI applications, where a fee of CHF 50 is due for every claim after the 10th, one might expect fewer claims than for EPO applications. However, the claim fees appear to be of secondary importance to IPI applicants: purely domestic applications had (surprisingly) more claims on an average than applications with an EPO sibling (13.8 claims vs. 11.97).

Given the statistical analysis above and the results of the accelerated assessments by IPI search personnel, a reasonable conjecture would be that about 87% of the recent Swiss national patents may lack novelty and/or an inventive step. In which case, we are likely observing the final state of a self-sorted equilibrium. A couple of explanations spring immediately to mind. The first is the large economic importance of Europe for Swiss business means a European patent will make the most sense for the typical Swiss firm in the vast majority of cases; the EP route via a single authority is likely simpler and cheaper for better inventions with a bigger patent family. The second explanation has to do with signaling and asymmetric information, whereby patents not examined for novelty and inventiveness pose little credible legal deterrence to competitors again making the EPO patent more desirable. This would be Gresham's law of currency debasement applied to patents: namely, the "bad" Swiss national patents strongly incentivize those with "good" inventions to apply at the EPO lest deterrence be diminished. Those left in the national system are a minority of applications with either specific domestic filing strategies, or less novel and anticipated inventions.

2.5 Conclusion

In the first section, we saw how many of the traditional quality metrics have a considerable time lag and the typical use of backward citations can be ambiguous. We then showed how a claim-based approach addresses that ambiguity, and subsequently showed it to be a plausible and valid measure of patent quality. After modeling the choice to obtain a search report, we then put the metric to work in order to assess the patent quality of the Swiss national patent stock, and find that between 84 and 90% of recently granted Swiss national patents are probably neither novel nor inventive. Future research on patent quality may look at how this prospective metric correlates with traditional retrospective measures.

2.6 Acknowledgments

I would like to thank the Federal Institute of Intellectual Property for the support in conducting this project, but would add that the views expressed herein do not necessarily reflect the policy neither the opinion of either IPI nor the Swiss government. I would also especially like to thank Dr. Heinz Müller of the IPI input and feedback, and Christian Soltmann of the EPO for his help with the procuring the initial data to get started. I would also like to thank the editor and referees for their constructive comments and corrections.

Chapter 3

Competition and Invention Quality: Evidence from Swiss firms

3.1 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. In this paper we provide empirical evidence of the role of access to international competitive markets for the innovation process of firms. In particular we investigate - in a first step - the meaning of the access to international, competitive product markets for a) the number of patented inventions, b) the quality of such inventions, and - in a second step - we investigate c) the relationship between invention quality and the domestic commercial success of innovative products emphasising the role of access to international competitive markets.

Although the competition-innovation relationship has been a topic of debate within the literature for a long time and studied in many facets (cf. e.g., Scherer (1967), Aghion et al. (2005), Gilbert (2006*a*)), there are still undiscovered aspects that could play an important role in better understanding this fundamental and still questioned relationship in empirical innovation economics.

In this paper, we discuss and provide empirical evidence for three further facets of the competition-innovation relationship. Our first contribution refers to the measurement of patent quality and competition. We measure the quality of patented inventions based on a principle component analysis on five quality indicators; these are forward citations, generality, family count, NPL counts and number of claims. We also 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), to take into account the complex competitive reality of firms, which can hardly be captured by single competitive measures such as the C4 ratio or the HHI (Hirshman-Herfindahl Index).

Our second contribution refers to the international dimension of competition. Technological markets are truly global. Competition, however, is usually measured on a national level (cf. Table 3.1). This might deter the empirically observed effects of competition, since innovative firms might face much less domestic competition than competition on an international level. Considering competition on international (technological) markets, however, is decisive for the firm's invention behaviour and innovation success, especially for firms in smaller economies.

Our third contribution refers to econometric issues. 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 innovation 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 3.1 plots the quality of patent output from Switzerland over time, and reveals the variance in quality over 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 3.1 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.

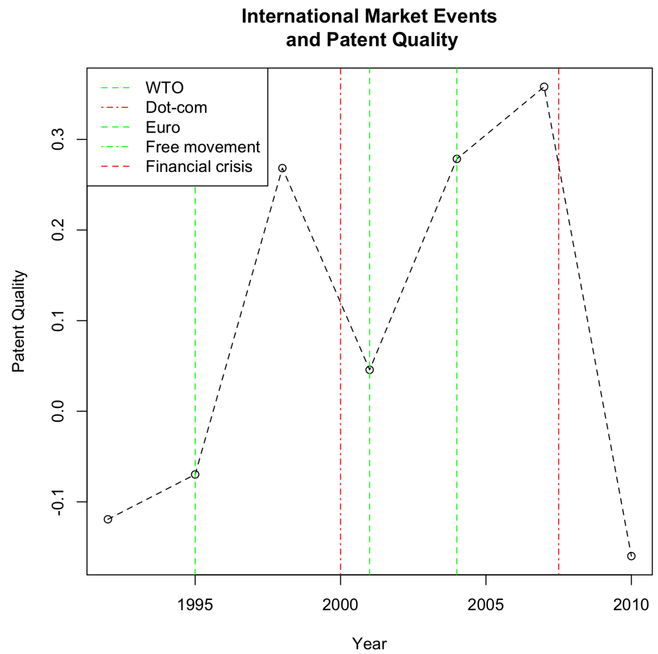

Figure 3.1: Patent quality may depend on international market conditions. This leads to asymmetric effects between exporters and non-exporters. We find evidence for three general phases: pre/post-WTO (1990+1993/1996+1999), pre/post-Euro (1996+1999/2002+2005), and pre/post global financial crisis (2005/2008). 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.

To investigate the meaning of international competitive markets for the invention quality and the domestic commercial success of innovative products, we can use representative firm-level data for Switzerland covering the period 1990 to 2013. Switzerland is a very interesting case for our research questions, since it is not only a very small, technologically advanced country, but it resides also many firms that compete on international technological markets. Hence, it can be seen as a perfect model country. We use firm-level fixed effects estimations and instrumental variable regressions to consider unobserved firm-level heterogeneity. Moreover, we use Bayesian multiple imputation techniques to consider potential selection effects. The results confirm that access to international markets drives inventions, however, to be exposed to contested international markets is significantly more important for the quality of inventions than for their quantity. We have also found that the quality of inventions is significantly and positively related to the economic success of innovative products. Most interestingly, however, access to international competitive markets not only increases the quality of inventions, but also increases the effect of invention quality on sales of innovative products. This shows that the advantages of companies in international competitive markets go beyond technological quality; improved user-friendliness, complementary services, compatibility with other technologies, etc. are examples of such non-technical advantages, which also increase the sales of innovative products on domestic markets.

Consequently, political measures that limit the access to international competitive markets are likely to decrease inventive quality and the domestic market performance of innovative firms accordingly. This would also lower the incentives to invest in the generation of new technologies, since the expected ex-post benefits from technological developments are smaller (Cohen 2010). Small, technologically advanced countries would stand to loose competitiveness due to their small and more competitively sheltered markets. 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. The simple policy implication is that trade barriers, which limit access to larger international (technological) markets, might seriously dampen high quality inventions, decreases domestic innovative sales, 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.

3.2 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. Succinctly stated, our paper highlights the fact that market size and the type of competition in those markets leverages invention quality to generate firm sales; invention quality pays-off in competitive, bigger international markets. In terms of a contribution, we underscore the importance of competitive international markets for patented inventions. We first take a look at the writings surrounding competition and innovation, market size and innovation, and how firm performance is related to inventive quality.

3.2.1 (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 competitive 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 the tyranny of competition. The table below provides an overview of the key works.

Table 3.1: Statistical Studies of Innovation & Competition

Study	Dependent	Conclusions
Scherer (1965*b*)	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 & 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 & Reiss (1984)	R&D expenditures	No statistically significant correlation with concentration
Culbertson & 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 & 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 & 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 & Vandekerckhove (2012)	R&D investment	Dependent on product differentiation, Bertrand vs. Cournot competition, and spillovers
Beneito et al. (2014*a*)	Patents	Firms learn over-time in with decreasing marginal effect

Adapted and extended from Gilbert (2006*a*)

3.2.2 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 discuss innovation using more general growth models (e.g. Grossman & 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 & 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 & Levine (2008*b*) 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*a*)."

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 & 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 & 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 & 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[1], finding that larger market size does not necessarily lead to more varieties because it "[m]ay induce such an increase in expenditure on cost reduction that it may leave less room for entry (pg. 424)", and "[e]ntry costs taking into account fixed investments to improve quality (pg. 424)", implying that by competing firms invest in quality products and better technology to lower costs, there may be fewer products. 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). Beneito et al. (2017) find that companies at the edge of bankruptcy have a such a strong incentive to innovate that it overcomes the negative Schumpetarian effects of strong competition on innovation. Amongst the internationalized firms in our paper, we are more likely observing the "escape-competition effect", whereby incumbents try to gain margin and edge on one another through innovation.

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, increasing market concentration. Conversely, low market concentration 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; there are also patent pools of cross-licensing competitors. Adjacent citations within a IPC class are some indication of competition (Baudry & 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.[2] Patenting firms by their nature compete with others directly in the legal space, and will ring-fence inventions with patents Schneider (2008). Forming an competition index of various subcomponents, Beneito et al. (2014*b*) show that patents can stifle competition to an extent, but that the net effect of them on innovation is positive; we employ a similar concept of a competition index and build different types of markets using PCA to determine innovation outcomes. 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.

[1]One way firms compete is by directly trying to influence this substitutability, rather than completely exogenous, firms try to shape product substitutability through non-price competition, e.g. through licensing or service contracts.

[2]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 & 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 & 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 & Alegre (2007), using a panel of French biotechnology, show that innovation is related to export intensity. Cassiman & 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 & 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 & 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.

3.2.3 Innovation and Firm Performance

Hall & 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 (1965*a*), 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 & 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 3.2 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 & 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 & 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 3.2: Selected empirical studies on patents, patent quality and sales

Study	Sample	Variables	Method	Conclusion(s)
Scherer (1965*a*)	488 of Fortune's top 500 U.S. industrial firms in 1955	sales growth	regression	patents positively related to sales
Scherer & Comanor (1969)	57 pharma firms 1955 - 1960	Innovative product sales 2 years after market introduction	(partial) correlation	patents are related to subsequent sales
Brouwer & 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	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 & 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 & Ietto-Gillies (2009)	786 enterprise from UK CIS	innovative sales per employee	Heckman selection	intra-firm collaboration is more salient for innovation
Klomp & 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
Beneito et al. (2014*a*)	5082 Spanish firms	sales	time-series panel	R&D experience leads to more sales likely through quality

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 & 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.

3.2.4 Our Contribution

We place our paper between two notions of competitive innovation and innovation-based firm sales performance. 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 competitive markets. We focus on patent quality because patents themselves are more closely entwined with the legal strategy in competitive environment (cf. Lanjouw & Schankerman (2001)). Quality metrics such as forward citations are contaminated with elements of market structure, distribution, and not untainted measures of quality — one reason why we adopt a synthetic measure.

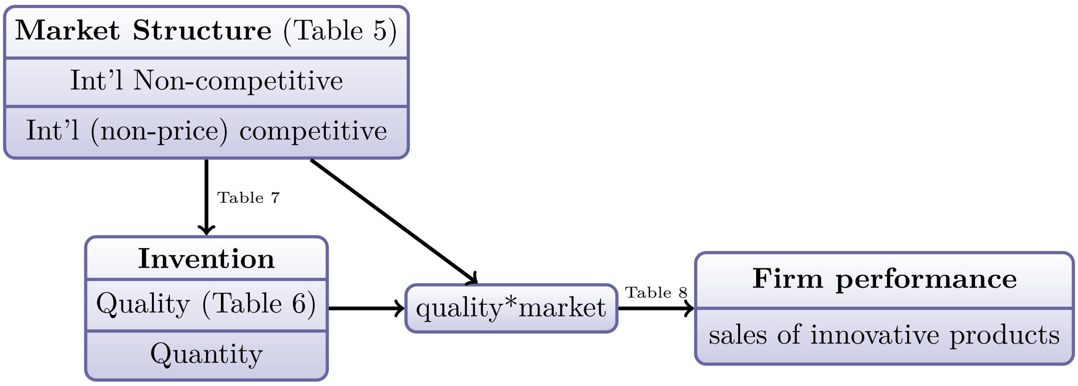

Figure 3.2: Map of the paper

Figure 3.2 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 domestic 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 domestic 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). 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 & Cloodt (2003))." In this context, he showed such companies with European (i.e. high quality) patents had higher subsequent sales than those with national patents.[3]. We add to his

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

research by testing this conjecture with a larger sample with a more direct measure of quality, and provide more insight into the teleology of producing quality. Our contribution specifically shows how inventive quality plays a role in determining sales outcomes in different competitive environments.

3.3 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 & Veugelers (2002); Laursen & Salter (2006); Leiponen & 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 3.3.

Table 3.3: 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 3.4 presents the summary statistics for that unimputed sample.

Table 3.4: Sample Summary Statistics

	Min	μ	Max	σ	Description
Innovative Output					
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					
intNonCompetMarket	-2.97	0.00	3.19	1.11	1st principal component for competition variables
intCompetMarket	-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. We incorporate our competition variables into the analysis, along with the export share, which is both a proxy for market size of the firm, and competition. Using PCA, we extract the variance attributable to competition from the export share by identifying those components on which it loads along with competition variables, thus identifying a latent form of competition extant in international markets.

Table 3.5: Principal Component Loadings of Market Attributes

	Int'l Non-competitive	Int'l Competitive
priceCompetition	-0.47	0.45
nonPriceCompetion	0.18	0.73
degreeCompetition	-0.66	0.25
exportShare	0.56	0.45
$\lambda=$	1.10	1.07

Other components were eliminated by the Kaiser criterion.

From Table 3.5 we infer two primary types of competitive environments (markets) for firms that can be characterized:

International non-competitive: the "market" (component) is characterized by low price competition, a few principal competitors worldwide, and a high internationalization;

International competitive: this second type of "market" is most 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 dimension, but one where the degree of competition, i.e. number of competitors is less salient than in the first market as evidenced by the lower absolute factor loading.

The other two components did not meet the Kaiser criterion of having an Eigenvalue greater than 1, and we disregard these in this paper, and concentrate on those two international markets.

In the first case, we would expect less innovation as the market goes from international large and competitive to small and less competitive. 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 employing intellectual property, a legalistic way to compete; it is a competitive environment, which is not essentially based on price, and is less related to both price and the number of competitors in the market.

3.3.1 Patent Quality

"Patent quality" as a proxy for invention quality 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

[4] Link to questionnaire, pg. 2

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 legal realities of appropriation through the international intellectual property regime; furthermore, we need a metric divorced from business logic, or organizational capacity. 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 actually 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, information of any one bibliometric measure of patent quality is confounded by a number of other factors. 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*b*), for example, finds a trade-off between both the quantity and quality. Patents with multiple owners tend to be of higher quality (Briggs & Wade (2014), Hottenrott & 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 market, thus this particular quality metric thus reflects the market structure.

We mitigate, but not entirely eliminate, these endemic methodological problems in two ways: 1. we normalize the variables by year and IPC4 class in order to purge some time variance and patent class variance; 2. we compute the common "quality" factor amongst the constituent metrics using principal components (see Table 3.6). This is essentially the approach first taken by Lanjouw & 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 3.6 shows the components to our quality metric. The first constituent, forward citations, measures the scientific and commercial relevance (Fischer & Leidinger (2014), Hirschey & 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 & Schankerman (2004), Thoma (2014)). We compute these according to the OECD's handbook on measuring patent quality (cf. Squicciarini et al. (2013)).

Table 3.6: 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 3.6 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

[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 PATSTAT 'prs table', PCT status, number of applicants, patent generality, fraction of adverse citations

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 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 less inventive firms, 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, elucidated in Section 3.4.3.

3.4 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 domestic 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.

3.4.1 Estimation of invention quality and invention quantity

Equation 3.1 shows the equations on invention quality and quantity. $y_{i,t}$ stands for the quality of inventions and the quantity of inventions, respectively. $\mathbf{MSMC}_{i,t-1}$ is a multi-criteria measure for market structure (international non-competitive/competitive market structure) issuing from the factor analysis and $\mathbf{MS}_{i,t-1}$ 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 3.4.3.

$$y_{i,t} = \mathbf{MS}_{i,t-1}\boldsymbol{\gamma} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + \tilde{\pi}Z + c_i + u_{i,t} \tag{3.1}$$

$$y_{i,t} = \mathbf{MSMC}_{i,t-1}\boldsymbol{\gamma} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + \tilde{\pi}Z + c_i + u_{i,t} \tag{3.2}$$

$$y_{i,t} \in \{ln[\text{patents}_{it}], ln[\text{patentQuality}]_{it}\} \tag{3.3}$$

$\mathbf{X}_{i,t-1}$ 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[8] following Aghion et al. (2016) in a similar econometric set-up, 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 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.

