International patent applications and trade

An empirical analysis of the effect of trade margins on patent flows

Master Thesis

University of Zurich

Department of Economics

Chair: Prof. Dr. Josef Zweimüller

Supervisor: Christian Kiedaisch

Oliver Bucher

Field of study: Economics

E-mail: oliver_bucher@outlook.com

January 13, 2014

Abstract

This thesis gives new insights on how bilateral trade influences the number of patent flows. The empirical and theoretical literature considers bilateral trade as an important factor to explain patterns of international patent applications. The empirical analysis confirms the positive effect of trade with data about 187 countries and 84 patent offices. It turns out that this effect on patent flows can be attributed to both trade margins, since the regression estimates an average elasticity of 0.8 for the number of product varieties in trade (the extensive margin) and 0.3 for the trade volume per product variety (the intensive margin). The analysis indicates that the number of international patent applications within an industry is the most elastic with intermediate levels of trade. Thus, on the aggregated level these results imply that, if trade volume is fixed, patent flows are maximized for balanced trade margins. In fact, the empirical analysis finds evidence that the influence of the extensive margin on patent flows follows an inverted U, as long as the trade volume remains constant.

Table of contents

1 Introduction ... 4

2 Patent applications and regimes ... 6

2.1 Intellectual property rights and patenting ... 6

2.2 Harmonization of international patent systems ... 6

2.3 Routes to international patents ... 8

2.4 Differences across patent offices ... 8

3 The microeconomic perspective ... 9

3.1 Incentives to patent ... 9

3.1.1 The traditional motivations ... 9

3.1.2 Reasons not to patent ... 10

3.1.3 Alternative mechanisms ... 11

3.1.4 The strategic motivations ... 11

3.2 Which firms file patent applications and for what invention? 12

3.3 The probability of a firm to patent abroad ... 14

4 Determinants of international patent flows ... 16

4.1 A theoretical model ... 16

4.2 Empirical evidence ... 19

4.2.1 Gravity forces ... 20

4.2.1.1 Market size and wealth ... 20

4.2.1.2 Distance ... 22

4.2.2 Trade-related drivers to international patents ... 23

4.2.2.1 Bilateral trade and patent flows 24

4.2.2.2 Foreign direct investments 26

4.2.2.3 Alternative measures of trade 26

4.2.3 Patenting costs and fees 28

4.2.4 Intellectual Property Rights 28

4.2.5 R&D and human capital 29

4.2.6 Combinations of explanatory variables 31

5 Empirical analysis 32

5.1 Theoretical framework and hypotheses 33

5.2 Data 41

5.3 Estimation techniques 44

5.4 Empirical results 47

5.5 Discussion 52

6 Conclusion 54

7 References 56

Appendix 61

1 Introduction

A country's productivity growth depends primarily on the availability of new technology. In the context of economic globalization, such new technologies are increasingly determined by foreign firms, which makes international diffusion of new technology a major driving force for productivity growth (Eaton & Kortum, 1996). For this reason, the research community has given attention to the identification of the factors that determine international diffusion of new technology.

International patent flows represent a widely accepted concept to measure the international transfer of new technology, since new technology is a result of inventive activity and must be patented in every country where it needs to be protected. Despite the fact that international patent applications are transfers of knowhow and do not directly imply the diffusion of technology itself, patent flows are in most cases induced by the intention to trade patentable innovations and thus are associated with technology transfer. In the last two decades, international patent flows (and thus international technology transfer) have experienced an important surge. Not only has the total number of international patent applications almost doubled in ten years, but also have the patent applications filed by non-residents, on average, surpassed the number of patents applied by residents (Yang & Kuo, 2008).

A central question to the debate about explaining patent flows is why firms patent abroad and what affects their decision to do so. Protecting exports or foreign direct investments seems an evident incentive, although strategic motivations are increasingly found to be important, too (Peeters & van Pottelsberghe de la Potterie, 2006). In either case, a firm's decision to file an international patent depends on factors that affect the profitability of technology transfer (Bosworth, 1984). Chan (2010) shows that the invention type and characteristics of the firm are important factors in this context. Furthermore, the attractiveness of the destination market and the relationship the firm's home country maintains with that destination market also plays an important role in this decision. In order to explain patent flows between two countries, the literature focuses on source and destination country characteristics as well as attributes referring to the relationship between the involved countries. Important determinants include market size, wealth and bilateral trade. Bilateral trade is of particular importance as it contains physical transfers of new technology. Bosworth (1984) was the earliest to provide evidence for a positive impact of trade on patent flows arguing that protecting exports is a major motivation for patenting abroad. His findings have been confirmed by Yang and Kuo (2008), among others.

Trade influences patent flows positively because more product variety in trade (the extensive margin of trade) augment the number of products facing a threat of imitation abroad and/or because larger export volume per product variety (the intensive margin) increases the economic incentive to protect innovations by patents. In turn, the trade margins' relative importance for determining patent flows may depend on the type of innovations for which patents are applied, i.e. whether innovations create new product varieties or improve the quality of existing products.

This thesis aims to provide evidence for the effect and the relative importance of trade margins on international patent flows. The analysis proceeds from a modified regression model of Lybbert and Zolas (2012), decomposes trade flows into its extensive and intensive margins and tests their effect on patent flows during a period of 1995-2009. In order to control for industry-specific effects, disaggregated data is constructed according to an algorithm derived by Lybbert and Zolas (2012). On both the aggregate and disaggregate level, data reveals that not only patent flows but also combinations in trade margins vary considerably between country pairs, even if trade volumes are similar. A plausible implication is that certain combinations of trade margins promote patent flows more than others do. One expects to observe more patent flows the more industries engage in trade and the more products they export (extensive margin). At the same time, industries might only patent their products abroad as long as individual trade volumes are high enough to justify the costs for patenting, while patent flows within an industry eventually become inelastic with respect to trade once the majority of its patentable export products are filed abroad.

The empirical analysis confirms the positive influence of trade as suggested by previous research and provides evidence for a positive effect of both trade margins on patent flows, although the estimates are inconclusive regarding the relative importance of the trade margins. The results also lend support to the hypothesis that patent flows are on average higher if trade margins are balanced, as within narrowly defined industries, patent flows seem most elastic for intermediate levels of trade volumes.

The thesis is organized as follows: section 2 gives a short overview on current patent systems in the context of international patent applications. Section 3 discusses common motivations of a firm to patent, and in particular the factors that influence a firm's decision to do so. In section 4, the literature about the determinants of international patent flows is reviewed. The theoretical and empirical framework is explained and its results discussed in section 5, while section 6 concludes.

2 Patent applications and regimes

2.1 Intellectual property rights and patenting

A patent enables an inventor to prevent others from producing, using, selling or even importing the invention (Chan, 2010). The protection is limited to the national borders of the validating patent office and expires usually after 20 years (OECD, 2009). This gives the holder of the patent a timely restricted Intellectual Property Right (IPR) and should serve as an instrument to enhance inventive activity. However, this exclusive right assigns the holder of a patent a competitive advantage in form of a monopoly. He solely can decide who may use the invention and issue licenses. He may even sell the right to use the invention and make someone else the new owner of the patent. Still, a patent application discloses information about the invention and, thus, enhances the diffusion of the invention, with the price that the patent concentrates the right upon the invention for quite a long time period (van Pottelsberghe de la Potterie & Francois, 2009). Kumazawa and Gomis-Porqueras (2012) conclude therefore that an ideal patent system balances the returns to an invention in form of an exclusive right and the diffusion of new technology by means of adjusting strength, coverage and duration of the patent protection.