[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.

[8] We calculate the knowledge or patent stock is using the perpetual inventory method, and a depreciation rate of 15%.

We also have a control for "management quality", an often neglected variable in innovation equations.[9] 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 (*wagePercentileInCH*) (see Table 4.11 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. For the patent counts, we use a fixed-effects over-dispersed Poisson model, taking the discrete nature of patent data into account. Hence, we control for unobserved, time-invariant heterogeneity and also address potential serial correlation in both models.

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.

3.4.2 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 3.4 is estimated by a fixed effects estimator with heteroscedasticity robust (clustered) standard errors. In Equation 3.5, we endogenize invention quality and estimate the reduced form using an instrumental variable approach.

$$
\begin{aligned}
ln[\text{innoSales}]_{i,t} &= \gamma_1 \mathbf{MSMC}_{i,t-1} + \gamma_2 ln[\text{patentQuality}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} && (3.4)\\
ln[\text{innoSales}]_{i,t} &= \gamma_1 \mathbf{MSMC}_{i,t-1} + \tilde{\pi} ln[\widehat{\text{patentQuality}}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} && (3.5)\\
ln[\text{innoSales}]_{i,t} &= \gamma_1 \mathbf{MSMC}_{i,t-1} \cdot ln[\text{patentQuality}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} && (3.6)\\
ln[\text{innoSales}]_{i,t} &= \gamma_1 \text{exportShare}_{i,t-1} \cdot ln[\text{PatentQuality}]_{i,t-1} + \mathbf{X}_{i,t-1}\boldsymbol{\beta} + c_i + u_{i,t} && (3.7)
\end{aligned}
$$

We interact invention quality with the proxies for market structure and exportShare in Equations 3.6 and 3.7.[10] Again we use a fixed effects estimator with heteroskedasticity robust standard errors. Since the results for the instrumental equation (3.5) and the fixed effects equation (3.4) 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 3.6 and 3.7). $\mathbf{X}_{i,t-1}$ is a set of control variables like in Equation 3.4 including the base variables for interaction effects in Equation 3.6 and 3.7.

3.4.3 Endogeneity Issues

Endogeneity is a potential problem in our setting, and we made several attempts to address it. 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.

[9] "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.

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

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 3.1). 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 not directly related to innovative sales.[11]

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 & 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 liberalization affects patent quality along the firm's degree of exposure to international markets. 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:

$$\text{Z} = [\text{exportShare}_{t=0} \cdot \{\text{boom} = 1 \wedge \text{bust} = -1\}] \tag{3.8}$$

In Equation 3.8, 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. We also find that the boom and bust instruments are uncorrelated with the innovative sales (p-values of 0.32 and 0.36 respectively.) conditional on the covariates. One might believe our instrument is correlated with exports, but those exports would be included in the innovative sales, and we see that the instrument is uncorrelated with innovative sales. 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 controlled for in our past demand variable. The results of this IV estimation are shown in the appendix Table 3.12.

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

[11] The instrument is significantly related to invention quality and statistically unrelated to innovative sales (dependent variable).

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.[12]

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*b*)), 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.

$$\begin{aligned}(Pr\{Y = y_i \perp O\}) \vee (Pr\{Y = y_i \in M|X\} \\ \approx Pr\{Y = y_i \in O|X\})\end{aligned} \tag{3.9}$$

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:

$$Y \wedge X \in \mathbf{T} \sim f(\boldsymbol{\theta} = \mathcal{N}_k(\boldsymbol{\mu}, \boldsymbol{\Sigma})) \tag{3.10}$$

[12]Referring to our original quality model in Section **??**, firms competing on quality have already incurred the sunk costs of research, any price competition on their part further market share away from competitors.

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

$$\mathcal{L}(\boldsymbol{\theta}|T) \propto Pr\{T|\boldsymbol{\theta}\} \tag{3.11}$$

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:

$$Pr\{T|\boldsymbol{\theta}\} = \sum_{\mathbf{m}=i}^{M} Pr\{T|\mathbf{m},\boldsymbol{\theta}\}Pr\{\mathbf{m}|\boldsymbol{\theta}\} \tag{3.12}$$

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.[13] 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.

3.5 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 domestic commercial success of innovative products considering market structure as a mediating factor.

3.5.1 Market Structure and Innovation Output

Table 3.7 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 [14] 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.

[13] See King (2010) for a bit more color on the technique.
[14] $e^{0.3} = 1.30$

Table 3.7: Competition and Innovation Output (FE)

	$\text{Patents}_{i,t}$ (Ia)	$\text{lnQuality}_{i,t}$ (IIa)	$\text{Patents}_{i,t}$ (Ib)	$\text{lnQuality}_{i,t}$ (IIb)
priceCompet_{t-1}	-0.055^{***}	0.02		
	(0.006)	(0.04)		
$\text{nonPriceCompet}_{t-1}$	0.070^{***}	0.05		
	(0.007)	(0.04)		
$\text{degreeCompetition}_{t-1}$	0.017^{***}	0.02		
	(0.004)	(0.03)		
exportShare_{t-1}	0.301^{***}	0.43^{***}		
	(0.037)	(0.10)		
$\text{intNonCompetMarket}_{t-1}$			0.059^{***}	0.08^{**}
			(0.005)	(0.03)
$\text{intCompetMarket}_{t-1}$			0.040^{***}	0.11^{***}
			(0.006)	(0.03)
$\ln[\text{firmSize}_{t-1}]$	0.170^{***}	0.11^{***}	0.226^{***}	0.11^{***}
	(0.013)	(0.03)	(0.013)	(0.03)
$\ln[\text{knowledgeStock}_{t-1}]$	0.922^{***}	0.26^{***}	0.815^{***}	0.26^{***}
	(0.035)	(0.09)	(0.03)	(0.09)
$\ln[\text{knowledgeStock}^2_{t-1}]$	-0.031^{***}	-0.01	-0.02^{***}	-0.01
	(0.002)	(0.01)	(0.002)	(0.01)
$\text{shrEmplHiEduc}_{t-1}$	-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)
$\text{techPotential}_{t-1}$	0.064^{***}	0.07^{**}	0.060^{***}	0.08^{**}
	(0.009)	(0.03)	(0.009)	(0.03)
$\text{wagePercentileInIndustry}_{t-1}$	-19.9	-1.90^{***}	11.41	-1.87^{***}
	(31.9)	(0.33)	(31.8)	(0.33)
$\text{wagePercentileInCH}_{t-1}$	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

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Poisson model for patent counts; OLS for patent quality.

In addition, invention quality and invention quantity are driven by different factors. We see that the "knowledge stock" tends to have a linear and positive and monotone effect on invention quality and an inverted-U shaped effect on invention quantity.[15] We also see that market structure matters for inventions. Both invention quantity and invention quality are driven by the market structure. We find evidence that international non-competitive type markets boost the quantity and the quality of inventions: going from a domestic to an international non-competitive market boosts patenting by about 6%. Going from a domestic market to an international competitive market raises the number of patents by about 4%.[16] Those same market structure effects on invention quality are slightly higher at about 8% and 11% for international non-competitive markets and international competitive markets, respectively. This again in the context of only patenting firms. Both market types seem to be of

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

[16]The effects of non-competitive and competitive international markets are not significantly different

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 that past success on international markets has a stronger effect on invention quality than on invention quantity. 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 3.7 despite the fact that Hausmann test between the fixed-effects and random effects models does not exceed the critical value (Chi^2 (13 df) value of 5.89 (95%); p=0.001).[17]

3.5.2 Innovation Performance, Competition, and Invention Quality

In a second step we investigate the relationships between invention quality, market structure and innovation performance, measured by domestic innovative sales, which is to say the amount of revenue issuing from products which are 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 3.4.3).

[17] 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.

Table 3.8: Innovation Sales Performance and Competition

	$\ln[\text{innoSales}]_{i,t}$ (domestic market)			
	(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)
wagePercentileInIndustry	2.83^{***}	2.83^{***}	2.86^{***}	1.33
	(0.60)	(0.60)	(0.60)	(1.56)
wagePercentileInCH	-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^{**}	$\mathbf{0.79}^{***}$
	(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)		
$\text{intNonCompetMarket}_{t-1}$			0.17^{***}	0.31^{***}
			(0.04)	(0.11)
$\text{intCompetMarket}_{t-1}$			0.83^{***}	0.54^{***}
			(0.05)	(0.12)
$\text{intNonCompetMarket}_{t-1}*\ln[\text{inventionQuality}_{t-1}]$			0.04	
			(0.03)	
$\ln[\text{inventionQuality}_{t-1}]*\text{intCompetMarket}_{t-1}$			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

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$; (s.e.). INSTRUMENTED sample is not imputed.

In Table 3.8, presents the main results (firm-level fixed effects estimates). The instrumental variable regressions are presented in the Appendix (Table 12).

We see that entirely exporting firms have about 28% more innovative sales than completely domestic firms (Table 3.8; column V). The market structure is also important for innovative sales; larger number of principal competitors (degreeCompetition) lead to fewer innovative sales, consistent with economic theory (cf. (Kraft 1989)). However, more contested markets, with a large degree of non-price competition, increases the benefits from invention quality. 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 - like expected - positively related to innovative sales.[18]

[18] This effect implies 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, the positive significant coefficient on the interaction between quality and competitive (non-price type) international market would seem to indicate these firms benefit by trying to distinguishing themselves from the competitors. Contrast this with the insignificant coefficient for the interaction between quality and non-competitive international market, whereby dominant firms have little to gain by enhancing quality in an already dominated market. This would seem to challenge our Schumpeterian Mark II vision of the world, a world in which the number of principal competitors worldwide (market structure) is the determining factor rather than than the mode of competition, it is not entirely inconsistent in that the competitive market is still the more innovative one. 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 in international markets, rather than price competition, significantly leverages invention quality in terms of innovative sales.

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, but it is activated by access to an international market.[19]

In Column Boom-Bust of Table 3.8 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 decreases, too. The effect size standard panel estimates are downward biased towards zero.[20]

3.6 Conclusion, Research Outlook & Policy Implications

Against the background of important political decisions, such as the "Brexit" or restrictions in international market access, we examine the relationship between access to internationally competitive markets and the quantity and quality of inventions. In a further step, we examine the influence of patent quality on a company's national innovative sales, taking into account the effect of market structure and international competition. We can use a comprehensive, representative firm-level data for Switzerland covering the period 1990 - 2013. We merge the firm-level information with the patents statistics and create multi-criteria measures for competition and patent quality using principal component analyses. This type of variables are better mirroring the economic reality of firms compared to single indicators for competition and patent quality. We also provide some simple theoretical explanations based on consumer preferences for the empirical observation of the literature that access to international markets is conducive both to patenting and producing higher quality inventions.

Based on firm-level fixed effects estimates and 2SLS estimations we find that a) firms competing in larger markets produce higher quality inventions, b) access to internationals competitive markets

[19] These results are available upon requests: in a nutshell, we see little variance among patenting firms in terms of non-price competition, since all patenting firms are non-price competitors to a certain degree. We also see that the number of principal competitors (degreeCompetition) does not show any effect. This is because patents segment the market by definition, lowering the number of principle competitors we might expect. This low within-group variation leads to a null effect within the patenting-only sample.

[20] Table 3.12 in the Annex presents both the boom and bust separately. The effect sizes are of a similar magnitude

increases patent quality stronger than patent quantity, and c) higher quality inventions translate directly into higher domestic sales, if and only if the firm has access to international markets; the effect is even higher if the firms are operating in *competitive* international markets.

Figure 3.3 shows those relations.

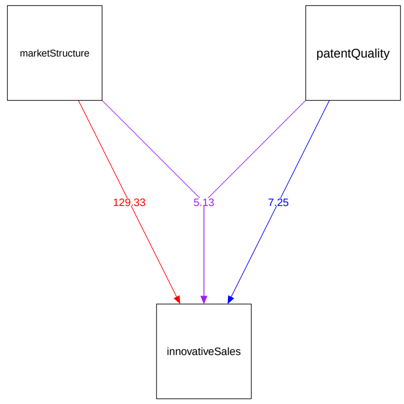

Figure 3.3: Basic structure and results of our investigation. Coefficients are in percent change of our variables and change in domestic innovative sales. Selling into international non-price markets explains much of the performance relation. Doubling patent quality raises sales by about 7%, and the 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 considerable investments into high risk and potentially high return projects. In Figure 3.3 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. Frictionless access to larger markets implies that firms can further specialise 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 internal factors such as labor quality – reducing barriers to access international markets are important not just for the domestic consumer benefits, but also conducive to quality 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.

3.7 Appendix

Table 3.9: 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 3.10: 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
wagePercentileInInd	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
wagePercentileIn 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
intNonCompetMarket	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
intCompetMarket	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

Table 3.11: 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)
$\text{lnPatentStock}_{t-1}$	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 3.12: 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)
$\text{lnPatentStock}_{t-1}$	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)
intNonCompetMarket	0.40^{***}	0.03	0.30^{***}	0.30^{**}	0.31^{***}
	(0.15)	(0.18)	(0.11)	(0.12)	(0.11)
intCompetMarket	0.10	-0.02	0.65^{***}	0.35^{**}	0.54^{***}
	(0.15)	(0.17)	(0.12)	(0.14)	(0.12)
wagePercentileInCH	4.62^{*}	-5.84^{**}	-1.74	-5.90^{***}	-1.73
	(2.71)	(2.84)	(1.55)	(1.68)	(1.65)
wagePercentileInIndustry	-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

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$; (s.e.). 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 3.13: 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)
$\text{lnPatentStock}_{t-1}$	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)
wagePercentileInCH	−1.04	−0.96	−1.17
	(1.23)	(1.23)	(1.23)
$\text{shrEmplHiEduc}_{t-1}$	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)
$\text{techPotential}_{t-1}$	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)	
$\text{nonPriceCompet}_{t-1}$	0.31***	0.32***	
	(0.12)	(0.12)	
$\text{degreeCompetition}_{t-1}$	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)	
$\text{intNonCompetMarket}_{t-1}$			0.45***
			(0.11)
$\text{intCompetMarket}_{t-1}$			0.60***
			(0.11)
$\text{intNonCompetMarket}_{t-1}$*$\text{portQuality}_{t-1}$			0.13**
			(0.06)
portQuality_{t-1}*$\text{intCompetMarket}_{t-1}$			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

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Chapter 4

The Cost of Patent Protection: Renewal propensity[0]

4.1 Introduction

4.1.1 Motivation

It is interesting to see how much analysis is devoted to consumer and business behavior related to price sensitivity, but so little analytical attention is devoted to the fees and incentives of government fees in general, and those of the intellectual property system in particular. When it came to setting Switzerland's maintenance fee structure some 2 years ago, management had little but good business intuition and past experience to make, what in effect was a multi-million franc decision. It is fair to say that said decision rested primarily on administrative, legal, and revenue implications rather than considerations of inter-temporal social welfare or the strategic incentives of the applicants and patentees. Switzerland's patent office's own experience is very similar to those of other national offices. Specifically, the European patent office has wrestled with the question at a large multi-lateral scale, and until very recently the UK patent office took only revenue considerations into account. Large questions remain about EPO revenue, the political economy of national patent office funding, industry's demands for low fees, and multilateral integration. Beyond the European patent system, we have seen Ecuador drastically increase renewal fees to the highest in the world raising questions about whether fees can be used to negate the patent right. At the other extreme Italy removed renewal fees entirely for a brief spell creating a tangle of active patents. Such divergent views on fee policy raise obvious questions about optimal renewal fee policy.

It is within this policy context, this paper looks at one specific aspect of fee-setting that has been empirically neglected, namely that of the renewal or maintenance fees. These are fees which are typically paid annually by patentees to patent offices in order to preserve their exclusionary right within a jurisdiction. Whereas the literature has dealt with the issue of patent application fees and costs fairly thoroughly, the topic of renewal fees, which is the primary source of income for patent offices, and potentially a key but neglected policy lever, has received comparatively little quantitative scrutiny.

Aside from the policy implications, renewal fees are worth investigating in their own right because they diachronically lay bare the intricacies of patent strategy, international commerce and trade, and provide information about the underlying value of both the technology and exclusionary right. In this sense, patentee renewal behavior reveals economic information that is distinct from patent application data alone.

[0]Published *World Patent Information*

4.1.2 Literature Review and Contribution

The majority of the work on fees has centered around application propensity. The first econometric work, known to us, is Adams et al. (1997), who addresses demand forecasts for patent applications. He finds that a 1% increase fees leads to a one-off decline of about 0.12% in applications, which wears off, leading to an increase in applications in subsequent periods. The positive and negative coefficients essentially offset one another with the net effect being about zero (pg. 514). de Rassenfosse & van Pottelsberghe de la Potterie (2007) looks at the role of costs of the national office in the context of the European patent system; de Rassenfosse & van Pottelsberghe de la Potterie (2009*a*) extends the investigation into patenting by looking at the propensity to patent within the inventive population conditional on governmental policies. In a similar vein, using advanced time-series panel techniques, van Pottelsberghe de la Potterie & de Rassenfosse (2012) demonstrates that fees play a role in the international demand for patent protection. de Rassenfosse & van Pottelsberghe de la Potterie (2013) provides the most recent and thorough treatment of patent fees by providing a survey of the literature theretofore. Beyond the academic literature, there have been a couple of *ad hoc* measurements of elasticity USPTO (2013) and WIPO (2014). In terms of theory, Gans et al. (2004) builds on some of the earlier theoretical work in the field done by Ariel Pakes, and highlights the tension between funding the work of the patent office and socially optimal fee policy where high fees encourage quality and low fees encourage patentees to file and disclose information to competitors.

Table 4.1 provides a convenient overview work related to patent price elasticity (η) along with the methods and data employed.

Table 4.1: Overview of Patent Fee Elasticity Estimates

Study	DV	Methods & Data	η [lo , hi]
Adams et al. (1997)	Filings	Univariate ARIMA & multivariate ARDL US applications	[-0.12, +0.13]
Archontopoulos et al. (2007)	Claims	One-off 2004 US claim fee change[0]	[-0.1,-0.2]
de Rassenfosse & van Pottelsberghe de la Potterie (2007)	Filings	First diff rOLS ts-panel for 29 EPC countries in 2003	[-0.45, -0.56]
Harhoff et al. (2009)	"Validations"	Cross-section MLR for 1995, 1999, 2003 EP cohorts	[-0.30,-0.34]
de Rassenfosse & van Pottelsberghe de la Potterie (2009*a*)	Filings	Cross-country rOLS of 34 EPC countries	[-0.5, -0.3]
van Pottelsberghe de la Potterie & Danguy (2009)	Maintenance rate	OLS 15 EPC members, JP, US	[-0.084]
van Pottelsberghe de la Potterie & de Rassenfosse (2012)	Filings	IFGLS, LSDV, GMM & ECM ts-panel for US, JP, EP	[-0.06,-0.12]
Swiss PO internal	Renewal	Event analysis of 2014 fee change for each renewal cohort	[0_{Y20}, -0.34_{Y5}]
de Rassenfosse (2013*a*)	Quality	Block testing for 1982 US fee change	[+0.01,+0.12]
USPTO (2013)	Renewal	Probit model of renewal propensity	[-0.056,-0.338]
WIPO (2014)	Filing choice	Probit model of PCT or Paris route filing	[-0.014,-0.028]
This study	Renewal	Logit, Poisson, Cox-PH, MMLR ts-panel 46 countries 1980-2013	[0,-0.25]

Adapted and extended from Table 5 van Pottelsberghe de la Potterie & Mejer (2010)

Table 4.1 reveals that while the estimates of fee sensitivity in various contexts are very heterogenous, there nevertheless emerges a clear common pattern that all are less than unity and negative.

This paper sheds more light on the role of renewal fees and their structure on applicant behavior. In particular, it contributes to the renewal fee-setting discussion currently going on at the European patent office. The closest work done on this particular question comes from a report for the Internal Market and Services Directorate General on the common patent van Pottelsberghe de la Potterie & Danguy (2009). The authors use aggregated time series cross-section data to estimate the elasticity by way of the fraction of patents maintained. Their estimates have several short-comings in that: they use a single year (2006) for GDP, opt for an inappropriate linear model for a fractional response variable, take the fees and GDP in levels rather than logs, and do not cluster their estimates by country and/or time which likely understates their standard errors substantially. It is not entirely clear what inference can reasonably be drawn from their estimate.

In contrast, USPTO (2013) takes a micro-approach, and deploys a more concise and appropriate probit model of an applicant's decision of whether to renew conditional on the fees, but it is unclear

[0]Archontopoulos points out the discontinuity, this author calculates the point elasticity at -0.10 based on patents with more than 20 claims and two 11 month windows before and after December 2004. Based on the same data Van Pottelsberghe de la Potterie computes -0.20.

how generalizable the US fee structure is to other countries: US patentees make three maintenance payments instead of paying annual renewal fees, which means patentees are paying for several years with a single payment. Since fees exhibit tight ranges in those studies it is also harder to generalize the estimates to new situations or jurisdictions. On a more practical level, better elasticity estimates should help patent offices optimize fee structures to generate revenue, better incentivize patentees, and/or provide better guidance on implementing policies to either encourage innovation or improve patent quality. It goes beyond the state of the art by showing how large fee changes might alter behavior by estimating the hyper-elasticity of the fee response in an international cross-section.

The second contribution is methodological. Aside from the USPTO's investigation USPTO (2013), the general strategy heretofore has been to estimate aggregate statistics while neglecting the basic attributes of the individual patents. The methodology employed here incorporates cross-country effects, essential for understanding a global patent strategy and patentee and patent attributes, and lays a foundation for how these might best be modelled in an extensible econometric framework using the public information from PATSTAT. Moreover, the patent-level approach advanced here should yield more accurate estimates than the methods used heretofore in the literature. It also allows for an exploration of what a heterogenous fee structure may have on particular groups of interest to policy-makers, such as small business or individual inventors. By disentangling the market effects from the patent attributes, we add to the literature surrounding multinational patent strategy and valuation.

The structure of the paper is as follows: the next section presents a simple renewal model of patentee behavior, then we will look at the data behind the estimation, explore the results, and finally derive certain policy implications.

4.2 Model

In this section we present a simplified model of patentee behavior largely based on the work of Pakes (1986) and Bessen (2008) that will motivate and clarify the empirical strategy. In Pake's model, he essentially treats renewals as a type of rolling call option on the exclusionary right, where patentees receive updated information as to its value. The simplified model here is that the invention's value is static from its inception, and that value drives the underlying motivation for the observed renewal behavior.

The value of the would-be patentee's invention ($E\{V_{inv}[\cdot]\}$) is the sum of the discounted profits under both a granted scenario with probability γ less invention and application expenses and an ungranted/unprotected scenario $(1-\gamma)$. In this idealized model, profits come from certain cash-flows; this might be the case in the form of patent licensing where the technology is developed for a partner. The model could be extended to account for random profits, but we leave it in this simpler form for clarity and tractability. The application process is very long and is pitted with strategic decisions. Many patents do not survive the grant procedure, and patentees often withdraw or abandon the application before the first fees come due; the fees are indexed by year (y) because there is a renewal fee due at each year. The *ab initio* value of the patent is the sum of future profits discounted, along with the annual renewal fee, which varies by year (y). The discount rate (δ) can be interpreted as comprising both the technological rate of obsolescence and the financial opportunity costs: $\delta = \text{interest}_j + \text{obsolescence}_{IPC}$. The interest rate will largely depend on the currency of the target jurisdiction and the rate of technological obsolescence on the field of invention; we include these as controls in our empirical model.

$$E\{V_{inv}[\cdot]\} \equiv (1-\gamma)\sum_{y=0}^{\infty}\frac{\pi_y}{(1+\delta)^y} + \gamma(\sum_{y=0}^{20}\frac{\tilde{\pi}_y - \text{fee}_y}{(1+\delta)^y} + \sum_{y=21}^{\infty}\frac{\pi_y}{(1+\delta)^y}) \quad (4.1)$$

A good working assumption is that $E\{V[\cdot]\}$ follows a log-normal distribution. Since the value function $V[\cdot]$ depends on factors such as the intrinsic characteristics of the patented technology, competitiveness of the field, the length of a technology's cycle, intrinsic value proposition, and elasticity of demand, we can expect them to influence the renewal propensity via both the profits (π_y) and rate of obsolescence subsumed in the discount rate (δ). We do not observe all inventions in the patent record, hence we would expect to observe but a subset where the expected total profit under the monopoly less costs is greater or equal to zero. Naturally, the observed filed inventions are those whose concomitant patent rights are at least as much as the filing expense ($E\{V[\cdot]\} \geq \text{filingCosts}$).

That is to say the patentee with a marginal invention ensures that expected value of patenting dominates the patentless strategy before filing:

$$E\{(1-\gamma)\sum_{y=0}^{\infty}\frac{\pi_y}{(1+\delta)^y}\} \leq E\{\gamma\sum_{y=0}^{20}\frac{\tilde{\pi}_y - \text{fee}_y}{(1+\delta)^y}) + \sum_{y=21}^{\infty}\frac{\pi_y}{(1+\delta)^y})\} - \text{filingCosts} \tag{4.2}$$

This model suggests that the observed patents' values are left-truncated based on the level of the costs up until the first maintenance payment and grant probability (γ), and profit under the patent monopoly. Aside from the protected market size, within the *patented* invention profit function ($\tilde{\pi}[\cdot]$) are added additional strategic and legal aspects, which influence the value of the exclusionary right. These include, but are not limited to, portfolio synergies, hold-up value, enforceability within the jurisdiction; we do not explicitly model these as they enter only indirectly through the monopoly profit of the patent.

Since the left side of the value represented in the weak inequality 4.2 above is unobserved because those patents are not in the patent system, it leaves us with patents whose values are greater than the application cost threshold. These patents are observed in the patent population despite that the distribution of these values is censored at renewal year 20.

$$E\{V_{patentRight}\} = \gamma(\sum_{y=0}^{20}\frac{\tilde{\pi}_y - \text{fee}_y}{(1+\delta)^y}) - \text{filingCosts} \tag{4.3}$$

Things can be further simplified by eliminating the grant probability, as would be the case by assuming that the patentee can forestall an examination decision at zero cost for the patent term, or assuming the country has a register patent (as does Switzerland). Even without such assumptions, we can mathematically simply absorb the patent examiner's grant decision (γ) into the depreciation rate ($\delta = \text{interest} + \text{obsolescence} + \gamma$); δ can also be extended to include all manner of scenarios (e.g. sensitivity to legal challenge) or made time dependent (i.e. a δ_t which would be higher during a grant phase).

$$E\{V_{patentRight}\} = \sum_{y=0}^{20}\frac{\tilde{\pi}_y - \text{fee}_y}{(1+\delta)^y} - \text{filingCosts} \tag{4.4}$$

This implies that for, unexamined utility models, register patents, offices with higher grant rates, and systems with long backlogs, we should expect that the marginal patent filed has less value. We point this out is because any observed sensitivity to fees is likely to be highly conditional on the specificities of a given system where the value of the marginal patent differs.

The patentees' optimal renewal decision is to renew if and only if the remaining value of doing so is greater or equal to the fee ($\text{NPV} \geq \text{fee}_y$). We assume (based on lots of empirical evidence) that the expected logged summed values of these individual cashflows follow a log-normal distribution. Hence, we can translate from the individual case to the population case by way of the law of large numbers, we thus admit a depreciated density function where the initial value reduces to our log-normal assumption:

$$F_V = \int_0^{\infty}\frac{\mathcal{LN}[\mu, \sigma^2]}{(1+\delta)^y}dv \tag{4.5}$$

The probability of a patent having died through year, given fee_y, can be thus defined by the cumulative density of the population:

$$P\{\frac{V}{(1+\delta)^y} \leq \text{fee}_y\} = F_V \tag{4.6}$$

Equation 4.6 states that a patentee's patent whose value is less than the fee does not renews, and the one whose patent's value is greater than that fee renews. It follows that marginal propensity for renewal given two fees is the percentage not renewing and the percentage change in fees:

$$\eta_y \quad = \quad \frac{F_V[v', y] - F_V}{(\text{fee}' - \text{fee})/\text{fee}} \tag{4.7}$$

From this theoretical model of an aggregate level specification, we can turn it into a skeleton for our empirical regression models in the rest of the paper. The fee change in percentage terms can be estimated the change in fees using a logarithmic approximation. Empirically, $F_V[v', y] - F_V$ is the renewal rate at a given year; the renewal rate is simply the average of the binary decision to renew or not.

$$\eta_y((\text{fee}' - \text{fee})/\text{fee}) \quad = \quad F_V[v', y] - F_V \tag{4.8}$$
$$\eta_y((\text{fee}'_y - \text{fee}_y)/\text{fee}_y) \quad \approx \quad \eta \cdot ln[fee_y] = F_V[v', y] - F_V \tag{4.9}$$
$$F_V[v', y] - F_V \quad = \quad \eta \cdot ln[fee_y] \tag{4.10}$$
$$\text{renewalRate}_y \quad = \quad \eta \cdot ln[fee_y] \tag{4.11}$$
$$\mu[\text{renewal}_{i,y} = 1] \quad = \quad \eta \cdot ln[fee_y] \tag{4.12}$$

Those last specification in Equations 4.11 & 4.12 forms the basic relation we are trying to estimate. Unto these, we add covariates ($\mathbf{X}$) and error ϵ that might confound the estimation of that relation.

$$\text{renewal} = \eta \cdot ln[fee] + X\boldsymbol{\beta} + \epsilon \tag{4.13}$$

Equation 4.13 is intentionally left general. We further specify it using different models and operationalizations that estimate η in a variety of ways. Having now defined the rationale behind the propensity to renew in the population given a type of microeconomic behavior, we get to the trickier task of estimating the actual propensity to renew.

4.3 Operationalization

4.3.1 Data Description

There are two primary sources of data. The first are the fee data which were typically collected from a variety of sources. For the European countries this was the official journal of the European patent office, whereby the fee changes were presumed to have been notified to members of the European patent convention. The US, Columbian, Japanese, Mexican, Chinese, Cuban, and Australian patent offices kindly furnished unofficial fee tables directly. Other countries' fees were obtained directly from the original legislation, which was occasionally difficult for the author to interpret in a foreign language. Procedural fees differ amongst countries. Hence any quantitative analysis comprising all these fee structures requires a common ontology. This means we coerced data into a common schema consisting of: 1. "application phase" fees; 2. post-application fees ("fees up through grant"); 3. and an annual renewal fee schema. While the other fees have been shown to be important, we focus primarily on the renewal fees, which provide the bulk of office revenues.

It is worth noting that several countries have different fee rates for individual, student, or small enterprises; these were partially collected but left aside for future research.[1] Given that multinational enterprises dominate the patent landscape, the assumption made throughout this paper is that the applicant is a large company, which pays the regular fee on time.

The patent data come from PATSTAT 2014a, and the registry data from the worldwide legal status ('prs') table for PATSTAT 2014b. Applicant details come from ECOOM's 2014a version of the Harmonized Assignee Names. Despite being a coherent dataset with a single, competent producer, there are still short comings in the data when it comes to the legal status of a given patent in a given country in a given year. There is incomplete coverage and artefacts, especially for the non-EP patents before 1980, we thus start our analysis after 1980. This date corresponds roughly to a two-year 'burn-in' period for the EPO, the beginning of coherent IMF macro-data[2]. National registry data also starts to become more consistent after this date.

[1] These fee types are occasionally flagged in the fee table.

[2] i.e. The World Economic Outlook Database

Even with the author's complete access to the Swiss registry data and institutional knowledge, there were discrepancies between PATSTAT and the national registry, which were still hard to explain. I imagine the case is similar in other jurisdictions with similar or inferior record keeping. The exact time of the lapse in the l525ep field of the 'prs' table is not always available, hence the prs_gazette_date, which in fact tracks the date the information makes it into the INPADOC registry, is used as an approximation for the patent's legal date of cessation. Occasionally, these dates match with the legal date reported by a country's registry exactly, more often though there is a lag between the legal date of effect, and the time that date makes it into the EPO's database. For Switzerland, this lag was about 242 days on average; hence patent ages are rounded down to the nearest integer. The Swiss event dates in this study were overwritten with the country's more accurate registry information. In addition to data lag and quality, registry data delivery from the various offices differ considerably from PATSTAT's biannual cycle so there are additional data censoring issues that also have to be dealt with. The approach take here was too examine the most likely year were registry data are available, and retain only uncensored cohorts in the various estimations.

Sample Construction Data analysis on the entire patent population is unwieldy (some models will not numerically converge), hence the population data were sampled. Specifically, they were sampled in a stratified manner by month and jurisdiction. The monthly stratification matches the granularity of the exchange rate data, which is an exogenous source of identification beyond the fee level. This in turn matches the typical mensual billing cycle of maintenance fees. The JPO and USPTO data, were sampled on a single day for each month for which there were records. The other jurisdictions were over-sampled proportionally to the number of applications at the JPO. For example, the German jurisdiction received about half as many patents as the JPO, so it was sampled on twice as many days. For the jurisdictions with many fewer patents, such as Cuba's, the entire population was included. The case of European patents represents a more complex instance. For patents that died at the EPO, the EPO is treated as a single 'country' with macro-variables proportional to its members' GDP. For patents surviving the EPO's grant procedure, the GDP series is spliced, with the European 'country' governing the pre-grant phase and the post-grant phase being governed by the member's GDP – meaning that the European GDP predicts the application to the EPO, and the GDP of the country where the patent right is maintained helps predict the renewal propensity. The net result of this stratified sampling strategy can be seen in Table 4.9 of the Appendix.