2.2 Harmonization of international patent systems

In general, an inventor who seeks to protect his invention in several countries has to apply at every national patent office. Consequently, costs and effort increase with the number of countries designated. Harhoff, Hoisl, Reichl, and van Pottelsberghe de la Potterie (2009) unsurprisingly find a decreasing propensity to patent with increasing costs. An international harmonization of patent systems has begun more than a century ago, but is far from being accomplished, yet. The Paris Convention of 1883 founded the first international intellectual property protection agreement, namely the International Union for the Protection of Industrial Property. Members of this union guaranteed not to discriminate against citizens of other member countries vis-à-vis to their own nationals regarding protection of industrial property.

Additionally, it established the right, that anyone who filed an invention for the first time, enjoyed priority status (a priority right) for patenting the same invention in another union member country (Kumazawa & Gomis-Porqueras, 2012). The practice of assigning the first application of a particular invention (the priority filing) the right to patent anywhere else is still a cornerstone of today's international patent laws. This way no one else is allowed to apply for a patent underlying the same invention, independently whether the holder of the priority filing exercises his right to patent in a country or not (Chan, 2010).

In 1977, the Convention on the Grant of European Patents (EPC) established the European Patent Office (EPO), the first entity where one single patent grant procedure is necessary for protection in some or all of the nowadays 38 member states. Once an application is approved by the EPO, it must still be validated, put in force and renewed in each designated country, because of their differing legislation and renewal fees (van Pottelsberghe de la Potterie & Francois, 2009).[1] The World Intellectual Property Organization (WIPO) made a further step towards harmonization by establishing the Patent Cooperation Treaty (PCT) in 1985[2]. The PCT allows nationals of member countries to file an international application at their domestic patent office and may designate up to 45 member states or regions (Kumazawa & Gomis-Porqueras, 2012). Still, the applicator must undergo the application process at every designated country's patent office. Nevertheless, this route has become the most popular among applicants with a global patenting strategy (OECD, 2009).

Following the PCT, the agreement on Trade Related aspects of Intellectual Property Rights (TRIPS) as part of the General Agreement of Tariffs and Trade (GATT) and binding for all member countries of the World Trade Organization (WTO) was put into place during the Uruguay Round in 1986-94. This treaty established conditions for national patent offices to guarantee certain protection of IPR by setting a minimum standard of the application procedure, minimum protection period of 20 years and protection for all technology fields (OECD, 2009). As its name indicates, the major objective of the TRIPS agreement consists in protecting principally innovative export products or processes from imitations in the destination countries. The agreement was mainly pushed by developed countries and their

[1] Despite the large coverage of the EPO, the patent applications it receives are often second filings referring to a priority filing from one of the national patent offices of an EPC member state. Moreover, some national patent filings are never redirected to the EPO (van Pottelsberghe de la Potterie & Francois, 2009).
[2] The PCT counts no less than 148 contracting states to date (see http://www.wipo.int/pct/en/).

innovative firms that were engaged in export to or foreign direct investment in developing countries and dissatisfied with the local IPR protection (Cardwell & Ghazalian, 2012).

2.3 Routes to international patents

An inventor who wishes to patent internationally files the initial patent application at a national or regional (e.g. the EPO) patent office. The invention described in the patent application can either be a product or a process, but must fulfill four main criteria in order to be approved: it must be industrially applicable, novel[3], an inventive step[4] and accepted as patentable under law[5] (van Pottelsberghe de la Potterie & Francois, 2009). This initial patent application is called the priority filing and is associates with a priority date. According to the OECD Patent Statistics Manual (2009), for second filings in other countries, the patentee has three options: *first*, he may apply directly at another national patent office within 12 month from the priority date, as the inventor enjoys priority status as long as he applies in another country that signed the Paris Convention from 1883. *Second*, the applicant can file a single international PCT application and assign a large number of countries with the advantage to extend the maximum time until entering the national stage of every designated country up to 30 months (instead of 12). *Third*, an initial (or second) filing at the EPO leads to easier subsequent applications in European countries. In all three strategies, the second application filings refer to the priority filing. This network of patents is called a patent family. The application is published 18 months after its initial filing, which leads to the disclosure of detailed information about the invention.

2.4 Differences across patent offices

Differences between national (and regional) patent offices are large, making the second stage complex for patentees who wish to apply in many countries. This is also true in case of the three most important patent offices, the EPO, the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO). The most idiosyncratic system is according to Kortum and Lerner (1999) the USPTO, due to its structure shaped by numerous historical judicial decisions. In addition, the US patent system consists of a complex legal process in

[3] The invention must be novel in a sense to exhibit new characteristics that are not known in its technical field.
[4] A person with average knowledge in this field would not be able to derive this product or process easily.
[5] Patents are granted in all technology fields, although in most countries laws of nature, natural phenomena and abstract ideas are not.

order to sort out precedence of rival inventors, while the European patent system grants a patent to whoever applies first (Kumazawa & Gomis-Porqueras, 2012). As a consequence, the EPO registers the date of filing and the USPTO the date of invention as the priority date.

Van Pottelsberghe de la Potterie and Francois (2009) argue that the EPO is probably the least attractive in terms of the complexity and the high costs associates with that. On the other hand, he finds that the JPO allows fewer claims per patent, such that more patents must be filed for the same invention, which raises costs. Every patent office maintains his own structure of application or validation fee as well as renewal fees, as illustrated by Harhoff et al. (2009) with EPC countries. Moreover, the enforcement of patent protection in case of violation of patent laws differs strongly in terms of procedure, costs and effectiveness (Maskus & Penubarti, 1995). In many cases translations are required, inducing further costs.

In sum, there is still a lot to be harmonized among national and regional patent offices. International patent applications are still challenging due to the high complexity of the patent systems as well the costs associates with them. Consequently, a firm or inventor needs to evaluate carefully where patent protection might be worthwhile, i.e. in which country the benefits exceed fixed and potential costs.

3 The microeconomic perspective

3.1 Incentives to patent

3.1.1 The traditional motivations

Behind the traditional and most evident motivation for patenting is the desire to protect one’s innovation from local or imported imitations (Eaton & Kortum, 1996). As expressed by Grupp and Schmoch (1999), a patent helps a firm to appropriate innovation rents because technology is a public good. In other words, a firm patents in order to maintain a competitive advantage for commercializing its product, which is clearly induced by the demand in the local market (Peeters & van Pottelsberghe de la Potterie, 2006). The same reasoning applies to motivations underlying international patenting. A firm patents abroad if it intends to export or manufacture the product outside the national market. There are constellations which are less obvious. For example, a US firm exporting to or producing an innovative product in Taiwan which is almost exclusively consumed by the local people wants to protect its innovation from imitations. It applies for a patent in Taiwan, and maybe in the US as well. However, not the local imitators in Taiwan represent the biggest threat, but firms in Taiwan's neighboring country China. Now even if those Chinese imitations have to be imported and cannot enter the Taiwanese market legally, the US firm might opt for patenting in China to prevent imitation at the source.

3.1.2 Reasons not to patent

One of the reasons to refrain from patenting is without doubt the direct costs resulting from filing a patent, such as application, validation and renewal fees. These costs are especially significant for international patenting strategies. Patenting is more complex with an increasing number of countries designated, since fee structures differ strongly across patent offices which raises costs for legal advice, support and translation. In addition, potential defense costs need to be considered in the case a rival infringes the patent law. The negative impact of costs on patenting is empirically well proven. Cohen, Nelson, Richard, and Walsh (2000) find with data from a survey about R&D managers of US firms in 1994, that application and defense costs represent a main factor that prevents innovative firms from patenting. Harhoff et al. (2009) report negative influences of validation and renewal fees, as well as translation costs on the numbers of patents filed at European patent offices.