4.3.2 Fees

Since the renewal fees are our object of investigation it is worth looking at them specifically. Most countries have an annual maintenance fee cycle, and the models are set up within such a logic. It is worth noting not all countries have this policy: the US has a three payment system, and until recently, New Zealand was on a four payment maintenance schedule. Most payments fall due within the application month. As an interesting exception, Israel allows patentees to pay for the entire lifespan up front; Switzerland also used to allow prepayments in exchange for a discount. These pre-payment options seem to be the rare exception rather than the rule. Hence, the working assumption for our estimations is that applicants pay in the month in which fees are due.

We tried three different approaches with respect to the fee currency. Simply relying on changes in the base currency led to weak identification; fee changes are relatively rare events. The second, more complex approach, was to translate the fees into the *applicant's* probable local currency based on the average monthly exchange rate in which the fee fell due; in addition to being complicated to implement, this approach seemed to introduce noise into the initial estimates as evidenced by higher standard errors than the dollar-based model, and was abandoned. Following the WIPO (2014), a third approach of translating local fee currency into nominal U.S. dollars on a monthly basis seemed to be a good compromise, and yielded more precise estimates. This is the approach used throughout. Figure 4.1 below shows the distribution of fees in U.S. dollars.

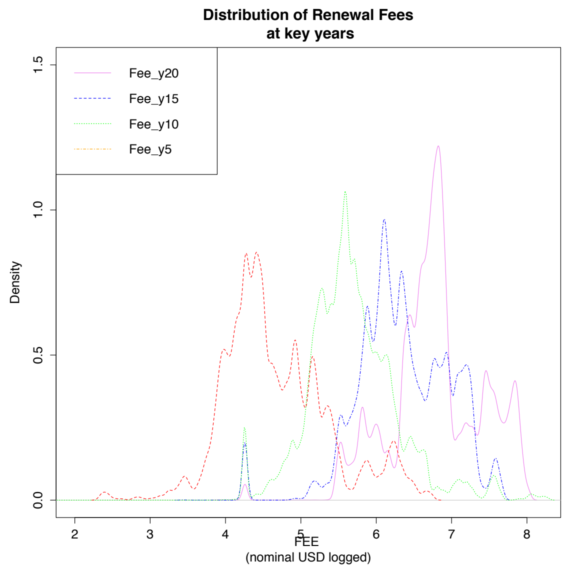

Figure 4.1: Distribution of the fees at key renewal years 5,10,15, and 20.

The additional variance of the exchange rate effects notwithstanding, the jurisdictional fee effects remain visible in the multi-model distribution of Figure 4.1.

Progression in Fees

In most fee systems, the renewal fees are progressive. The logic of this progression is likely more organic and historic than rational. However, the current justification for a progression in the fees is that it encourages inventors to "use it or lose it" by incentivising retrocession of the invention back into the public domain. Public welfare, revenue, and distribution have all likely had a hand in the current state of things. An alternative explanation may lie in revenue concerns: as we saw in the model above, stronger patents tend to last longer. A jurisdiction can be viewed as a monopolist selling an exclusionary right at a lower price earlier on in a patent's life, which is a form of price discrimination amongst patentees with different willingness to pay. In this way the state can collect more of the patentee's surplus, which should positively impact revenue. An alternate distributional rational is that the stronger players pay for a system whence they derive the most benefit. Low initial fees can also be seen as possibly pro-competitive in that they encourage more numerous weaker competitors to file. Figure 4.2 below shows the typical progression in the sample.

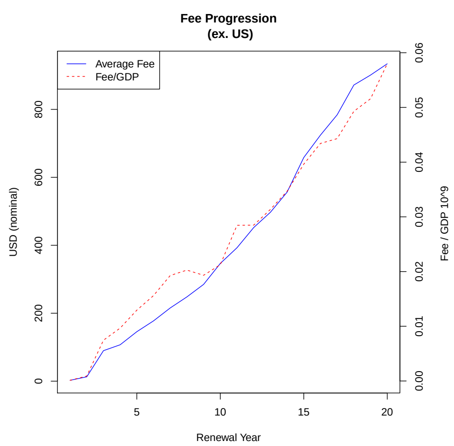

Figure 4.2: General fee progression of the sample in nominal U.S. dollars terms and in relative terms to billions of GDP. Noteworthy are the linear trend, and the fees nigh zero in the initial years.

Trend in Fees

Aside from the general progression of the fees, there are certain trends to consider. Table 4.2 contrasts the evolution in fees over our period of inquiry.

Table 4.2: Total Renewal Fees over Time

	1980			2014			
	total fees	GDP (10^9)	fee/GDP	total fees	GDP (10^9)	fee/GDP	Δ
AT	5'892	80	73.6	16'718	445	37.6	-49%
BE	1'449	122	11.9	5'899	535	11	-7%
CH	3'198	113	28.4	9'485	694	13.7	-52%
DE	12'660	826	15.3	17'901	3876	4.6	-70%
FR	3'676	691	5.3	7'574	2886	2.6	-51%
GB	4'002	542	7.4	7'691	2828	2.7	-63%
LU	590	6	91.2	3'863	64	60.2	-34%
SE	4'633	131	35.3	8'985	580	15.5	-56%

Fees in nominal 2015 in U.S. dollars.

In 1980, the average fee was about USD 2'400 per patent over its life time; using the official US CPI, this is about 6'900 in current U.S. dollars. By 2014, that amount averaged about 9'600 in nominal terms, which represents a healthy 39% *increase*.

However using the value model above, we expect our inventors to be influenced by the costs relative to the market opportunity rather than absolute costs. Returns to scale are one of the defining features of intellectual property. We thus deflate the fees using the IMF's nominal GDP figures. Doing so paints quite a different picture. In 1980, a patentee could expect to spend about USD 7.4 / billion GDP to maintain her patent right in Great Britain. By 2014, that same patent costs only USD 2.7 / billion GDP to maintain, which represents a 64% *decrease*; Great Britain is not alone. In 1954, a Swiss patent would have cost about USD 28.4 / billion GDP to maintain over its lifetime[3]; today, it costs about USD 13.7 / billion GDP to maintain. Only Belgium's fees seems to have roughly kept pace with economic growth at -7%.

Given the rise of the tertiary service sector, comparisons using GDP across time may not be entirely appropriate. For Switzerland between 1969 and 2012, adjusting fees by R&D expenditures, leads to a less drastic comparison CHF 2.31 / million R&D and CHF 0.49 / million R&D today; nevertheless a fivefold decline.[4] de Rassenfosse & van Pottelsberghe de la Potterie (2013) finds similar steep declines for application fees deflated by the production wage (pg. 700). In more plain words, on a total lifetime cost basis, we should expect the marginal patent today to have much less private value than it did in 1980. We should also observe an increase in patenting, and a decline in patent quality. This picture is consistent with the contemporary stylized facts. Some of this fee to GDP attrition is likely to do with the decline in relative share the patenting sectors in the economy vis-à-vis the service sector. Having now explored the data and our variable of interest, we turn to the results of our empirical investigations.

4.4 Results

This section covers three different types of results. The first section compares a few specifications of different constellations of covariates. In the second section, we look at which model might be most appropriate. In the third and final section, we estimate the actual elasticities. There are far too many specifications to report; the goal was not to maximize predictive power or test one particular theory,

[3] The term was 2 years shorter, but there is a clear and inferred CHF 20 / year progression.

[4] 2012 R&D figures are based on the Swiss Federal Office of Statistics and the 1969 figures on (Dichtl et al. 1987, pg. 314) for the chemistry and machinery industries; R&D for these industries has largely been stable at ca. 0.8-1.2% of GDP.

rather the models presented here aim to make "fair" representation of the data and lay the foundation for further research.

The first set reports the stability across covariates. The second compares different approaches to modelling the phenomenon at each period, and the last section model deals with the estimates along the curve. We then take those results and estimate what renewal rates would look like for the unitary patent under the TOP4 and TOP5 proposals of the EU to set the fees for the new European unitary patent. The former having been adopted in June of 2015.

4.4.1 Covariate Specification

Before deciding on a particular model, it is worth looking at some of the covariates that might otherwise bias the fee elasticity estimates. In order to do this, we will use a standard logit model. A logistic regression model is a type of non-linear model where the dependent variable is typically a binary outcome. In our case it is the probability that a patent gets renewed conditional on a set of covariates X:

$$F[x] = Pr\{renewal = 1|\mathbf{X}\} = \frac{1}{1 + e^{-\mathbf{X}\boldsymbol{\beta}}} \tag{4.14}$$

While the *ceteris paribus* assumption is clearly too strong an assumption, the first model presents the naked estimate of the fee elasticity at year 8. Year 8 was chosen to incorporate U.S. data. Moreover the typical patent in the EP system has usually survived the grant stage gauntlet by this year. The average renewal rate, *conditional on making it this year*, in our sample at this age is relatively high at about 88% across countries.

Table 4.3: Parameter Stability across Covariate Constellation

Logit Marginal Effects of Renewal Probability at Year 8					
	Baseline	Macro	Applicant	Patent	Jurisdiction
$\ln[\text{fee}_{y8}]$	-0.001***	-0.009***	-0.001***	-0.002***	-0.053***
	[0.000]	[0.001]	[0.000]	[0.000]	[0.001]
$\ln[\text{GDP}_{y8}]$		-0.016***			
		[0.001]			
$\ln[\text{population}_{y8}]$		0.024***			
		[0.001]			
unemployment_{y8}		-0.402***			
		[0.014]			
isDomestic			-0.001		
			[0.001]		
isIndividual			-0.029***		
			[0.002]		
isUniversity			0.034***		
			[0.003]		
isCompany			-0.006***		
			[0.002]		
isGovNonProfit			0.009***		
			[0.003]		
isHospital			-0.057***		
			[0.017]		
ln[FWcites]				0.032***	
				[0.000]	
isEP				-0.035***	
				[0.001]	
p-val: IPC3				0.000	
p-val: jurisdiction					0.000
AIC	667623	665490	667162	657730	650023

[Robust standard errors] clustered by jurisdiction and year. *10,**5,***1 % significance levels.

Countries are very different with respect to patent legislation, and the take-away from these models is that jurisdiction effects cannot be ignored as evidenced by the lower AIC. Accounting for the jurisdiction remains the most important factor. The jurisdictional dummies absorb most of these legislative distinctions, but does not explain their underlying drivers.

The primary source of identification within jurisdictions comes from the exogenous change in the local currency agains the U.S. dollar. Within the fee panel we have some 75 different currencies, some jurisdictions changing currencies several times (e.g. Brazil). Additional we observe many jurisdictions in Europe pre- and post-euro. Because the fees vary mostly by country and fees are set annually, the errors were clustered by country and year. This did not change the inference, in fact the errors occasionally got smaller despite the fact that we have fewer patents per group. Incorporating year effects alone biases the fee coefficient toward zero because most of the identification is coming through the level of the fees in a given jurisdiction in a certain year which is correlated to the exchange regime. The weak predictive power of the models in Table 4.3 leaves much to be desired, and brings us to our second set of models.

4.4.2 Family Effects

The weak predictive power of the patent-level model, coupled with the knowledge that patents are maintained collectively around a given product or strategy, hint at intra-patent family dependencies. This means the decision in one jurisdiction may influence the outcome in another. To illustrate the point, we compare three simple log-log linear models using the common (non-exhaustive) attributes of the underlying invention, namely quality (here measured by forward citations) and complexity (as proxied by the number of inventors). Whereas above the renewal decision is binomial, we assume that the total fees paid is quasi-normal after taking the natural logarithm, which allows us to use a linear model to estimate the family quality effects.

The first in this class of models is a *patent-based* model with the total renewal fees paid over the lifespan in a given jurisdiction ($\text{feesPaid}_j = \sum_{y=1}^{age} \text{fee}_{j,y}$) as a *dependent* variable. The second is a family-based model with the total fees paid over the lifespan of the patent in the observable jurisdictions[5] of the 1980-1993 cohorts. We juxtapose these against a multivariate multiple linear regression framework, where the dependent variables are the total fees paid in multiple jurisdictions. Since, family size is a well known indicator of patent quality, each jurisdiction beyond the first introduces additional selection bias, we limit the analysis to dyadic families; while conceptually appropriate, there is a bias-variance tradeoff for the multivariate model to be cognizant off when comparing it to the single jurisdiction case. The skeletons of these models are presented below:

$$\begin{aligned}
\text{Patent} &\equiv ln[\text{feesPaid}_j] = ln[fwCites + 1] + IPC3 + \text{cohort} \\
\text{Family} &\equiv ln[\sum^{Juris} \text{feesPaid}] = ln[fwCites + 1] + IPC3 + \text{cohort} \\
\text{Multivariate} &\equiv [ln[\text{feesPaid}_{j=DE}], ln[\text{feesPaid}_{j=GB}]] = ln[fwCites + 1] + IPC3 + \text{cohort}
\end{aligned}$$

The equivalent family model is the sum over all jurisdictions, which is akin to a global patent monopoly renewal budget. The multivariate model underscores the common root cause between the two renewal outcomes in independent jurisdictions.

Table 4.4: Family Effects

	Patent	Family	Multi-jurisdiction
	ln[totalFeesPaid]		ln[totalFeesPaid]{GB,DE}
ln[fwCites]	0.20***	0.28***	0.32***
	[0.00]	[0.00]	[0.02]
ln[numInventors]	0.06***	0.39***	0.29***
	[0.00]	[0.00]	[0.03]
cohort	Not displayed for concision.		
IPC3	Not displayed for concision.		
R^2	0.06	0.20	0.06
N	371931	376829	14936
*10,**5,***1 % significance levels.			

Table 4.4 reveals why measuring family level effects at the patent level may not be fruitful. We see the budget elasticity measurement more than doubles when we take the family as a whole into account. Moreover, we have strong evidence to believe the the size of the organization, as proxied by the number of inventors listed on the patent, has little bearing on the renewal budget. When the patent level model is contrasted though against the more appropriate family models, organizational size seems to have a more meaningful effect–doubling the size of the inventor team increases the renewal expenditures by about 29-39%. It hence becomes clear that a patent-level model does not efficiently capture family level effects, possibly indicating a lot of idiosyncrasy at the patent level as to a renewal strategy. The quality of the patent, as proxied by the number of forward citations, also is slightly downward biased in the jurisdictional patent model vs. global family and multi-jurisdictional models.

While families common to Germany and Great Britain were used in the subsample, as they have many families in common, both the forward citation (i.e. technical quality effect) and organization size effects remain positively and strongly identified even when a different jurisdictional pair such as Switzerland and France are used.

[5] *ea sunt: JP GB CH FR AT DE BE SE LU EP*

4.4.3 Age-Conditional Model Specifications

Having now looked at potentially salient variables and bearing in mind that family-level variables are mere controls as they are mis-estimated at the patent-level, we now turn to the type of model that will be employed to estimate point elasticities along the renewal curve. We compare three different class of models, each with slightly different distributional assumptions. All of these might be appropriate for a patent office to use. The linear probability model despite its simplicity is computationally easy on massive patent datasets. The more complex logistic is useful to model a renewal decisions at the patent level where additional covariates might yield insight into applicant behavior or specific procedural effects within the office. Alternatively, taking a macro-view of a policy maker, the fLogit is appropriate for modeling fractional response variables bounded on the [0,1] interval, in this case the fraction of patents renewed.

Again, we compare specifications using the 8th renewal fee having conditioned the sample on survival through the 7th year.

Table 4.5: Specifications Compared

	LPM (OLS)	Logit ($\frac{dY}{\partial x}$)	fLogit
ln[fee$_{y9}$]	-0.09***	-0.09***	-0.07***
	(0.00)	(0.00)	(0.06)
isEuropeanPatent	-0.01***	-0.01***	-0.53***
	(0.00)	(0.00)	(0.14)
ln[fwCites]	0.03***	0.03***	0.77***
	(0.00)	(0.00)	(0.09)
jurisdiction	Not displayed for concision.		
N	750844		457
(Standard errors) clustered by jurisdiction and cohort.			
*10,**5,***1 % significance levels.			

The models would seem to agree in that the elasticities are -0.09 and -0.07 respectively; the fractional logit exhibiting a slightly lower marginal response. The fLogit model is not statistically significant, but with only 457 country-years and jurisdiction controls this is perhaps not too surprising. We thus get renewal fee elasticity estimates (η_{y8}) at year 8 ranging between 7 and 9%.

Renewal Fee Sensitivity over Lifespan

Now that we have look at both the covariate and model specification at the year level, we now apply the specification to the data across time periods to estimate the sensitivity to a fee burden along the renewal curve. Again, we use the logistic model that we saw above in Table 4.5 and benchmark it against the linear probability model.

Table 4.6: Age-Conditional Renewal Fee Elasticities

Renewal_y	η_{LPM}	s.e._{LPM}	η_{Logit}	s.e._{Logit}	$N_{\text{jurisdictions}}$	N_{cohorts}	N_{patents}
1	0.00	0.00	0.00	0.00	14	26	158234
2	0.01	0.00	0.00	0.00	18	27	251971
3	-0.00	0.00	-0.00	0.00	27	29	892972
4	-0.01	0.00	-0.01	0.00	32	28	915786
5	-0.01	0.00	-0.01	0.00	34	28	1008241
6	-0.03	0.00	-0.03	0.00	36	27	921421
7	-0.06	0.00	-0.07	0.00	40	26	818782
8	-0.09	0.00	-0.09	0.00	42	25	734140
9	-0.15	0.00	-0.15	0.00	42	24	593830
10	-0.14	0.00	-0.13	0.00	43	23	499608
11	-0.23	0.00	-0.25	0.00	42	23	413267
12	-0.17	0.00	-0.17	0.00	42	22	349334
13	-0.20	0.00	-0.18	0.08	40	21	267894
14	-0.17	0.00	-0.19	0.00	40	20	216056
15	-0.13	0.00	-0.14	0.00	40	19	179546
16	-0.12	0.01	-0.12	0.01	36	18	149311
17	-0.04	0.01	-0.04	0.01	34	17	124102
18	-0.01	0.01	-0.01	0.01	35	16	102331
19	0.00	0.00	0.00	0.00	32	14	77574
20	0.02	0.00	0.02	0.00	34	14	64820

Samples conditioned on registry information and non-zero fees.

Table 4.6 highlights some of the deficiencies in the dataset where for the higher years data when availability is an issue, and in the earlier years many countries have zero fees, even conditioning on non-zero fees (i.e. fees > 0) reveals very low elasticities, which indicates that patents at this stage likely have an option value far beyond the current fee structure. Sensitivity to fees increases through years ten/eleven, and then decreases as the remaining population consists of a more valuable core of patents. The early years are particularly unreliably estimated as there are very few countries with renewal fees in the first few years of an international patent's life. The data for those jurisdictions with fees during the first few years tend to be older cohorts with worse registry coverage. The "fashion" of zero fees for renewal years 1-5 underwent policy diffusion over time, and hence there are few jurisdictions late in the sample with fees in the early years when good registry data would be available.

4.4.4 Patent Lifespan and Total Maintenance Costs

In addition to looking at the years individually, we also look at the total renewal fee load over the lifespan of the patent. We do this because we know that applicants have the entire fee trajectory when making decisions, and hence stop renewing on a given year conditional on the sum of fees paid and the sum of the fees left in the term. In other words, the year-by-year estimates presented above may be biased because of the total subsequent and previous fee load. In order to investigate these effects, we opted for a estimate an over-dispersed generalized linear Poisson model, where the age of the patent is the count outcome. This type of model is used to model count data. Ideally, we would have liked to use the entire data set and all cohorts with more countries, and model the fact that the data is censored in the year 2013. Unfortunately, with this large of a dataset, using a framework with every jurisdiction and cohort censored individually proved too challenging for the numerical solver, and gave unreliable results when trying to account for this censoring. Instead of the statistically accounting for the censoring, the sample was restricted to those cohorts for which we have the entire lifespan of data. The results of this model are shown in Table 4.7.

Table 4.7: Poisson Lifespan Model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.616***	0.028	127.261	0.000
ln[totalFees]	-0.139***	0.002	-78	0.000
ln[GDP_{y10}]	-0.042***	0.002	-22.482	0.000
$unemployment_{y10}$	-1.232***	0.035	-35.441	0.000
ln[$population_{y10}$]	0.067***	0.002	35.205	0.000
ln[fwCites + 1]	0.073***	0.001	104.883	0.000
ln[numInventors]	0.039***	0.001	44.858	0.000
isDomestic	0.016***	0.002	6.592	0.000
EP	-0.092***	0.002	-50.879	0.000
ln[portfolioSize]	0.008***	0.000	27.591	0.000
	Cohort dummies not displayed for concision.			
	Sector dummies not displayed for concision.			
	Jurisdiction dummies not displayed for concision.			
	IPC3 dummies not displayed for concision.			
N=487,220; fee errors clustered on jurisdiction and cohort.				

The Poisson model indicates a total a fee elasticity of around 14% after taking the macro variables at year 10 into account along with the applicant's portfolio size. We again see quality, as measured by forward citations, and organizational size, as proxied by the number of inventors, positively influences renewal behavior.

4.4.5 Forecasting Attrition and Fee Progression Path

In the Poisson model above we saw renewals modeled as the entire fee load over the lifespan of the patent. Another way to model the renewals is to look at the attrition over time. In exchange for parsimony, the second, but less familiar approach to estimating the total cost effects, was to borrow the Cox proportional hazard model with time-varying covariates from clinical research. The Cox model is semi-parametric, making no strict assumption about the distribution of the baseline hazard rate. It does assume that the hazard is a log-linear combination of the explanatory variables. Rather than the covariates being static, we can model the influence of the variables at each year. That is to say the age of the patent is divided into 20 intervals where each interval has a set of covariates that differ in time. This allows us to better model the effects of varying unemployment and GDP evolution over time. This better accounts for the optionality of the patent in that an applicant may decide to abandon the patent at any time based on the prevailing economic conditions and fee structure.

This would be fundamentally uninteresting given the exponential link function, which is similar to the underlying Poisson process of the model above, but it allows us to look at an attrition given a time trajectory of covariates. This particular technique would be useful for forecasting patent renewal rates in that it allows for the incorporation of other forecasts (such as GDP) which might be useful for offices or for owners that adjust their protection based on some time-varying effect

The basic model is a Cox proportional hazards model, where the patents die according to an arbitrary baseline hazard function of time:

$$\lambda[t] = \lambda_0[t]e^{X\beta} \tag{4.15}$$

$$\tag{4.16}$$

A patent (p) with a given covariate vector has a hazard proportional to this baseline:

$$\frac{\lambda_p[t]}{\lambda[t]} = \frac{e^{X_p\beta}}{e^{X\beta}} \tag{4.17}$$

The concept of a baseline hazard can be extended to both jurisdiction, cohort, and IPC and whether the patent is an European patent in order to yield estimates comparable across both. Furthermore we can subdivide each patent term into a sequence of 20 renewal years, each with its own baseline hazard rate within a stratum, such a jurisdiction, and set of covariates—similar to a hierarchical mixed model. Since the hazard is proportional, the downside is that this technique absorbs the baseline effects from each of the strata. Table 4.8 shows the results of the estimates using this approach.

Table 4.8: Cox Survival

	coefficient
ln[fee_{y0-20}]	0.14***
	[0.017]
ln[GDP_{y0-20}]	0.22***
	[0.025]
$\text{unemployment}_{y0-20}$	2.08***
	[0.208]
$\text{population}_{y0-20}$	-0.22***
	[0.023]
ln[fwCites]	-0.18***
	[0.003]
jurisdiction	n/a
IPC1	n/a
cohort	n/a
EP	n/a
Likelihood ratio: 0.000	
Hazard stratified by jurisdiction, IPC1, cohort, EP	

We see that doubling the patent quality as measured by its family's forward citations reduces the hazard by about 18%. Doubling the fees in a given year increases the attrition hazard by about 14%. Less hazard is to say the patent lives longer. The business cycle is also matters – going from 5% to 10% unemployment increases attrition by about 10%. Curiously, doubling GDP *reduces* the likelihood of renewal by about 24%. While it might be easy to dismiss the counter-intuitive negative effect of GDP as spurious (which is still a possibility), this fact appears occasionally in the other models (cf. *supra*) and is worth reporting. One *ad-hoc* explanation is that applicants filed even the least valuable inventions in large jurisdictions like the USA, Japan, and Germany, where a tiny market share can be worth more than the entire market of a small jurisdiction. Alternatively, bigger economies may be more competitive — patentees may find their monopoly status more valuable but also more readily challenged. In any case, the model makes us aware of the potential confounding effects using this type of model.

To apply the approach and show how it might be used in policy counter-factuals, we apply it to the European unitary patent TOP4 and TOP5 proposals presented in March of 2015.

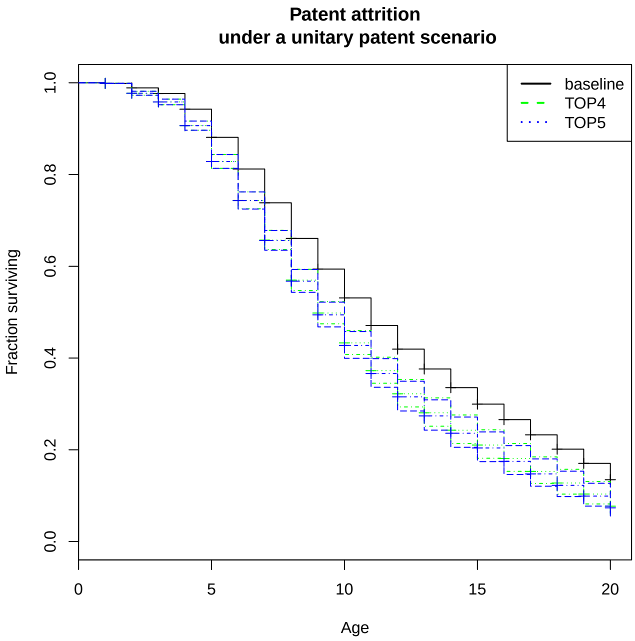

Figure 4.3: Potential attrition scenario under a unitary renewal TOP4 and TOP5 unitary fee regimes. Notice that the difference between the two proposals is well within the dashed confidence intervals. The “baseline” here are the average levels of the unitary countries, with GDP and population adjusted to form a common jurisdiction.

The forecast relies on the sample and makes no assumptions about future growth or patent composition trends, but it underscores that the two fee proposals are close together in terms of influencing renewal behavior, bring us back to the larger point about the triviality of the fee levels. Things like GDP growth, unemployment, population, and the viability of the jurisdiction are likely to influence the absolute level of renewals more than fees at their current historically low levels. In June of 2015, the Select Committee of the Administrative Council of the EPO endorsed the lower fee structure of the TOP4 proposal.

4.4.6 Absolute Fee Levels and Hyper-Elasticity

Since this paper is aimed at policy-makers worldwide, the marginal estimates at the global average values may not be particularly useful for setting fees because the more fees deviate from the average, the more inaccurate the point estimate becomes. To measure the second order effects of the absolute higher fee level, the approach taken here was to estimate the over-dispersed Poisson model presented in Table 4.7 at each level of fees, and collecting coefficients for the age elasticity with respect to price. Specifically, the model is estimated repeatedly from the 0^{th} to the $(1-\mu)^{th}$ percentile with a subsample spanning about 15 percentiles of the total fees ($\mathcal{N} \sim (\mu = 0.15, \sigma = 0.03)$). Within each window of data, the subsample is bootstrapped. Figure 4.4 shows the collected coefficients plotted against the fee percentile.

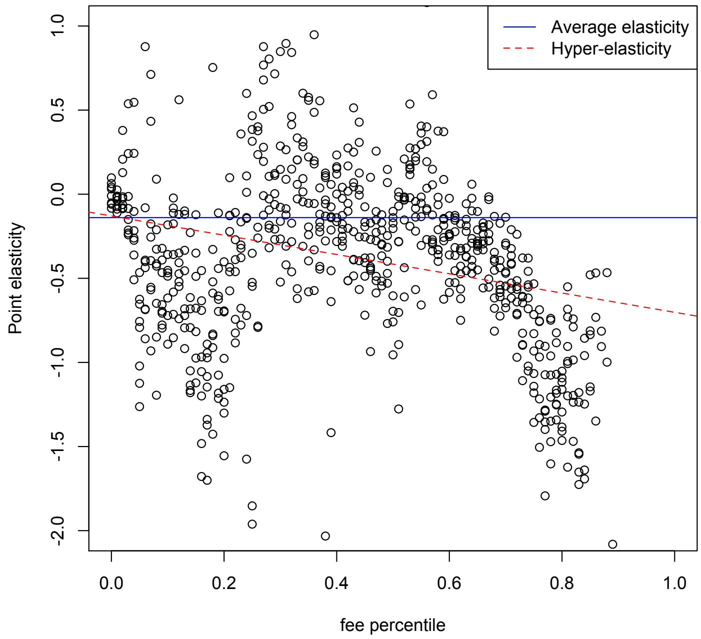

Figure 4.4: Subsampling the data into narrow windows paints a fairly noisy, but evident picture that patentees are more sensitive to fees the higher the total fee burden becomes. There seems to be more dispersion at the low end where non-fee factors may play a more important role in maintaining coverage.

The elasticity coefficients are regressed on the average fee of the random sample windows using iteratively weighted least squares (to militate against the outlier estimates of the narrow samples).

$$\eta = -0.9 \cdot ln[\text{totalFees}] \quad (4.18)$$
$$[0.065]$$

This theoretically means roughly doubling the fee load doubles the sensitivity with respect to total fees for the lifetime of the patent. Empirically, going from total fees at the 2^{nd} quartile (USD 6'100) to the 3^{rd} quartile (USD 9'400) means the fee elasticity goes from -0.5 to almost unit elastic at -0.97. Aside from statistical significance, this shift is economically significant, and indicates that governments do not have a quasi-unlimited ability to raise fees as the very low first-order elasticity might indicate. Patentees become more sensitive at the margin to renewing as fees increase.

4.5 Discussion & Conclusions

We have seen that blanket statements about renewal elasticities are hard to make given that renewals are conditional on the jurisdiction, owner, age, industry, family strategy. However, based on the estimates above, the average elasticity across models likely lies around 10% range. The results of renewal fee elasticity above reinforce previous findings of low and negative elasticities of other aspects of patentee behavior (applications, claims, etc.). The low elasticities indicate that patent fees are well below the utility of the exclusionary right their owners believe they confer. We would see elasticities much closer to unity if they were a major consideration in patentee renewal strategy. The basic significance of this is that patent offices have more room to raise fees while not jeopardizing their revenues.

We saw that typical factors, such as quality or applicant size, do play an economically and statistically significant a role in renewal decisions (cf. Table 4.3). This is especially visible at the beginning of the patent's lifespan where elasticities are small and during the final year where valuable patents go to term and the elasticity estimates are very low for those last renewal years (cf. Table 4.6). The larger meaning of these findings is that fees are not neutral to who obtains a patent (higher fees skewing toward larger multi-national players), nor with respect to the commercial quality of the population. The task of policy makers would be balancing these considerations.

4.5.1 Political Economy of Innovation and Revenue

For the most part, patent fees have been a source of office funding rather than a tool for steering innovation policy. Two exceptions come to mind, the first was Italy's brief experiment in reducing fees to 0 in an effort to boost innovation. While the experiment failed for reasons of political economy with the EPO, lowering fees was not likely to have much of an effect given the low elasticities we have measured here: excellent inventors would likely be little influenced by the magnitude of the fees.

At the other end of the fee spectrum is Ecuador with the highest fees observed in our dataset, which top out at over USD 20'000 for the 20th year. In Ecuador's February 27th 2013 contribution to the WTO's TRIPS council, it contends that such high fees are warranted a lack of information, excessive IP protection, inappropriate enforcement, and abuse of intellectual property rights, in particular patents without any consideration for effectively fostering "... social and economic welfare and ... a balance of rights and obligations' between producers and users, can constitute a kind of barrier to access to this kind of technology, particularly for developing countries." Given the low elasticities we have seen above, Ecuador's high fees may in fact be closer to the levels needed in order to maintain substantial policy leverage over patentee behavior. This policy leverage would come through raising the elasticity via the hyper-elasticity we saw in Equation 4.18.

The multivariate model and family models of renewal provide some evidence that patentees budget for protection across jurisdictions. If patentees have a total budget for protection, lowering the cost through the European unitary jurisdiction could lead to the patent being maintained longer in a non-unitary jurisdiction. Moreover, the advent of unified European patent would lend patentees generate additional optionality value to a patent family.

4.5.2 Quality Considerations

Society has an interest in encouraging both patents that meet the legal criteria of patentability *and* which are socially useful. The former typically is determined by an examiner or a court, and the latter by the market. Higher renewal fees coincide both theoretically and empirically with higher patent quality in the remaining population in that they encourage self-selection by raising the cost of a drawn out grant procedure, and encourage managerial discipline when it comes to deciding on the utility of maintaining a patent within a given jurisdiction. In this study, patents with more forward citations consistently are renewed at a higher rate in all the models.

We also saw, a particularly glaring aspect of the renewal fee structure that is likely incompatible with a quality objective, which is that many jurisdictions charge nothing for the first 1-3 years of protection (cf. Figure 4.2). Britain starts her renewal fees even later at year five, and Austria even later at year 6. Given the lack of any widespread fee policy during the early years, the effect fees at these years can only be inferred theoretically.

Given the model above and the typically short pay-back periods in the corporate world on the order of 3-7 years, the first years likely have the most option value–revenue maximizing patent offices or those trying to reduce the size of the exclusionary rent are thus likely ceding a lot of value in terms of revenue or social welfare. More perniciously, this backloaded fee structure is not conducive to the general goal of raising quality, and may be in part responsible for creating backlogs. Granting free optionality means more strategic applicants have an incentive to file weak patents and draw out procedures during this fee-free period. Perhaps an example of this inferred effect can be seen in Great Britain, where a large stock of patents are pending outside of the office, i.e. the national patent office is waiting on an action of the applicant (cf. Mitra-Kahn et al. (2013), Figure 2.6).