Studies with micro level data reveal the existence of factors other than costs or fees influencing patenting decisions the most. Peeters and van Pottelsberghe de la Potterie (2006) analyzed a survey about CEO's of Belgium's largest firms in 2001 and find that the most important perceived barriers to patenting are the inability to prevent imitations despite having a patent due to the lack of confidence in the patent system and its effectiveness. According to the study of Cohen et al. (2000), R&D managers do most often decide against patenting due to the difficulty to demonstrate the novelty of an invention and the risk that rivals might invent easily around their patent. Not surprisingly, both studies find that the risk of disclosing information about the invention plays a decisive role, too.

A handful of other reasons can be named. The lifecycle of a product may be too short in comparison to the long application procedure preceding a patent grant decision, or (international) patenting processes may simply be too complex (Cohen et al., 2000). Another important reason according to Peeters and van Pottelsberghe de la Potterie (2006) is the higher effectiveness of alternative mechanisms, as described in the following chapter.

3.1.3 Alternative mechanisms

As a matter of fact, firms regularly report in surveys that patenting is a relatively ineffective mechanism to appropriate innovation returns (Arundel, 2001; Cohen et al., 2000; Peeters & van Pottelsberghe de la Potterie, 2006). Popular alternative mechanisms to protect returns from inventions are lead time advantages and secrecy. Arundel (2001) analyzed a survey about European R&D-performing firms in 1993 and demonstrated that these two mechanisms are actually perceived to be more effective than patents. Cohen et al. (2000) report similar results. Secrecy and patents are considered to be mutually exclusive appropriation mechanisms, as patents necessarily disclose information about the invention. Interesting in this regard is that the perceived effectiveness of these two methods depends on whether the firm's innovation is a product or a process. Both studies find that firms consider patents to be more effective for product than process innovations, since imitations in processes are more difficult to detect. Further appropriation methods considered to be more effective than patents are complexity of product designs and complementary capabilities like sales, services or manufacturing (Arundel, 2001; Cohen et al., 2000).

Cohen et al. (2000) show that there exist large differences across industries. They identify some industries which outperform others in terms of effectiveness of patents, namely medical equipment and drugs as well as special purpose machinery, computers and auto parts. Nonetheless, patents do not seem to represent the most effective appropriability mechanism in any industry. However, they find also that no industry relies on one single mechanism, but often a bundle of mechanisms are jointly employed. As Arundel (2001) illustrates, this can even include both patents and secrecy in a dynamic implementation, where during the premarket development phase information about the invention is maintained secret and becomes disclosed in a later stage via a patent application, which gives the firm a lead time advantage over competitors.

3.1.4 The strategic motivations

Despite the high barriers to patent and the existence of more effective mechanisms, we observe a surge in (international) patent filings. Arundel (2001) mentions several possible explanations for this recent patenting behavior. A global improvement of IPR protection and enforcement possibilities could be a reason; or a shift from competition in prices towards competition in technical innovations. Another cause might be the rise of new technologies such as biotechnology or information technology where a large number of small firms are active.

These may all be reasonable explanations, although they have not changed the effectiveness of patents itself. The changing patenting behavior may rather be the result of a shift in the motivation to patent from traditional protection to more strategic reasons. Caviggioli (2011), Cohen et al. (2000), and Peeters and van Pottelsberghe de la Potterie (2006) list many such patent strategies that are unrelated to appropriating innovation rents and which mostly serve to obtain a competitive advantage. Blocking rivals by patenting where rivals sell or produce reduces their space and can even deter market entrance of new rivals. Some firms build so called patent fences in order to impede an entrance into the market[6]. Following the same reasoning, a firm may also patent where they sell or produce in order to avoid to be blocked or to prevent infringement lawsuits by rivals. Moreover, patents can also be used to issue licenses, which generate revenues, or patents may be traded or used in negotiations with partners or rivals.

The relative importance of these strategies is less evident. Caviggioli (2011) argues that blocking rivals and forcing them into negotiation has become the central motivation to patent, while Cohen et al. (2000) find the traditional motivations are still dominating patent decisions followed by blocking, preventing lawsuits and the use for negotiations. His results do not differ for product and process innovations. Still, strategic reasons to patent have gained importance in patenting decisions as confirmed unanimously by the literature revised in this section.

3.2 Which firms file patent applications and for what invention?

In terms of firm characteristics, there are traditional determinants derived from the Schumpeterian hypotheses which state, that large firms, firms with strong market power and firms with market and technological opportunities are more innovative and thus patent more, since we assume that patents are the output of an innovation production function (Peeters & van Pottelsberghe de la Potterie, 2006). In theory, the size of a firm raises R&D output (such as patents) more than proportionally due to economies of scale and scope as well as

[6] Cohen et al. (2000) underline the fact that firms do not build such patent fences because patents prevent effectively copying but because they do not. This is related to the problem that rivals can often "invent around a patent" earlier mentioned in chapter 3.1.2.

complementarities and spillovers between different departments. Additionally, large firms are often favored by capital markets for risky innovation projects. The empirical analysis of Peeters and van Pottelsberghe de la Potterie (2006) do not support this theory because it rather suggests that the size of a firm is unrelated to the probability of a firm having a patent portfolio. Arundel (2001), in turn, finds that large firms assign a higher value to patents relative to secrecy for appropriation purposes compared to smaller firms. Using the Mannheim innovation panel[7] about German firms, Licht and Zoz (1998) provide clear evidence in favor of large firms patenting proportionally more, a trend which is even more accentuated in the case of international patent applications.

The impact of market power on patenting is theoretically ambiguous since two effects oppose each other. According to the replacement effect, firms with strong market power innovate less, as their gains from innovation can only replace current gains. The efficiency effect states that those firms innovate more as they fight less their competition for the gains from innovation. Again, Peeters and van Pottelsberghe de la Potterie (2006) cannot identify a direct influence of market concentration on patenting behavior indicating that none of these effects dominates sufficiently.

Peeters and van Pottelsberghe de la Potterie (2006) observe that innovation strategies are better determinants for the probability a firm holds a patent than the traditional Schumpeterian hypotheses. As pointed out already, they suspect firms engaging in product compared to process innovations tend to patent more. This result is confirmed by Arundel (2001). Moreover, an innovation may be a complement or a substitute to existing products. Cohen et al. (2000) argue that firms innovating for substitutes patent more often, as this allows blocking rival products. Unsurprisingly, their empirical analysis reveals that firms collaborating with rivals or research institutions with respect to innovations patent more often, since information about inventions is more likely to be known by their rivals.

Differences in industries and in the nature of their products represent another aspect that affects patenting behavior through firm characteristics. Cohen et al. (2000) distinguish between complex and simple products. Complex products, such as electronics, consist of

[7] The Mannheim Innovation Panel is an annual German innovation survey conducted by the Centre for European Economic Research (ZWE). Among other tasks, it collects valuable data about innovative activities by German firms. Visit http://www.zew.de/en/ for more details.

many patentable parts. It is therefore essential to hold a patent portfolio that enables to control as many elements of the product as possible. This way, a firm prevents to be blocked and can use the patent portfolio in cross-licensing negotiations. Thus, firms involved in complex products industries tend to patent more and hold larger patent portfolios. Comparing broad sectors, firms engaged in manufacturing industries use more secrecy and patent less for protecting their innovation rents (Arundel, 2001).