4.5.3 Future Research

Revenue and political economy implications aside, understanding patent protection strategies could add some insight into explaining foreign direct investment (FDI) and international trade flows. For example, foreign patenting is often seen as an impediment to technology transfer to developing countries; by observing the monopoly right over time within that jurisdiction, we might gain insight into the evolution of a particular technological strategy or the direction FDI flows as managers prune their patent portfolios. In addition, with a comprehensive renewal fee database it becomes much easier to estimate the extreme values of the underlying value using the renewal fee method because the tail of the distribution of high value patents can be better ascertained.

Declaration of Interest Some of the data was gathered for a governmental fee change project whilst I was employed at the Swiss Federal Institute of Intellectual property. Currently, I work in an unrelated private industry do not have any financial interest in the results.

4.6 Appendix

Table 4.9: Summary Statistics by Jurisdiction

Jurisdiction	Patents	Sample Share	Cohorts	Cohort (σ)	Days alive (μ)	Days alive (σ)
AR	16781	0.007	1995-2010	2.6	2064	913
AT	56554	0.023	1980-2007	8.0	3239	1655
AU	127366	0.053	1980-2010	6.5	2557	1511
BE	74863	0.031	1980-2007	7.6	3163	1607
BG	23988	0.010	2002-2007	1.2	2150	715
BR	76132	0.031	1988-2007	4.7	3288	1696
CA	52392	0.022	1997-2007	2.9	2453	1068
CH	81007	0.033	1980-2014	7.7	3235	1613
CN	54265	0.022	1985-2007	5.9	2346	1267
CO	2244	0.001	1997-2009	2.4	1863	851
CR	875	0.000	1992-2009	2.6	2006	972
CU	113	0.000	1992-2009	5.2	5504	2077
CY	31426	0.013	1996-2007	2.3	2426	908
CZ	37864	0.016	1992-2008	2.8	2366	1008
DE	96479	0.040	1980-2007	7.3	3021	1604
DK	74082	0.031	1980-2007	6.5	2846	1489
EE	37746	0.016	1994-2008	1.4	2189	746
EP	71728	0.030	1980-2009	7.1	2718	1606
ES	75733	0.031	1980-2007	6.2	3248	1636
FI	72071	0.030	1980-2008	6.3	3008	1701
FR	78608	0.032	1980-2007	7.4	3321	1650
GB	150233	0.062	1980-2008	7.6	3277	1764
GR	61068	0.025	1986-2007	5.3	2856	1394
HK	33782	0.014	1992-2010	3.8	3254	1123
HU	45927	0.019	1991-2007	3.9	2137	976
IE	68799	0.028	1980-2007	4.5	2779	1309
IL	27428	0.011	1980-2010	5.9	4934	1723
IS	20269	0.008	2001-2007	0.7	2058	646
IT	89801	0.037	1980-2007	6.1	3242	1587
JP	38540	0.016	1981-2013	4.3	2417	1511
LT	28093	0.012	1992-2007	1.6	2091	726
LU	83599	0.034	1980-2007	7.0	2977	1524
LV	13669	0.006	2001-2007	0.6	1996	614
MC	48441	0.020	1991-2007	3.5	2600	1148
MD	1136	0.000	1992-2006	3.5	2133	1025
MT	849	0.000	2002-2007	0.2	1614	381
NL	68744	0.028	1980-2007	7.6	3261	1619
NO	31910	0.013	1980-2009	6.3	3077	2012
NZ	29774	0.012	1990-2008	5.4	5403	2178
PL	47349	0.020	1988-2007	2.4	2368	967
PT	67064	0.028	1980-2007	4.8	2771	1282
RO	24038	0.010	2004-2007	0.8	2121	685
RU	8609	0.004	1992-2007	2.8	2564	1245
SE	72815	0.030	1980-2007	7.4	3231	1590
SI	29264	0.012	1994-2007	1.6	2189	789
SK	48501	0.020	1985-2008	1.8	2246	887
TR	32468	0.013	2000-2007	1.8	2258	812
TW	19974	0.008	1991-2007	2.4	2643	1079
US	88986	0.037	1980-2013	6.4	3583	1152
Sample	2423447	1	1998.75	6.72	2880	1512

Table 4.10: Main Sample Moments

	cohort	daysAlive	totalFee	fwCites	unemployment_{y8}	fee_{y8}	GDP_{y8} (trillions USD)
25%tile	1995	1770	0	2.00	0.052	146	2
50%tile	2001	2476	2454	5.00	0.074	205	5
μ	1999	2881	3489	10.71	0.078	320	17
75%tile	2004	3520	5480	12.00	0.097	279	16
σ	7	1512	4283	22.40	0.041	424	35

Table 4.11: Variable Definitions and Summary Statistics

Variable	Description	Source
	Jurisdictional characteristics	
$fee_{y[X]}$	Renewal fee at year X	cf. text, data to be released in seperate article
unemployment	Unemployment rate at renewal year X	IMF
$population_{y[X]}$	Population of the jurisdiction at renewal year X	IMF
$GDP_{y[X]}$	GDP of the jurisdiction in USD at renewal year X	IMF
isEP	is an EP application (regional system effect)	PATSTAT
jurisdiction	1/0 dummy variable for the jurisdiction of the patent	PATSTAT
	Applicant Attributes	
isDomestic	Applicant is from the jurisdiction	EEE-PPAT
isUniversity	Applicant is a university	EEE-PPAT
isCompany	Applicant is a company	EEE-PPAT
isGovNonProfit	Applicant is a government/non-profit	EEE-PPAT
isHospital	Applicant is a hospital	EEE-PPAT
portfolioSize	Number of patents in applicant's portfolio	own calculation from EEPAT
	Patent Attributes	
fwCites	Count of forward citations	own calculation from PATSTAT
cohort	A dummy variable for the year of patent filing (time effect)	PATSTAT
IPC[X]	X-digit IPC code of the patent (industry effect)	PATSTAT
PATSTAT version 2014a; ECOOM-EUROSTAT-EPO PATSTAT		

Table 4.12: Direct Estimate Comparison

	P&D 2009		Thompson	
Variable	Estimate	t-value	Estimate	t-value
Intercept	0.365	5.3	1.134	54.42
GDP (10^{12} EUR)	0.080	13.53	0.018	5.6
FEE (10^3 EUR)	-0.084	-2.93	0.0080	-0.94
Age of the patent	-0.030	-14.83	-0.052	-55.7
Age of membership	0.005	4.83	-0.003	-6.48
Intellectual Property Index	0.052	3.34	0.0004	0.054
R2	80.2		0.95	
N	243		274	
Robust standard errors.				

Table 4.13: Attempt to reproduce van Pottelsberghe de la Potterie & Danguy (2009) using public data. The annual attrition rates ("Age of patent") are similar, but the estimates are quite different. The procedures in the DG report are not entirely complete, so it's hard to know whether the differences arise from aggregation, data differences, or the actual estimation.

Chapter 5

The (Anti-)Competitive Effect of IPRs

5.1 Introduction

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

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

1. IPRs incentivise innovation and hence raise R&D by increased returns.
2. IPRs strengthen a firm's market position and reduce competition, which may lower or raise R&D effort.

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

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

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

This paper is organized as follows. Section 5.2 surveys relevant findings from the IPR and innovation literature. In Section 5.3, we present the conceptual framework and the hypotheses to be tested. In Section 5.4 we discuss the data and variables, followed by the econometric results in Section 5.5. Section 5.7 concludes and points the direction for future research.

5.2 Selected Findings from the Literature

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

5.2.1 IPRs and Innovation

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

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

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

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

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

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

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

Harhoff et al. (2014) find a loose dichotomy between simple and complex inventions where patents can be used very strategically[2] in the latter case by holding up rival firms in their innovation. Using different methods and data, Lampe & Moser (2015) also find that complexity plays a role, whereby patents provided a legal nucleus for coordinated action in the form of patent pools, and leads to less innovation and is a type of innovation cartel. Marengo et al. (2012) formalizes this idea by distinguishing between product complexity and product quality. Using simulations of their formal model, they show that a type of anti-commons effect dominate for the complex products yielding lower rates of innovation.

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

Beyond these studies trying to explain the benefits of IPRs, there has been a fair amount of work that puts firm choice at the center. Section 5.2.2 explores this aspect.

[1] The historical records seem to indicate that local governments in Switzerland would occasionally grant both a prize and "privilegium", a type of monopoly, for the discovery of some particularly useful inventions.

[2] "Strategic use of the patent system arises whenever firms leverage complementarities between patents to attain a strategic advantage over technological rivals. This is anticompetitive if the main aim and effect of strategic use of the patent system is to decrease the efficiency of rival firms' production (Harhoff et al. 2014, 22)."

5.2.2 Firm Choice for Appropriation with IPRs

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

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

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

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

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

5.2.3 Competition and IPRs

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

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

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

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

5.2.4 Competition and Innovation Effort

Adjacent to the main thrust of our paper, we would like to note that our work closely relates to the debate on whether competition is conducive or obstructive to innovation. In both theoretical and empirical analysis, any kind of relationship appears to be possible, as the many surveys of the literature demonstrate (e.g. by De Bondt and Vandekerckhove (2012); Cohen (2010); Gilbert (2006); Aghion and Griffith (2005); or Reinganum (1989)). The seminal works on this relation hold that competition hurts innovation because a surplus is required to maintain it (Schumpeter, 1911, 1942), but can also foster it when firms are further driven to seek out consumer utility and exploit it through R&D (Arrow, 1962). Later Kamien and Schwartz (1976) as well as Aghion et al. (2005) developed Scherer's 1967 idea of a sweet-spot or inverted U-shape relation between competition and innovation into rigorous formal models.[3]

Testing a structural model with endogenous determination of both competition and innovation, Peneder & Wörter (2014) as well as Friesenbichler & Peneder (2016) provided empirical evidence for an inverted-U relationship for large firm samples from such diverse datasets as the *Swiss Innovation Survey* or the *Business Environment and Enterprise Performance Survey* (BEEPS) conducted in Eastern Europe and Central Asia.[4] Working with the same kind of survey data, the current paper builds on their core model of a non-linear relationship between competition and R&D in order to control for their joint and endogenous impact on IPRs within a consistent simultaneous system. Our focus then is on extending that model by the endogenous choice of IPR use.

5.3 Conceptual Framework

5.3.1 Assumptions and Hypotheses

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

Figure 5.1 summarizes their joint structure in the form of a probabilistic graphical model. Arrows indicate the presumed direction of causal impacts, aiming for an accurate dissection of indirect effects via the respective intermediary variables. Those in circles represent the endogenous variables of the model. The variables put in squares represent selected exogenous variable that are of particular interest. The system in Equation 5.5 provides further detail, while Section 5.3.2 describes the full set of exogenous controls and exclusionary restrictions that we used in the estimations.

[3] Using U.K. and U.S. manufacturing data, Hashmi (2013), for example, find a U-shaped relation between innovation, as measured by citation weighted patents, and competition in the USA, and an inverted U-shape in the UK (cf. Table 2); he posits that the U.K. manufacturing does not exhibit the leader-follower pattern show in Aghion et al. (2005). This relation between market power and innovative competition could simply be theoretically indeterminate; Žigić & Maçi (2011) delve specifically into this issue and show that with free entry, competition can be intensive even if there is high concentration in a technological industry.

[4] The survey is conducted by the EBRD in conjunction with the World Bank.

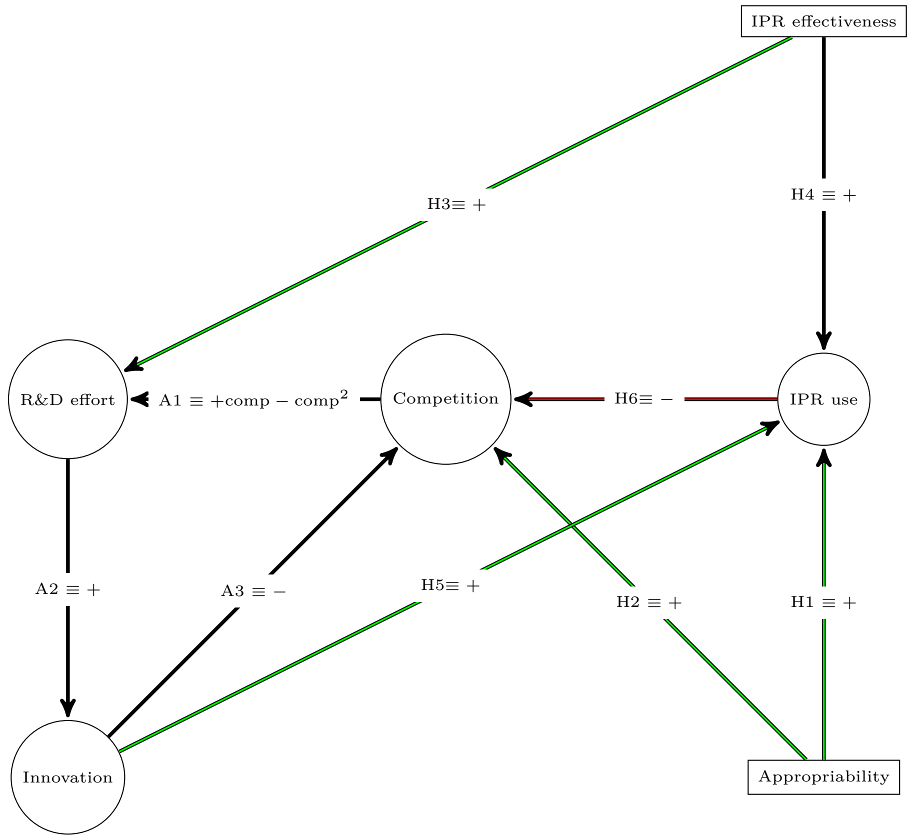

Figure 5.1: Skeleton of postulated causal graph for patent IPRs and competition. Endogenous variables are circles; selected exclusion restrictions are rectangular. Assumed relations are in grey.

In short, the received literature brings us to the following basic assumptions:

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

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

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

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

To begin with, we focus on the impact of general appropriability conditions at the industry level as characterized by the taxonomy of Peneder (2010), which was created from a large sample of respondents to the European Union's *Community Innovation Survey*. The first hypothesis links that industry level regimes developed for the EU companies with the individual IPR use of our Swiss firms:

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

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

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

[5] For example, music companies cannot avail themselves of the patent system, and the pharmaceutical sector does not typically use copyright. Moreover, intellectual property rights and licensing play key roles in these two industries, but are not essential for the oil and gas sectors where average field costs dictate production.

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

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

H3: *If firms perceive IPRs to be effective, they are likely to spend more on R&D.*

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

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

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

Finally, for a given industry and according technological regime (see Hypothesis 2), the actual use of IPRs help the individual firm to keep its competitors at a distance.

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

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

5.3.2 Structural Equation Model

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

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

R&D Effort

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

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

$$E_i \quad = \quad \gamma_1 C_i + \gamma_1^{sq} C_i^2 + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + h_i + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \mathbf{X}_{1,i} \boldsymbol{\chi}_1 + \upsilon_{1,i} \tag{5.1}$$

$\mathbf{X}_i$ represents a vector of variables, and υ_i is an error term. The equation is identified with our exclusion restriction $\tilde{O}_s$. It is a sectoral taxonomy built from the European Union's *Community*

Innovation Survey (CIS) micro-data. $\tilde{O}_s$ accounts for exogenous sectoral contingencies of R&D expenditures referred to as *opportunity* conditions. It affects the likelihood that an individual firm invests in its own R&D, whereas its impact on the innovation outcome is only indirect, through variation in R&D expenditures. By assumption and consistent with the causal structure of the model, the variable is therefore not correlated with the error term in the innovation production function.

Innovation Outcome

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

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

$$I_i \quad = \quad \epsilon_2 E_i + \tilde{\kappa}_2 \tilde{K}_s + \mathbf{X}_{2,i}\boldsymbol{\chi}_2 + \upsilon_{2,i} \tag{5.2}$$

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

IPR Use

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

The graph in Figure 5.1 demonstrates, how the presumably reverse causality between R&D and IPR strategy is resolved by means of a more fine-grained chain of effects that is intermediated by other endogenous variables. Aside from forms of strategic patenting and trademark, the impact of R&D on IPR use is largely conditional on some sort of (often minor) innovation. Conversely, the impact of IPR use on R&D incentives is conditional on their actual effect of reducing the number of competitors. For the purpose of identification, we break the endogenous cycle by using the industry level appropriability conditions aptype_*s* ($\tilde{A}_s$) and the firm's perception of the effectiveness of IPRs as exclusionary restrictions. Including both restrictions improves the model, indicating both can function as a valid exclusion restriction, we prefer the firm's perception. Theoretically it is more proximate to the R&D decision and the empirics seem to bear this out to a small degree. Empirically, including both improves the model, indicating the firm may not be unitary with respect to strategy and outcomes, or the survey respondent does not control IP strategy.

$$P_i \quad = \quad \iota_3 I_i + \epsilon_3 e_i + \delta_3^e d_i^e + \tilde{\alpha}_3 \tilde{A}_s + \mathbf{X}_{3,i} \boldsymbol{\chi}_3 + \upsilon_{3,i} \tag{5.3}$$

Competition

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

$$C_i \quad = \quad \iota_4 I_i + \epsilon_4 P_i + \delta_4^p d_i^p + \delta_4^e d_i^e + \tilde{\alpha}_4 \tilde{A}_s + \mathbf{X}_{4,i} \boldsymbol{\chi}_4 + \upsilon_4 \tag{5.4}$$

As in the Kamien-Schwartz '76 model, we assume that the rents from innovation depend on the characteristics of markets and technology and can either be fully appropriated by the innovator, or diffuse among a mixed ecology of innovation leaders and followers, who imitate and on average earn lower returns. In an ordinal ranking of firms that either do not apply new technologies, adopt them from external sources, or innovate on their own, we expect that a higher degree of innovation decreases the number of competitors.

The main exclusion restriction applies with regard to a sectoral taxonomy of appropriability conditions $\tilde{A}_s$, also derived from the EU-CIS. We consider that the characteristic differences in the distribution of appropriability measures at the industry level reflect exogenous sectoral contingencies, which correlate with the number of competitors by the individual firms. Furthermore, our model implies that the sectoral appropriability conditions affect innovation incentives only indirectly, that is if they have an influence on the intensity of competition. Consequently, they are uncorrelated with the error term in the innovation opportunity function. The same applies to population density and regulatory quality, which we assume to have a positive impact on competition, but exclude from the estimation of Equation 5.1.

Equation 5.5 summarizes our four endogenous variables within a joint system:

$$\begin{pmatrix} E_i \\ I_i \\ P_i \\ C_i \end{pmatrix} = \left(\begin{array}{c|c|c} \gamma_1 C_i + \gamma_1^{sq} C_i^2 & +\tilde{\omega}_1 \tilde{O}_s & +h_i + \tilde{\kappa}_1 \tilde{K}_s + \epsilon_2 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \mathbf{X}_{1,i} \boldsymbol{\chi}_1 + \upsilon_{1,i} \\ \epsilon_2 E_i & +\tilde{\kappa}_2 \tilde{K}_s & +\mathbf{X}_{2,i} \boldsymbol{\chi}_2 + \upsilon_{2,i} \\ \iota_3 I_i & +\epsilon_3 e_i & +\tilde{\alpha}_3 \tilde{A}_s + \delta_3^e d_i^e + \mathbf{X}_{3,i} \boldsymbol{\chi}_3 + \upsilon_{3,i} \\ \iota_4 I_i + \epsilon_4 P_i & +\tilde{\alpha}_4 \tilde{A}_s & +\delta_4^p d_i^p + \delta_4^e d_i^e + \mathbf{X}_{4,i} \boldsymbol{\chi}_4 + \upsilon_{4,i} \end{array} \right) \tag{5.5}$$

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

5.4 Data

Our empirical analysis is based on data from the *Swiss Innovation Survey* (SIS) observed across 7 waves of a comprehensive survey[6] conducted between 1999 and 2015 and collected by the Swiss Economic Institute (KOF) at the ETH Zürich. Observations come from a stratified random sample of

[6] Available from www.kof.ethz.ch

firms having at least five employees within all relevant industries in manufacturing, construction, and service sectors. The stratification covers approximately 28 industries and, within each industry, three size classes (with full coverage of the upper class of firms). The firm panel is highly unbalanced, but by pooling the data we can use a sample of ca. 10'900 observations for our final estimations.[7] The SIS is similar in content and structure to the EUROSTAT *Community Innovation Survey* (CIS) in other European countries, which is the primary data source for measuring firm-level innovation activity in Europe. CIS surveys have been coordinated internationally to confirm validity across contexts and constitute a reliable source for innovation studies.

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

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

The dependent variables are affected by a number of confounders, which we include as controls in each of the equations. We consider, in particular, the technological potential, human capital (proxied by the share of employees with higher education), foreign ownership, export status, firm size, firm age as well as time and industry dummies (see Table 5.1 for further details on the variables).

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

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

As a general caveat, we must assume that these exclusionary restrictions from the micro-data refer to firm-level characteristics, and are not biased by the firms' endogenous choices.

[7] Even though the endogenous causation invokes a certain time pattern and the data are available in a panel format, we do not apply lagged variables for two reasons. On the one hand, we have no information on the accurate time period required, e.g., for R&D inputs in a certain year to yield successful innovations in a later year, or of innovations to affect the number of competitors. On the other hand, due to the ordinal nature of most endogenous variables, the type of firm activities exhibits only little variation over time. Finally, we would loose many observations due to the unbalanced nature of the panel. The latter is a serious disadvantage, since the simultaneous system generally is rather sensitive to sample size (Friesenbichler & Peneder 2016, 538).

[8] While this can only be an imperfect proxy for the intensity of competition, the subjective nature of this measures has the advantage of capturing the intensity of competition as perceived by the individual firms. In contrast to conventional industry-based measures, they account for the fact that relevant markets are typically segmented. Compared to measures of market concentration, it has the additional advantage of capturing rivalry from both domestic and international competitors, which is particularly important in a small, open economy such as that of Switzerland.

Table 5.1: List of Variables

Symbol	Variable	Definition
		Endogenous Variables
These variables are part of the endogenous system and mutually influence one another.		
E_i	R&D effort	1 … intramural R&D = 0 2 …< R&D < 1.5% of total sales 3 … 1.5% < R&D ≤ 5% 4 … R&D > 5% of total sales
I_i	Innovation	1… Adaptive 1: pursuing opportunities other than from technological innovation (Non-innovators) 2…Adaptive 2: introducing new products and/or processes new to their firm but not new to the market (Technology adopters) 3…Creative 1: product/process innovator (new to the firm) developing innovation mostly on their own 4…Creative 2: introducing products new to the market
C_i	Competition	Number of principal competitors in the main product market worldwide; subjective firm assessment according to the following ordinal scale: 1 … Number of principal competitors ≤ 5 2 … Number of principal competitors > 5 & ≤ 15 3 … Number of principal competitors > 15 & ≤ 50 4 … Number of principal competitors > 50
P_i	IPR use	Non-linear binary combination of IP rights usage: $ln[(\text{patents}+\text{copyrights}+\text{trademarks}+\text{designs})^2+1]$
		Firm Exclusion Restrictions
Firm-level exclusion restrictions are variables that are particular to a given equation in the system, but are not appropriate in all equations for theoretical reasons.		
h_i	Hampering factors	Score of self-reported factors hampering innovation (or survey selection effect)
p_i^e	IPR effectiveness	Effectiveness of protection[9] of innovation-based competitive advantages (Likert 1-5)
d_i^p	Past demand	Past demand in primary market (Likert 1-5)
d_i^e	Expected demand	Expected demand in primary market (Likert 1-5)
		Sector Exclusion Restrictions
Three taxonomies of technological regimes (O_s, A_s, M_s) based on a sample of 78'000 firms from 22 European countries and clustering sectors by relative differences in the distribution of heterogenous firm types (see Peneder, 2010). The sectors are classified according to a characteristically high share of firms in Europe (other than Switzerland) with trait.		
$\tilde{O}_s$	Opportunity	1… neither intramural nor external R&D activities 2… acquisition of external R&D, machinery, rights, etc. 3… own R&D, but less or equal 5% of total sales 4…own R&D, more than 5% of total sales
$\tilde{A}_s$	Appropriability	1… no appropriation measures 2… appropriation only by secrecy, lead-time, or complexity of design 3… appropriation by design patterns, trademarks, or copyright (with or without strategic methods) 4… appropriation by patents (alone or with either strategic or other formal methods) 5… appropriation by patents together with other formal and strategic methods
$\tilde{K}_s$	Cumulativeness of knowledge	1… reporting neither internal nor external knowledge sources of high importance 2… creative firms with internal sources less important than external sources; adaptive firms with internal sources more or equally important 3 … creative firms with internal sources more or equally important than external sources; adaptive firms with external sources more important
		Control Variables
$\mathbf{X}[i,0]$	Tech potential	Technological potential (Likert 1-5)
$\mathbf{X}[i,1]$	Higher education	Share of employees with higher education
$\mathbf{X}[i,2]$	Foreign owned	Whether the firm is owned by a non-Swiss entity
$\mathbf{X}[i,3]$	Export share	Share of firm sales coming from exports
$\mathbf{X}[i,4]$	Age	Firm age in years
$\mathbf{X}[i,5]$	Size	Firm size in number of full time employees
$\mathbf{X}[i,6]$	Intercept	Level of null model

[9] IPRs are implied as this question is part of the IPR block in the survey.

Table 5.2: Summary Statistics

Statistic	Mean	St. Dev.	Min	Max
R&D effort	1.67	0.965	0	4
innovation	1.73	0.773	1	4
IPR use	0.363	0.876	0	4
competition	2.21	1.04	1	4
competition^2	5.97	5.266	1	4
hampering factors	0.013	1.22	-1.32	4.53
IPR effectiveness	1.08	1.18	0	4
demand past	3.15	1.03	1	5
demand expected	3.14	0.881	1	5
opportunity	2.19	1.08	1	4
cumulativeness	1.87	0.940	1	3
appropriability	2.59	1.67	1	5
techPotential	2.70	1.13	1	5
higher education	22.0	21.1	0	100
foreign owned	0.145	0.352	0	1
export share	22.98	33.9	0	100
ln[age]	3.98	0.668	0	6.36
ln[size]	4.01	1.37	0	10.57
N=10892				

5.5 Empirical Estimation and Findings

The theory behind the system represented by Equation 5.5 requires a fair amount of consideration with regard to the type of estimation. So in order to efficiently estimate the system simultaneously, we use the three-stage least square estimator (3SLS) suggested by Zellner & Theil (1962); this estimator has several advantages compared to a 2SLS panel estimator, which is typically used in order to instrument endogenous dependent variables. The theoretical endogeneity implies that we must insert the estimated values of the dependent variables among the regressors in another equation, and hence expect their residuals to be correlated: the 3SLS approach uses generalized least squares to account for such a correlation structure. Taking advantage of the correlated error structure across equations, like seemingly unrelated regression (SUR), 3SLS is more efficient than 2SLS, and therefore gives more precise estimates in limited samples (Madansky 1964). There is an additional advantages if the system contains at least one over-identified equation, which is the case (cf. Table 5.4 for the over-ID tests). Otherwise, both methods are consistent and hence coefficients asymptotically equivalent.[10]

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

Since all coefficients and standard errors are estimated simultaneously, statistical tests involving coefficients can be performed conveniently. This makes it easier to test our hypotheses and to simulate the endogenous system, while also taking into account the indirect effects across different equations. For instance, we can quantify the indirect effects of a firm's perception of IPR effectiveness on com-

[10]Full information maximum likelihood would have been another choice, but that estimator is more sensitive to the underlying distributions. Green (2003, 409) states: "As always, the small properties remain ambiguous but by and large whereas systems estimators is used, 3SLS dominates FIML nonetheless (one reservation arises from the fact that the 3SLS estimator is robust to non-normality whereas, because of the term $ln[\mathbf{\Gamma}]$ in the log-likelihood, the FIML estimator is not. In fact the 3SLS and FIML estimators are usually quite different numerically".

petition via a firm's IPR use, thus accounting for indirect effects consistent with theory shown in our causal graph presented in Figure 5.1.

Table 5.5 reports the results for all four equations from the simultaneous system.

Turning to the first equation, the results confirm the expected inverted-U shaped impact of competition on R&D effort. This finding is consistent with assumption A2 and the results reported in Levin et al. (1985), Aghion et al. (2005), Woerter (2014), Peneder & Wörter (2014), and Friesenbichler & Peneder (2016). Among the exogenous variables, higher growth of demand in the past 3 years, higher expected demand growth in the coming 3 years, better opportunity conditions at the sector level, a higher technological potential, a higher share of personnel with tertiary education and exports all tend to increase the firms' R&D effort. Conversely, the aforementioned positive impact does appear to be relevant for R&D effort, which amounts to rejecting hypothesis H3.

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

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

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

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

3SLS IV System

Table 5.3: Full 3SLS System

	R&Deffort	Innovation	IPRuse	competition
		Endogenous System		
competition	11.2***			
	(3.57)			
competition^2	-2.18***			
	(-3.59)			
R&Deffort		0.306***		
		(9.60)		
Innovation			0.487**	-36.8***
			(3.13)	(-28.0)
IPRuse				-3.10***
				(-4.91)
		Firm Variables		
haperingFactors	0.011			
	(0.73)			
IPReffectiveness	0.005		0.091***	
	(-0.29)		(1.16)	
pastDemand	0.074***			0.294***
	(2.99)			(6.28)
expectedDemand	0.091***		0.030***	1.28***
	(4.01)		(2.62)	(12.9)
		Exogenous Sector Variables		
Opportunity	0.435***			
	(2.47)			
Cumulative	-0.147	-0.026***		
	(-1.113)	(-3.60)		
Appropriability			0.063***	0.824***
			(4.37)	(6.02)
		Control Variables		
techPotential	0.066***	0.022***	0.029***	2.04***
	(3.92)	(3.19)	(2.83)	(12.5)
higher_education	0.008***	-0.000	0.002***	0.078***
	(7.11)	(-0.797)	(3.93)	(8.514)
foreignOwned	-0.119	0.005	-0.067***	-2.34***
	(-2.17)	(0.820)	(-2.86)	(-5.15)
exportShare	0.008***	-0.000	0.005***	0.076***
	(9.54)	(-1.46)	(15.5)	(9.95)
ln[Age]	0.024	0.011	0.017	0.564***
	(1.01)	(1.04)	(1.39)	(2.36)
ln[Size]	0.017	0.041***	0.078***	2.82***
	(0.69)	(6.62)	(6.37)	(15.6)
intercept	-11.9***	0.838***	-1.40	30.9***
	(-3.45)	(14.9)	(-9.99)	(20.1)

N=10'967; (t-stat); *10%,** 5%,*** 1%. Industry and year dummies omitted for concision.

Instrumental variable tests conducted by 2SLS estimations for each pair of equations with a causal connection confirm that all of them are correlated with the endogenous variable (rejecting the Anderson canonical correlation test for under-identification), while the fact that they are predetermined guarantees (by assumption) that they are uncorrelated with the error terms (Table 5.4). The Sargan Test for over-identification has also been passed (see Table 5.4).[11]

[11] We test the instruments of the system in Section 5.5, in a 2SLS framework by recursively inserted the predicted equation into another and then test whether the exclusion restrictions hold in a partial model. Exclusion restrictions are limited to those, which are exclusion restrictions in the full model. This means concretely that while $ln[Age]$, for example, may be construed as an exogenous regressor in a 2SLS framework, it is a control in the 3SLS system, and thus cannot be used for identification in our 2SLS battery of IV tests.

Table 5.4: Summary of IV Test Statistics

Endogenous variable	Under-identification *Anderson L-M (p)*	Weak identification *Cragg-Donald Wald (F)*	Over-identification *Sargan (p)*
R&D effort	0.009***	3.10	0.960
Innovation	0.017**	3.78	0.345
IPRuse	0.009***	4.73	0.371
Competition	0.000***	4.90	0.113

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

5.6 Simulation

In order to understand the implications of the model we compute the changes in the endogenous system by shocking select exogenous variables by two standard deviations, by moving from one standard deviation below the mean to one standard deviation above the mean. The algebra behind this system is presented in Appendix 5.8. Table 5.5 shows the equilibrium shift in percentage terms.

Table 5.5: Simulated Changes (%)

Endogenous Variable	R&D effort	Innovation	IPR use	Competition
Exogenous Variable				
Size	3.9	-13.2	123.6	-0.4
IPR effectiveness	-0.8	1.4	54.3	0.1
Appropriability	2.8	-4.6	71.5	-0.4
Demand	2.8	-4.5	21.4	0.00

Simulated $\frac{\partial y}{dx}$ of endogenous variables based on $+2\ \sigma$ around μ_x

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

5.7 Summary and Conclusions

IPRs are a popular policy tool to foster innovation. But their actual impact can be more ambiguous then is generally perceived. In short, the pro-IPR rationale originates in the problem of appropriability,

[12] Thompson & Wörter (2017) presents a simple model for this effect.

or missing markets for new knowledge. When it bears characteristics of a *public good* with non-rival and non-excludable use, the fact that producers cannot fully appropriate the social returns undermines their incentives to invest own effort and resources. Thus the situation will typically provoke an *under-supply* of innovation. When IPRs are effective, however, firms can use them to appropriate the economic benefits of own innovations. IPRs thus transform public goods into *club goods*, where consumption is excludable but still would be non-rival. The consequence is a tendency towards *under-consumption*, since the individual price to pay becomes larger than the social cost of use. [13]

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

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

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

– Treated as a purely exogenous variable, which reflects technological characteristics of an enterprise's narrower knowledge domain, a higher *effectiveness* of IPRs significantly increases R&D effort.