The effect of exporting firms and firms with foreign ownership is of particular interest here. The former effect is expected to influence patenting behavior positively, as an exporting firm faces more competition. In this regard, Han and Lee (2007) suspect foreign patenting to be a survival strategy for exporting firms. Licht and Zoz (1998) demonstrate that exporting firms and firms with a high export share do not only patent more often abroad but also at home. This effect is even larger if the firm engages intensively in innovation. In the case of foreign patenting, Han and Lee (2007) observe that both export orientation and foreign ownership have a positive effect on Korean firms to patent in the US. They argue that foreign firms or firms with foreign affiliates patent more, because they have greater opportunities for international networking in technological development. Peeters and van Pottelsberghe de la Potterie (2006), in contrast, fail to detect any influence of foreign ownership or "internationalization of firms" on their patenting behavior.

3.3 The probability of a firm to patent abroad

Chan (2010) derived an econometric model which identifies determinants for the probability to patent internationally among firms active in the agricultural biotechnology sector. The model is solved by backward induction. In the first stage, the probability of receiving a grant on the patent application is estimated. The second stage estimates the probability of filing an application given the likelihood of grant and considering that a firm patents abroad only if expected profits exceed patenting costs. We focus on factors that explain these two stages as they reveal the author's hypothesis on the system determining the decision to patent abroad.

Four kinds of determinants are integrated to the model: patent laws, revenues from patenting, patent costs and country fixed effects. Variables about patent laws describe the level of patent protection and possible law changes. In the context of patent harmonization it is often argued, that firms are sensible to IPR protection in their decision to patent abroad (Huang & Jacob, 2013; Xu & Chiang, 2005). Patent costs refer to the filing and renewal costs in as well as PCT membership of the destination country. Obviously, costs decrease the patenting probability, as they reduce total profits from a patented invention. Revenues from patenting are, among others, explained by the value and the global share of total imports and exports of the destination country in the biotechnology sector. Chan (2010) argues that a country's exports underline the location's importance as a production site in this sector, while its imports are a proxy for demand. Both aspects are expected to favor patent inflows. Revenues depend also on the type of the invention, in this particular case on crop variety. Country fixed effects account for unobserved factors, such as differences in enforcement costs. Most of these variables describe the destination country with the exception of crop describing the invention type.

Chan (2010) estimates his model with data of patent families with an initial filing in the US and possible subsequent filings in seven destination countries or regions. Only nine biotechnology firms are considered. It turns out, that country fixed effects capture a large part of the variation in patenting. In other words, unobserved factors concerning the destination country seem to be of major importance. Exports and imports of the recipient country have both a positive and significant influence on patent inflows. The type of the invention has also a significant impact as well as filing costs, while patent laws seem to influence firms barely in their patenting decision.

This model gives an idea of variables which might play a role in the decision of a single firm to patent abroad. However, this model has three important limitations. *First*, agricultural biotechnology is a highly specific industry, whose firms exhibit very similar characteristics in size, research and development, etc. A more general setting need to control for firm characteristics as they play an important role in the decision to patent abroad, as showed in chapter 3.2. *Second*, only nine of the largest firms entered the analysis. As they are all multinational enterprises, Chan (2010) had no need to include variables referring to the relationship between source and recipient country. And *third*, the model considers only inventions for which an initial application in the US has already been filed. This is a strong selection criterion as it includes only the most valuable inventions. Although Chan (2010) controls for the invention type, the decision to patent also depends on quality and other characteristics regarding the invention. Consequently, a firm's decision to patent abroad is a function of all those aspects, as expressed in the following equation:

$$Pr(Patent_{ijmt}) = f(\boldsymbol{q}_{mi}, \boldsymbol{X}_{mi}, \boldsymbol{B}_j, \boldsymbol{C}_{ij}). \quad (1)$$

In other words, the probability of a firm m of country i to patent its invention q in country j at time t is a function of destination country j's attributes, denoted by the matrix $\boldsymbol{B}_j$, and variables concerning the relationship between source country i and destination country j, denoted by matrix $\boldsymbol{C}_{ij}$. Relevant firm characteristics enter the function via matrix $\boldsymbol{X}_{mi}$ and attributes regarding the invention via vector $\boldsymbol{q}_{mi}$.

4 Determinants of international patent flows

4.1 A theoretical model

On the aggregate level, theoretical models explaining international patent flows with macroeconomic and other country specific attributes are still scarce. Eaton and Kortum (1996) provide an exemption. They set up a model of innovation and technology diffusion to explain relative productivity and growth. Relative growth is determined by domestic innovative output, measured by domestic patent applications, and the ability to adopt innovations from abroad, which is quantified by means of international patenting. I refrain from outlining the model in detail, since the ultimate objective of their set-up is to explain growth differences and not patent flows. However, international patenting is an endogenous variable in this model, and the selection of its determinants is therefore relevant to the present problem. They model the number of patent flows as a function of the source country i's research effort, destination country j's variables such as market size, IPR protection and costs for patenting, as well as the likelihood that an invention of i is adopted into the available technologies in j. The latter expression, a probability measure quantifying the rate of technology diffusion, is in turn a function of the level of human capital in j as well as variables describing the relationship between two countries such as geographical distance and imports of j from i.

Another theoretical framework was set up by Park (2013). The following is a simplified illustration of his model. It has similar properties to the model of Eaton and Kortum (1996), with a few exemptions that will be highlighted in the course of this task. His model explains variations in international patent filing from three kinds of heterogeneity: source country, destination country and the value of an invention. To begin with the inventor's decision, we observe a patent application if the following is true:

$$\Delta V = V^{PAT} - V^{NOPAT} \geq c, \tag{2}$$

in other words, the net benefit ΔV of having a patent is the difference between the value of a firm with (V^{PAT}) and without (V^{NOPAT}) a patent. This must exceed the costs of patenting c. By using the net benefit of patenting for the firm instead of the absolute value of a patent from its commercialization, the model allows for the existence of alternative mechanisms to protect innovation rents (see section 3.1.3). This is a new feature compared to the set-up of Eaton and Kortum. Variation in the values of inventions is also a new property and introduced the following way: Assume a country i has Q_i patentable inventions which it ranks in an ascending order according to their quality, i.e. $q_i = 1,2, \dots, Q_i$.

In one period, the profit from invention q_i marketed in country $j \neq i$[8] reads $\pi_j(q_i)$, hence it depends on its quality and the destination market. The profit function is linear and thus can be written as $\pi_j(q_i) = q_i\bar{\pi}_j$, where $\bar{\pi}_j$ represents the market size of the destination country j. Firms risk profit reductions due to imitations in market j. Park models them in the fashion of a tax on profits. Imitations appropriate invention rents at rate $h \in [0,1]$, which in turn depend on the level of IPR protection θ_j in country j. Left as net profit is therefore:

$$\pi'_j(q_i) = q_i\bar{\pi}_j\left(1 - h(\theta_j)\right). \tag{3}$$

In order to obtain the value of a firm with a patent (V^{PAT}) in equation 2, all future profits need to be discounted and summed up:

$$V_j(q_i) = \int_0^\infty e^{-rt}\,\pi'_j(q_i)dt = q_i\bar{\pi}_j\left(1 - h(\theta_j)\right)/r, \tag{4}$$

where the real interest rate is denoted by r. In the case the firm does not patent, the rate of appropriation is independent of the level of IPR protection θ_j and thus becomes a destination country specific constant $\bar{h}_j$ (instead of $h(\theta_j)$). Consequently, the discounted present value of the net benefit from patenting is:

$$\Delta V_j(q_i) = V_j(q_i)^{PAT} - V_j(q_i)^{NOPAT} = q_i\bar{\pi}_j\left(\bar{h}_j - h(\theta_j)\right)/r. \tag{5}$$

[8] The model presented here is limited to international patent flows. In the original set-up of Park (2013) the source and destination country are allowed to be the same and thus it includes also domestic patent filings.

The link to the absolute number of patent flows between two countries is done by calculating the threshold quality value q_{ij}^* of the invention for which patenting is just not profitable in market j, i.e. $\Delta V_j(q_{ij}^*) - c_j = 0$. Solving this equation for q_{ij}^* yields

$$q_{ij}^* = r \cdot c_j / \left[\bar{\pi}_j \left(\bar{h}_j - h(\theta_j)\right)\right]. \tag{6}$$

Inventions with a higher quality will be patented in country j, in contrast to those with lower quality. A closer look at equation 6 reveals that the threshold level is entirely determined by destination country characteristics, or $q_{ij}^* = q_{ij}^*(x_j)$. The number of patent flows from country j to country n can now be calculated:

$$P_{ij} = Q_i - q_{ij}^*(x_j) = Q_i - r \cdot c_j / \left[\bar{\pi}_j \left(\bar{h}_j - h(\theta_j)\right)\right]. \tag{7}$$

With this equation we can identify a number of factors that influence international patenting decisions. The expression Q_i refers to the quantity and/or quality of the inventions in the source country, which Park calls inventiveness or inventive capacity. Following Eaton and Kortum, he includes a variable for inventiveness to equation 7, specifically the ratio of scientific workers and engineers to the total work force. In order to control for differences in the quality and quantity of inventions of the source countries, he modifies this ratio to $\tau_i = \tau S_i^{\gamma} L_i^{1-\gamma}$ instead, where S is the number of scientists and engineers, L total labor, and τ and γ are parameters. However, the inventive capacity does not only affect the quantity of patentable inventions, but also the threshold level for patenting:

$$P_{ij} = Q_i(\tau_i) - q_{ij}^*(x_j, \tau_i). \tag{8}$$

Clearly, inventive capacity of the source country increases the number of inventions and lowers the threshold level by increasing the overall invention quality. As these forces are bilateral, inventiveness favors patent flows. Based on equation 7, one can draw similar conclusions for destination country characteristics: costs of patenting c_j decreases international patenting, while the market size $\bar{\pi}_j$, the level of IPR protection θ_j and the constant appropriation rate $\bar{h}_j$ have a positive impact on the number of international patents. Park interprets the latter expression as the imitative capacity of the destination country. Clearly, firms tend to pattern more often if the imitative threat to unprotected innovations is high.

In sum, Park presents a simple model that conditions patent flows between two markets on source and destination country attributes. Eaton and Kortum additionally included variables concerning the relationship between the source and the destination country. In compliance with the notation in equation 1, these theoretical models suggest that the total number of patent flows is a function of origin country *i*'s characteristics, denoted by matrix $\boldsymbol{A}_i$, destination country *j*'s attributes ($\boldsymbol{B}_j$) and the relation between the two involved countries ($\boldsymbol{C}_{ij}$):

$$Patent\_flows_{ijt} = F(\boldsymbol{A}_i, \boldsymbol{B}_j, \boldsymbol{C}_{ij}). \tag{9}$$

The models imply effects of these variables on patent flows which coincide with our expectations. The next step is now to verify whether data confirms the direction of these effects.

4.2 Empirical evidence[9]

As data has become available, a number of studies have empirically tested a wide range of variables including variables referring to the three main aspects described by Park (2013) in order to explain international patent flows. However, the existence of limited theoretical models motivated numerous researchers to fall back on a popular model within the trade literature. It is the gravity model of trade that explains most successfully current and especially past patterns in trade of goods. It turns out that patterns of patent flows resemble the ones of trade flows. According to Nepelski and De Prado (2012), the gravity model is therefore a theoretical concept which is suitable for an empirical analysis of international patent flows.[10]

The pioneers in applying the gravity equation on international patent data were Sláma (1981) and Bosworth (1984). Many studies followed with modified versions in form of mainly simple log-linear or linear equations using better data and more sophisticated statistical tools. Besides, the models of Eaton and Kortum (1996) and Park (2013) have also been estimated. Despite differences among these studies regarding the datasets at hand, the applied empirical

[9] See appendix 1 for further details regarding the empirical studies presented here, such as the used dataset, dependent and explanatory variables, or the research question.

[10] The gravity equation also serves in other patent related contexts as a model to explain relationships between two countries. For example, Picci (2010) uses the gravity equation to test determinants for international collaboration with data on international patenting.

strategy or the context of research, five main aspects are commonly considered crucial in determining patent flows and thus will be addressed in this chapter: (1) Gravity forces, such as market size and distance, (2) trade, (3) patenting costs and fees, (4) intellectual property rights, as well as (5) R&D and human capital.

4.2.1 Gravity forces

4.2.1.1 Market size and wealth

The principal gravity forces employed in the classical gravity equation of trade, and of international patenting, refer to market size and distance. Market size is most often approximated by GDP. A market with a high GDP does not only imply a high output level but generally also strong demand in both input and consumption goods. Consequently, such markets are more attractive for exports or foreign direct investments (FDI). We learned earlier that the traditional motivation for patenting is protection of innovation rents through commercialization. Hence, large markets increase the incentive for protection in case the firm intents to commercialize innovative products. This is called the demand pull effect (Yang & Kuo, 2008). Besides, Bosworth (1984) argues that a small economy may even lie below a certain threshold level with respect to its size, such that patenting costs exceed expected gains in a minor market. In the case of process and industrial goods innovations, small countries may additionally receive fewer patents as their economies are often more specialized and thus can accommodate fewer innovations (Bosworth, 1984; Yang & Kuo, 2008). This is independent of whether the motivation to patent is of traditional or strategic nature. The direct implication that countries with a high GDP receive on average a larger number of international patent applications, has been confirmed unanimously by the empirical literature (Bosworth, 1984; Sláma, 1981; De Prado & Nepelski, 2012; Lybbert & Zolas, 2012; Park, 2013). Yang and Kuo (2008) even tested the effect of the ratio between the destination to the source country's GDP on international patenting and found a significantly positive relationship. However, their explanation is no different from those above, i.e. larger destination markets increase attractiveness for international patenting.

Nepelski and De Prado (2012) as well as Lybbert and Zolas (2012) find the same effect for the market size of the source country. In a large market more firms exist and innovate, which leads to more patenting independently of the destination country (Sláma, 1981). Only a few studies have included this variable, while others tried to account directly for the national level of innovative effort by incorporating R&D input. We return to this later.

GDP per capita was also repeatedly considered as a determinant for patent flows. GDP per capita may be viewed as an indicator for individual demand and supply of innovations, respectively. For the recipient country, Harhoff (2009) states that it is a proxy for wealth which in turn determines individual demand for innovative products. According to Park (2013), patenting fees are generally higher in high income countries, however, patent agents are scarce in developing countries, which makes low income countries relatively expensive after all. High labor costs in developed nations may act as a counter force for firms who wish to market their products via FDI (Bosworth, 1984). For the origin country, GDP per capita is a proxy for the economic development and, hence, measures the capacity to invest in research (Caviggioli, 2011; Harhoff et al., 2009). A plausible explanation may also be that rich consumers in the home market spur innovative activity. In the case of both the source and the destination country, all studies mentioned identify a positive impact of GDP per capita on patent flows. As GDP per capita is highly correlated with human capital and research effort, some analyses account directly for these variables of inventive capacity instead. The model of Eaton and Kortum (1996) includes relative productivity measured by source country GDP per capita to destination country GDP per capita. They find a positive influence on patents per source country labor, but do not give a theoretical explanation for this outcome. Again, one could argue that the result for the ratio is driven by the potential of only one country instead of the relative potential.