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

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

– Confirming an inverted-U relationship between competition and innovation effort, the full endogenous system further implies that fewer competitors tends to raise R&D, when initial competition has been strong, and tends to further reduce it, if initial competition has been weak.

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

Further research is certainly warranted. This study covered but Switzerland – a small country – with lots of unobserved competition. Future research would attempt to implement this in one or

[13] The well known and more specific problems, such as strategic hold-up of competitors, are easily understood as particular instances of this general tension.

several markets where all the competitors can be observed. Moreover, our key outcome variable, *IPRuse* could be improved by matching with the patent, trademark, and design databases.

5.8 Appendix

5.8.1 Reduced Form

The foregoing exposition describes the economic rationale and identification strategy for our endogenous system. We can also solve the system to obtain a reduced form of the model, which is then written in terms of exogenous variables and coefficients. We drop the error terms from the system for concision of exposition. First, we substitute the firm's effort identity into the innovation Equation 5.2 to yield the innovation identity:

$$I_i = \epsilon_2(\gamma_1 C_i + \gamma_1^{sq} C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}$$

We substitute this now into the IPR strategy Equation 5.2

$$\begin{aligned} P_i = \; & \iota_3(\epsilon_2(\gamma_1 C_i + \gamma_1^{sq} C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) \\ & + \epsilon_3 e_i + \delta_3^e d_i^e + \tilde{\alpha}_3 \tilde{A}_s + \boldsymbol{\chi}_3 \mathbf{X}_{3,i} + \upsilon_{3,i} \end{aligned}$$

We substitute that identity into competition Equation 5.4

$$\begin{aligned} C_i = \; & \iota_4(\epsilon_2(\gamma_1 C_i + \gamma_1^{sq} C_i^2 + \rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) \\ & + \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) + \epsilon_4(\iota_3(\epsilon_2(\gamma_1 C_i + \gamma_1^{sq} C_i^2 \\ & + \rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) \\ & + \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) + \epsilon_3 e_i + \delta_3^e d_i^e + \tilde{\alpha}_3 \tilde{A}_s + \boldsymbol{\chi}_3 \mathbf{X}_{3,i} + \upsilon_{3,i}) \\ & + \delta_4^p d_i^p + \delta_4^e d_i^e + \tilde{\alpha}_4 \tilde{A}_s + \boldsymbol{\chi}_4 \mathbf{X}_{4,i} + \upsilon_4 \end{aligned}$$

In Equation 5.6, next we group the competition terms outside of the inner expression:

$$\begin{aligned} 0 = \; & \iota_4 \epsilon_2 \gamma_1 C_i - C_i + \iota_4 \epsilon_2 \gamma_1^{sq} C_i^2 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 C_i + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq} C_i^2 + \\ & \iota_4(\epsilon_2(\rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \\ & \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) + \\ & \epsilon_4(\iota_3(\epsilon_2(\rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \\ & \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) + \\ & \epsilon_3 e_i + \delta_3^e d_i^e + \tilde{\alpha}_3 \tilde{A}_s + \boldsymbol{\chi}_3 \mathbf{X}_{3,i} + \upsilon_{3,i}) + \\ & \delta_4^p d_i^p + \delta_4^e d_i^e + \tilde{\alpha}_4 \tilde{A}_s + \boldsymbol{\chi}_4 \mathbf{X}_{4,i} + \upsilon_4 \end{aligned}$$

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

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

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

$$\begin{aligned} a = \; & \iota_4 \epsilon_2 \gamma_1^{sq} + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq} \\ b = \; & (\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1) \\ c = \; & \iota_4(\epsilon_2(\rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \\ & \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) + \\ & \epsilon_4(\iota_3(\epsilon_2(\rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \\ & \tilde{\kappa}_2 \tilde{K}_s + \boldsymbol{\chi}_2 \mathbf{X}_{2,i} + \upsilon_{2,i}) + \\ & \epsilon_3 e_i + \delta_3^e d_i^e + \tilde{\alpha}_3 \tilde{A}_s + \boldsymbol{\chi}_3 \mathbf{X}_{3,i} + \upsilon_{3,i}) + \\ & \delta_4^p d_i^p + \delta_4^e d_i^e + \tilde{\alpha}_4 \tilde{A}_s + \boldsymbol{\chi}_4 \mathbf{X}_{4,i} + \upsilon_4 \end{aligned} \quad (5.6)$$

This leads to the following substitution in Equation 5.4 for competition:

$$C_i = \frac{-(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1) \pm \sqrt{(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1)^2 - 4ac}}{2(\iota_4 \epsilon_2 \gamma_1^{sq} + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq})}$$

We can now substitute back into the R&D effort in Equation 5.1 to get the value in terms of the exogenous variables:

$$
\begin{aligned}
E_i \quad = \quad & \gamma_1 (\frac{-(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1) \pm \sqrt{(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1)^2 - 4ac}}{2(\iota_4 \epsilon_2 \gamma_1^{sq} + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq})}) + \\
& \gamma_1^{sq} (\frac{-(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1) \pm \sqrt{(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1)^2 - 4ac}}{2(\iota_4 \epsilon_2 \gamma_1^{sq} + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq})})_i^2 + \\
& \rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}
\end{aligned}
$$

And now the innovation equation:

$$
\begin{aligned}
I_i \quad = \quad & \epsilon_2 (\gamma_1 (\frac{-(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1) \pm \sqrt{(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1)^2 - 4ac}}{2(\iota_4 \epsilon_2 \gamma_1^{sq} + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq})}) + \\
& \gamma_1^{sq} (\frac{-(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1) \pm \sqrt{(\iota_4 \epsilon_2 \gamma_1 + \epsilon_4 \iota_3 \epsilon_2 \gamma_1 - 1)^2 - 4ac}}{2(\iota_4 \epsilon_2 \gamma_1^{sq} + \epsilon_4 \iota_3 \epsilon_2 \gamma_1^{sq})})_i^2 + \\
& \rho_1 R_i + \epsilon_1 e_i + \delta_1^p d_i^p + \delta_1^e d_i^e + \tilde{\omega}_1 \tilde{O}_s + \tilde{\kappa}_1 \tilde{K}_s + \boldsymbol{\chi}_1 \mathbf{X}_{1,i} + \upsilon_{1,i}) + \\
& \tilde{\kappa}_3 \tilde{K}_s + \boldsymbol{\chi}_3 \mathbf{X}_{3,i} + \upsilon_{3,i}
\end{aligned}
$$

Appendices

6.1 A Note on Patent Quality

In this section, we shall explore a series of empirical and theoretical reasons why patent quality and value can be measured using bibliometric measures. Then, initial evidence is provided how quality can been identified from the various metrics.

6.1.1 Manifestations of Patent Quality from the Literature

The literature surrounding patents is now replete with subtle correlations between a patent's bibliometric traits, and its value or underlying technical and legal merit. These range from simple, to complex requiring occasionally nuanced calculations. The 13 used in this paper represent the primary ones, but are by no means exhaustive. These are briefly explained below. Squicciarini et al. (2013) provides a much more thorough investigation of their statistical properties.

Claims: Number of claims in the patent document, a measure of strategic and legal value of a patent.

Adverse citations: This is like a backward citation measure, but it looks specifically at the fraction of backward citations (Xs, Ys) that are deleterious to novelty or inventiveness, a measure of legal robustness. **?** shows how adverse citations are relevant for grant decisions, and can be used as a better measure of a patent population's legal and technical quality.

Forward citations: Number of forward citations are a measure of technical relevance. These appear as raw counts, or are occasionally normed by creating a window (typically 5 years). There are other norming techniques such as percentile ranking, industry ranking. This paper norms the counts by age and logs them.

Family size: Number of members in the docDB family; family sizes a measure of widespread commercial viability.

PCT status: Patent family has used the patent cooperation treaty (procedure) and has a WIPO application member. It is a measure of revealed patenting costs.

NPL count: number of citations to non-patent literature, a measure of technical relevance. Deng et al. (1999) finds this to be a statistically significant predictor of market value of listed firms.

Patent scope: is the unique number of IPC4 classes a patent has. It captures the applicability of the measure to various technical fields.

Grant count: number of granted family members, a measure of legal robustness.

Title activity: the number of title changes, normalized by patent family size. Patents that undergo reassignment tend to be more valuable Serrano (2005).

Number of inventors: a measure of sunk research costs; presumably inventions issuing from large (expensive) teams are more valuable.

Number of applicants: a measure of sunk research costs; presumably inventions with more owners are more complex and/or valuable.

Active life: Sum of all active periods for a patent family's members, a measure of revealed value. Here it is normalized by the number of family members.

Generality: A measure of general commercial application of a patent, it refers to the concentration of a forward citations received by the from a given class of patents, normalized by the age of the patent (to avoid citation time attrition). Defined on the interval [0-1], patents with little generality are limited to a narrow field of application.

Grant lag: A measure revealed value, logged interval between first priority date and first grant within a patent family, normalized by average time to grant by cohort and application authority. Presumably, applicants with high quality patents want to swiftly guide them through the system.

Oppositions: High value or legally broad patents are often attacked *in utero*. This measure counts the number of legal oppositions launched against members of a patent family.

6.1.2 Decomposing Patent Quality

A key insight of Lanjouw & Schankerman (2004) was that using factor analysis of multiple indicators reduces the overall variance in the measurement of the underlying patent quality. The basic premise behind the analysis is that patent quality can better be measured by using a composite metric that eliminates much of the noise inherent to any one dimension. The table below reveals the raw relation between these measures.

Table 6.6: Correlation between Patent Quality Indicators

	PCT	Family size	Claims	NPL	Scope	Adverse cites	Grants	Oppositions	Inventors	Active life	FW cites	Generality	Grant lag
PCT	1												
Family size	0.38	1											
Claims	0.19	0.16	1										
NPL	0	0.01	0	1									
Patent scope	0.1	0.39	0.17	0	1								
Adverse cites	-0.02	-0.13	-0.04	0	-0.1	1							
Grants	0.1	0.33	0.12	0.01	0.36	0.03	1						
Oppositions	0.42	0.21	0.21	0	0.16	-0.07	-0.02	1					
Inventors	0.19	0.43	0.04	0	0.16	-0.06	0.15	0.2	1				
Active life	-0.44	-0.42	-0.17	0	-0.19	0.01	0.03	-0.25	-0.19	1			
FW cites	0.16	0.31	0.17	0	0.53	-0.05	0.15	0.18	0.15	-0.17	1		
Generality	0.22	0.38	0.15	0	0.59	-0.09	0.02	0	0.2	-0.28	0.4	1	
Grant lag	0.2	0.16	0.05	0	0.12	-0.02	-0.02	0.38	0.23	-0.08	0.08	0.14	1

Not all the correlations are noteworthy, but a few stand out as needing a comment. Upon closer inspection, the negative relation between the PCT status and the total active life of the patent has to do with the fact that there a many "stub" applications that get filed via the PCT procedure, but never make into the national phase (or last only a short time therein). So while a patent filed via the PCT, pursued through all national grant phases, might be a good indication of expense, the simplicity of the procedure also lends itself to mass filings. It looks like there is some tradeoff between wide-coverage as evidenced by the family size and the duration of the coverage as captured by the negative correlation of -0.44. While non-patent literature (NPL) seems to have lost much of its salience, the remaining faint correlation between grants reinforces the notion that these patents are possibly closer to the cutting edge of science.

Using these 13 sub-indicators, a single patent quality index was formed using the principal component with the highest Eigenvalue. To avoid excess lossage in the PCA step, missing values for some of the patent document indicators were imputed using Gary King's Amelia II for R. Table 6.7 reveals the loadings of the various sub-indices.

There is no guarantee that "patent quality" can be identified using principal components analysis because it presumes that such a common factor underlies the various manifestations of quality identified in the literature. Table 6.7 displays the factor loadings for the first four components identified using scaled PCA.

Table 6.7: PCA Decomposition vs. Theory

	'Patent Quality'	PC2	PC3	PC4	E{Sign}
PCT	0.24	-0.34	0.26	-0.25	+
Family size	0.44	0.06	0.27	0.10	+
Claims	0.17	-0.20	-0.09	-0.49	+
NPL cites	0.00	0.01	0.02	-0.04	+
Patent scope	0.40	0.10	-0.40	-0.05	+
Adverse cites	-0.10	-0.01	0.02	-0.50	-
Grants	0.37	0.32	0.21	0.22	+
Oppositions	0.24	0.38	0.24	-0.46	+
Number of inventors	0.20	-0.52	0.22	-0.08	+
Active life	0.28	-0.01	0.41	0.27	+
FW cites	0.33	-0.05	-0.42	-0.10	+
Generality	0.35	0.01	-0.44	0.16	+
Grant lag	0.08	-0.55	-0.07	0.24	-

Only Eigenvectors with an Eigenvalue > 1 shown.

While the signs of the Eigenvectors are theoretically arbitrary, their patterns are not. The last column of Table 6.7 displays the pattern of signs we would expect to see were there something akin to "quality". With the exception of the grant lag, the first principal component seems to fit the theoretical bill for something akin to patent quality/value. The other components do not have any obvious interpretation to the author. Figure 6.2 lends credence to the idea that the first component says something important about the nature of the patent.

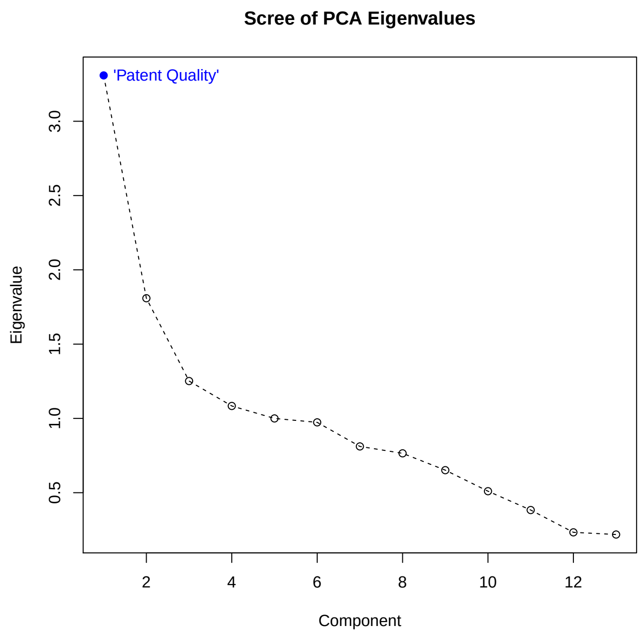

Figure 6.2: The scree plot for the 13 principal components reveals that one component describes a decent portion of the variance between patents.

Figure 6.3 shows the distribution of patent portfolio quality using a few common measures; with many odd distributions, it paints a vivid picture as to why no single metric is a robust proxy for patent quality. Through the normalization procedure inherent to the principal components analysis, the resultant distribution is more amenable to regression analysis. But beyond the pure mechanics of OLS there is good theoretical justification for using the "quality index" over the individual covariates in that principal components should be tossing out many of the aspects correlated with the innovation model covariates for reasons beyond patent quality. For example, the firms that report a high level of appropriability may use a lengthy procedure as a strategy.

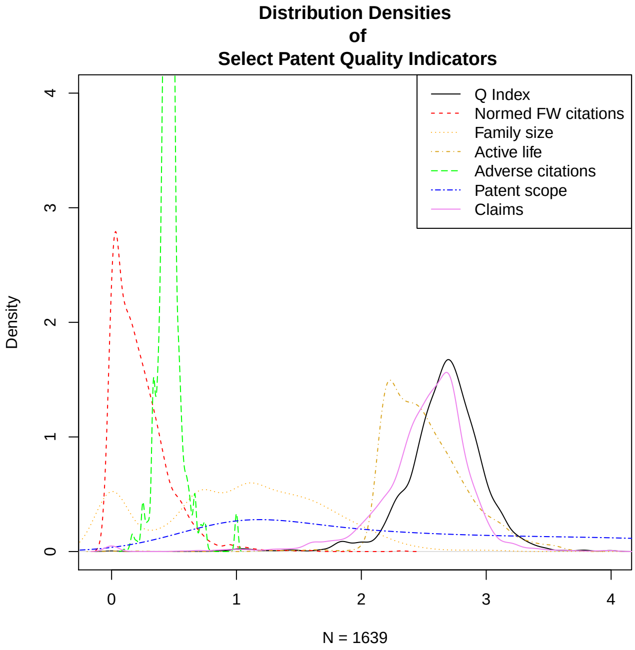

Figure 6.3: The distribution of patent portfolios formed on each of the indicators has a distinct distribution. The quality index (in black) "normalizes" these.

Next, the patent quality index was aggregated at the mean patent by three-year period and firm. The solid black distribution in Figure 6.3 shows the distribution of the variable of interest, patent quality.

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kof@kof.ethz.ch
www.kof.ethz.ch
#KOFETH