Alternatively to GDP, the population size has been used to account for the market size. Both Harhoff et al. (2009) and Caviggioli (2011) find a positive influence of the population size on patent flows when controlling for GDP per capita. This is in line with the results obtained when GDP is used to approximate the market size. The advantage of the population size for measuring the market size is that this variable can be considered as exogenous which does not necessarily have to be true for GDP.

Overall considering market size and wealth, push forces (origin country potentials) seem to be more important than pull forces (destination country potentials) in explaining international patent flows (Harhoff et al., 2009). This indicates that the supply of research and the production of innovations influences patent flows more heavily than the demand for innovations at the destination country.

4.2.1.2 Distance

A second important gravity force is the distance between two countries. First referring to a geographical dimension only, now other forms of distance have been considered, such as language barriers, technological distance or whether the involved countries have a colonial history. In the trade literature, distance found its way into the gravity equation in order to account for all kinds of trade barriers. As it turns out, these barriers also exist with patent flows, even if less pronounced and in some cases for distinct reasons.

The geographical aspect is still the most important. Lybbert and Zolas (2012) use geographical distance between two countries' capitals, in order to control for transaction costs in doing business abroad. For exporters, it is mostly transportation costs that occur, which increase with geographical distance. Sláma (1981) emphasizes that not only costs play a role but also the cultural distance which may on average grow with geographical distance. Harhoff (2009), Nepelski and De Prado (2012), Sláma (1981), as well as Yang and Kuo (2008) confirm a negative relationship between the geographical distance and patent flows. The effect is less pronounced than with flows of physical goods. Eaton and Kortum (1996), Eaton, Kortum and Lerner , Lybbert and Zolas (2012), as well as Sun (2003) find only a weakly negative or even no effect. Lybbert and Zolas (2012) control for the existence of a common border, but do not find a significant or at least a consistent influence on patenting.

Language barriers occur not only in form of translation costs, but are also an indication for cultural differences that could complicate the patenting process in a first and doing business in a second step (Nepelski & De Prado, 2012). Empirically, the effect of a common language on patent flows is clearly positive, even when controlled for geographical distance. The results of Nepelski and De Prado (2012) confirm this on the aggregate level. In contrast, Lybbert and Zolas (2012) find only a significantly positive effect if patent flows are broken down to the industry level. Besides, they also include a dummy variable for country pairs with colonial ties. Surprisingly, their results are contrary to expectations and clearly negative on the disaggregated level.

Distance can also refer to industry specific differences with respect to patent applications of the two involved countries. Caviggioli (2011) calculated this technological distance by considering the share of each country's patent applications in the main IPC classes[11]. Each country is placed on an 8 dimensional technological space according to its technological specialization. The Euclidean distance between the technological coordinates of two countries, measures how far apart their specialization points are situated from each other. It is assumed that countries with similar specialization in innovation patent more at each other's patent offices. In fact, Caviggioli (2011) finds a negative impact of technological distance on patent applications, but the effect is only significant when the regression does not control for variables measuring market size and wealth. The results may be more conclusive if the destination country would be replaced by a smaller more specialized country, since Japan has a large and diversified industry and thus its specialization point is probably closest to those of other large economies.

With increasing globalization, both geographical as well as cultural distance may lose importance in the future, whereas increased technological specialization is likely to lead to more accentuated international patenting between countries innovating in similar industries. However, on a global scale it remains to be established whether technological distance has after all an effect on patenting.

4.2.2 Trade-related drivers to international patents

The traditional motivations for patenting predict that a deep economic involvement of two countries boosts patent flows between them. Economic involvement refers to the extent to which production and markets of two countries are linked together, and can be measured by the level of exports or FDI (Caviggioli, 2011). As early emphasized by Bosworth (1984), the causality between patents and trade is not unambiguous. Patent flows may not only be explained by trade, but trade may also be a function of patents. Chang (2013) highlights that traditional economic theory focused mainly on the question whether innovation influences exports. Eto and Lee (1993) argue that trade patterns depend indeed on technological advantages which may be measured by patenting. However, when considering the factor of strategy trade patterns also constrain industrial strategies which in turn determine patenting

[11] The main IPC classes refer to the first digit in the IPC number of the Intellectual Property Classification (see http://web2.wipo.int/ipcpub/).

strategies. Despite the possibility of reversed causation, studies generally assume that the causality is unidirectional from trade to patents. Under this assumption, there is still the issue of a possible time lag regarding the effect of trade on patenting. Chang (2013) suspects exports to facilitate the acquisition of knowledge which in turn can lead to increased innovation and thus patenting. Consequently, exports may serve as a channel for international knowledge spillovers.[12] Such a learning process is not likely to happen without delay. In fact, Girma, Gorg, and Hanley (2008) analyzed manufacturers in Ireland and the UK with regard to the effect of exports on innovation. In the former case, they actually found an effect of Irish exports on their innovation with a time lag of one period, while no relationship whatsoever has been found in the case of the UK. Possibly due to limited evidence about the existence of such a time lag, the literature analyzing the effect of trade on patenting refrained so far from including a delay. An exemption is provided by Chang et al. (2013), although with alternative trade variables. We return to this in chapter 4.2.5.

4.2.2.1 Bilateral trade and patent flows

There are a variety of trade variables that have been found to influence patent flows, although for different reasons. The most important one is without doubt trade, i.e. export values of the patent applicant country to the patent issuing country, because firms have a higher incentive to apply for patents in foreign markets where they earn or have potential to earn considerable revenues with exports. In most studies, its effect is positive and significant, which is in line with the traditional motivations to protect exports from imitations. Hence, the degree to which a country exports to a foreign market has a positive influence on the attractiveness for patenting in that market. However, the gravity forces do also account for the attractiveness of a particular market. They predict that larger markets and lower trade barriers lead to a higher propensity to patent, because they increase effective and potential revenues from trade and FDI for the source country. In a gravity equation, the market size and the wealth have therefore an influence on the interpretation of the effect of trade on patent flows.

[12] Coe and Helpman (1995) find such a learning effect also for imports, arguing that foreign R&D expenditures spur domestic innovation via importation of innovative products.

Nevertheless, Bosworth (1984), Caviggioli (2011), Lybbert and Zolas (2012), Sun (2003), Xu and Chiang (2005), and Yang and Kuo (2008) included both trade and gravity forces to their equation. Despite the use of different datasets, they all concluded that trade has a positive impact on patent flows while the coefficients for the gravity forces are significant and manifest expected signs. The magnitude of the effect of trade on patenting is difficult to compare, as the empirical models differ between the studies. However, one observes that the coefficients for trade are in most cases significant on a high level (above the one percent confidence level). Interestingly, Xu and Chiang (2005) find a stronger effect for low and middle income recipient countries than for high income recipient countries. The fact that they observe a high correlation between foreign patents and GDP within the low and middle income sample but not with the high income sample might explain in part the different results with regard to patenting for samples of countries in distinct development stages. However, the reason is yet unanswered in the literature.

The studies focusing on one country for in or outflow of patents report mixed results. On the one hand, Caviggioli (2011) who used data on Japan as the destination country obtains only significant results for trade when excluding gravity forces. He justifies this result with the fact, that Japanese consumers have a particularly strong preference for domestic products, wherefore trade and FDI attain relatively low levels. As a consequence, foreign patenting in Japan may especially be driven by strategic motivations. On the other hand, foreign patent applications in China were analyzed by Hu (2010), who finds a negative influence of imports to China on patenting. Last but not least, Bosworth (1984) reports a negative effect of trade on the inflow of patents to the UK, although on an insignificant level.

In consequence of these contradicting results, I propose to give more weight to studies working with global datasets, such as Lybbert and Zolas (2012). Their results seem to be more consistent, especially when patent flows are broken down to the 4-digit SITC product level. It turns out that the effect of trade on patenting is slightly weaker on the disaggregated level, but more significant. Within industries, Eto and Lee (1993) observe that patenting is stronger influenced by trade with industrial products than by trade with technology. However, we should consider these results with caution, because they are based on simple correlations.

4.2.2.2 Foreign direct investments

Foreign direct investments can serve as an alternative to exports in order to market products abroad. Therefore, we expect the effect of FDI on patent flows to be similar as in the case of trade. Yang and Kuo (2008), for instance, included both trade and FDI to their equation and found indeed a positive and highly significant impact of FDI on patent flows. The magnitude is considerably larger compared to the one detected for trade. Bosworth (1984) considered the impact of activities by multinational firms in the country where patent is applied for on patenting. As FDI is often undertaken by such multinational firms, this variable measures a similar effect. In fact, his results confirm the important role of FDI in explaining foreign patenting. The coefficients obtained by Caviggioli (2011) are less convincing, as they are insignificant in all models. Once again, this might be the consequence of particularly low levels of FDI and trade in the Japanese market.

The effect of FDI when trade is excluded from the equation has also been found to be positive and highly significant in the analysis conducted by Chang, Chen, and McAleer (2013). However, Nepelski and De Prado (2012), who did not include trade variables either, report strongly contradicting results, i.e. a consistently negative and significant influence of FDI on foreign patenting. Unfortunately, the authors do not name any possible reasons for the sign of these coefficients and why it is contrary to expectations. After all, FDI may not only be an alternative to exports, but maybe reflect also other motivations that hinder foreign patenting or are just unrelated to them. Indeed, Caviggioli (2011) presumes that it is not clear whether exports and FDI are substitutes or complements. This makes it problematic to include both FDI and trade in an empirical regression. Additionally, trade and FDI are often highly correlated, which leads to multicollinearity and thus to inaccurate estimates. For example, Sun (2003) dropped FDI from its regressions in order to avoid this issue. In the case FDI is not included to the regression we do not know whether its effect on patent flows is captured by trade variables, gravity forces or third variables, because the effect of FDI is not fully established, yet.

4.2.2.3 Alternative measures of trade

A number of alternative variables for measuring trade that have been used for explaining patent flows are worth to be mentioned. In general, these variables account for country specific characteristics, since they do not measure trade between two countries, but instead trade-related values of either the source or the destination country.

The widely used variable in this regard is the total value of imports of the country receiving the patent applications. There are several reasons that can justify the inclusion of imports. Huang and Jacob (2013) use total imports as a determinant for patent flows while considering only the manufacturing industry. The effect of manufacturing imports on patent flows is insignificant. However, recall the empirical model of Chan (2010) which included imports as a proxy for the demand of foreign products and exports of the recipient country to measure the destination country's importance as a production site. Both have been found to influence patent flows positively. Alternatively, they included global import and export shares to the equation, although with inconsistent outcomes. Given this results, the attractiveness of a market may be better measured by the classical gravity forces than import or export values.

Another way of using trade variables is illustrated by Chang et al. (2013) who analyzed determinants for domestic innovation measured by the national number of triadic patents, i.e. the number of inventions a country patented at the offices in Europe, the US and Japan. As the destination countries are fixed, trade variables are limited to the source country. Among others they included the ratio of total exports as well as FDI to GDP, but ignored any gravity forces instead. The export and FDI ratios measure the openness to trade of a certain country, but do not account for the source country potential regarding its economic or innovative power. As it turns out, exports and FDI are important determinants for triadic patents. Interestingly, their explanatory power is best when they are lagged by one period. This might be an indication that the effect in the direction from trade to patenting is actually stronger than the other way around.

An interesting and so far unique approach has been applied by Hu (2010) with the analysis of determinants for patent inflows to China. Additional to including trade into the equation, he controls for competing imports to China in the respective industry. Recall that he obtains negative coefficients for trade. Hu (2010) finds a plausible explanation for this phenomenon. Once competing imports are controlled for, trade may actually have a negative impact on patenting within industries, because a country that exports more to China may enjoy stronger market power in that industry, which represents an alternative instrument to appropriate returns from exports and thus lowers the necessity to patent in China. However, the negative coefficients for trade are only in a subset of models significant. But competing imports are positive and significant in all models. This raises the question whether competing imports is a justified determinant for patenting or if it mainly measures market attractiveness leading to the disappearance of its impact once the model controls for gravity forces. Moreover, this phenomenon may also be a particularity of China's economy and not applicable to the rest of the world.

4.2.3 Patenting costs and fees

As suggested by Chan (2010) and Park (2013), costs are an important factor in the decision of a firm whether to patent abroad, because high costs may motivate a firm to use alternative mechanisms to protect their returns from innovations. In fact, Park (2013) tests patent filing costs and finds that patent flows are cost elastic on a significant level. This finding is confirmed by Eaton et al. , whose analysis concludes that patenting fee reductions account for 40 percent of the 70 percent increase in patent filings at the EPO between 1990 and 2000. The old continent is particularly affected by patenting costs, since the market is highly fragmented with regard to the jurisdiction of the many patent offices, despite the reforms undertaken by the EPO. For this reason, Harhoff et al. (2009) controlled separately for validation, renewal and translation costs within Europe. All three factors appear to influence patent flows negatively, with validation costs having the strongest and renewal costs the weakest impact, while the usual gravity forces are still the dominant determinant. Their estimates indicate that the cost elasticity has increased over time, arguing that firms have a relatively inelastic budget for patent filings and that patent strategies target an increasing number of patent offices. Patenting costs gain consequently more importance for a firm's patenting decision.

4.2.4 Intellectual Property Rights

Strong protection of intellectual property is expected to increase the number of patents a country receives. The effect of foreign intellectual property rights (FIPR) on foreign patenting is empirically well documented. Examples are Eaton and Kortum (1996), Huang and Jacob (2013), Park (2013), and Xu and Chiang (2005) who all report positive and highly significant coefficients. The reason is evident: In countries where an infringement of a patent is prosecuted more severely, firms rely more heavily on patents vis-à-vis to alternative mechanisms to protect their returns from innovations. This reasoning also applies to strategic motivations for patenting such as forcing rivals into negotiations, since those strategies are only as effective as the enforcement power of the patent system. However, Yang and Kuo (2008) find only a positive effect of FIPR on patenting when FIPR is in an interaction term with a dummy for strong imitative abilities of the destination country. This implies that the effectiveness of patent protection is only relevant for the patenting decision of a firm if the applicant faces threat of imitation, which reflects appropriating innovation rents as the driving force behind patenting.

The strength of IPR in the source country has a positive impact on patent flows, too. Furman, Porter, and Stern (2002) observed that domestic IPR influence the propensity to patent internationally, as stronger protection for intellectual properties promote patenting of innovations and innovation itself. Caviggioli (2011) and Yang and Kuo (2008) obtain indeed positive and significant coefficients for the effect of IPR on outbound patenting activity.

The strength of IPR is clearly correlated with the development stage of a country, since rich countries host most of the innovating firms they wish to protect, while poor countries have often not the appropriate institutions to assure such protection or intentionally weaken protection for foreign patents in order to spur the emergence of own industries via a learning process with developing imitations. Consequently, when including IPR, FIPR or both of them together to the gravity equation, it is essential to control for the gravity forces of the respective countries, specifically for wealth.

4.2.5 R&D and human capital

Human capital and the effort of research and development influence patent flows through the innovativeness of the source country, and through the imitative and absorptive capability of new technology in the destination country. On the one hand, a country's ability to patent abroad depends on the expenses firms spend for research and development but also on the number and quality of its pool of researchers. In this sense, R&D and human capital can be considered as inputs for an innovation production function with national and international patents as the output. Hence, the more innovative ability a country has the more innovations it produces and the more patents it has to apply. This relationship is empirically well tested and most studies confirm its existence. Yang and Kuo (2008) find a positive and significant impact of absolute R&D expenses on patent flows, while Caviggioli (2011) also obtains positive and significant coefficients for the ratio of R&D expenses to GDP. The same ratio but with time lags was tested by Chang et al. (2013). It turns out that a time lag of one period explains the model best, however, their results are only weakly significant.[13] Eaton and Kortum (1996) as well as Park (2013) test for the influence of the number of researchers per labor force instead and also find a positive relationship. Another approach is undertaken by Nepelski and De Prado (2012) by controlling directly for the absolute output of the above mentioned innovation production function, i.e. they tested the inventive capability of the source country by means of the total number of patents domestic firms hold. Its effect is found to be highly significant and positive in the pooled sample, but in some subsamples it turns out to be negative. Sun (2003) used the number of patents a country holds in the US in order to account for the national innovation capability. However, the results suggest that there is no influence of this variable on patent flows to China. As much influence as R&D has on the propensity to patent, as much may it also have on the propensity to export, since R&D improves the quality of these exports and thus makes them more competitive in foreign markets, which in turn results in increased export quantities. Much like in the case with the market size, trade tends to be endogenously determined if R&D expenses and trade are jointly used in a regression analysis.

On the other hand, human capital in the recipient country is a decisive variable for patent inflows in two regards: *First*, a firm is more likely to patent its exports in the destination market when the threat of imitation is high, which in turn may be positively related to the level of human capital. *Second*, innovative technology can better be absorbed and thus marketed in countries where the level of technology is already high, which is again associated with the level of human capital. In fact, Eaton and Kortum (1996) as well as Yang and Kuo (2008) detect highly significant and positive coefficients for the effect of the average years of schooling on patent inflows. Nepelski and De Prado (2012) also control for the number of researchers to workers in the destination country and find a positive and this time a consistent effect on patent flows. Park (2013) goes a step further and calculate an index for the imitative capability of the recipient country considering the average ratio of R&D to GDP and the number of scientists per workers. His results are inconsistent. He argues that imitative capabilities only increase patenting if FIPR is strong. Recall that Yang and Kuo (2008) claimed the same in chapter 4.2.4.

[13] For detailed analysis of R&D expenditure lags and their influence on patent flows, see Han and Lee (2007) who used data on R&D expenditure of Korean firms and patent data of the USPTO.

4.2.6 Combinations of explanatory variables

All five main aspects turned out to play an important role in determining international patent flows, although to different degrees. Gravity forces represent the main determinant, especially market size and wealth. The demand for innovative products in the destination country is best approximated by the market size and the level of the average wealth, i.e. GDP and GDP per capita. Alternatively, a gravity equation can include the population size instead of GDP while controlling for GDP per capita, with the advantage that the population size is rather considered to be exogenously determined. As push forces have been found to have a higher impact on patent flows than pull forces, it is crucial to include adequate variables that account for the innovative capabilities and the potential of producing such innovations in the source country. Expenses in research and development and GDP may represent the best candidates for this, however, no study has tested them jointly, yet. A reason for which most studies limited their analysis to a handful of determinants is certainly the issue of collinearity and endogeneity among the explanatory variables. Xu and Chiang (2005), for instance, dropped GDP from the equation in order to avoid collinearity with trade and possibly to avoid trade being endogenously determined within the model. Distance is clearly less important for patent flows than for trade in goods. Nevertheless, the geographical distance and the existence of a common language may still have a significant impact, while the influence of technological distance remains to be investigated.

In accordance with expectations, bilateral trade has a positive impact on patent flows, since it reflects current economic involvement and with that the need to protect innovations. The explanatory power of trade on patent flows might increases when the analysis is broken down to the industry as in Lybbert and Zolas (2012). Including FDI is problematic if tested jointly with trade, since its effect on patent flows is not fully understood, yet, and the relation between trade and FDI is unknown. The fact that trade itself is determined by gravity forces is a delicate issue. On the one hand, there is certainly an endogeneity problem if these variables appear simultaneously in a regression equation, but on the other hand the estimated effect of trade may be inflated if gravity forces are excluded. In order to evaluate how severe the estimates suffer from trade being endogenous, a regression analysis should therefore compare the results for the effect of trade with and without including its determinants such as gravity forces. Alternatively, Yang and Kuo (2008) used an instrumental variable (IV) approach.

Their results do not change much when using IV, neither do the coefficients of the trade variables nor the ones of FDI.

Further factors that influence patent flows are costs and fees for patenting as well as intellectual property rights. IPR should only be included if the model controls for wealth. FIPR exhibit most explanatory power if used in an interaction term with the imitative capabilities, such as the level of schooling or the ratio of researchers to the total labor force of the destination country.

5 Empirical analysis

Given the evidence that trade has a positive effect on patent flows, the empirical work proceeds by investigating which aspects of trade lead this effect. Note that the term trade has referred so far to the value of traded goods and is henceforth also denoted trade volume. A glance at the data reveals that the volume of trade differs strongly between country pairs. For instance, in 2005 the US exported to Canada goods worth USD 176 billion while only USD 9 billion to Spain, despite similar export market sizes. Besides, new trade theory tells us that

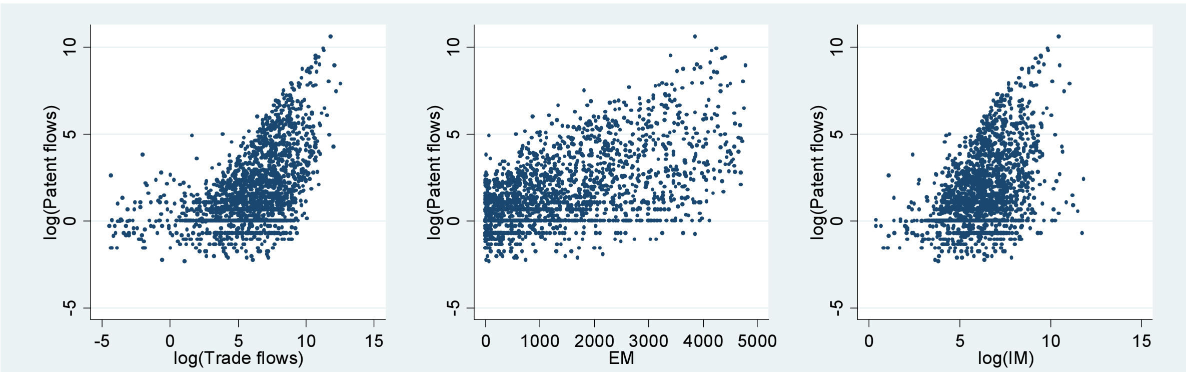


Figure 1: Patent flows are positively related to trade and trade margins (in 2005).

countries produce and export different product varieties, which are either differentiated by characteristics or quality. Therefore, the number of varieties and the volume of each variety in trade may vary considerably across countries. The fact that the US trades more with Canada than with Spain implies that their trade with Canada includes a wider set of product varieties (the extensive margin of trade) and/or a higher trade volume within at least one product variety (the intensive margin). A higher intensive margin in turn is either the result of increased quantities traded, a higher export price or both of them. The fact that trade affects patent flows positively, means either the extensive margin (EM), the intensive margin (IM), or both of them must have a positive impact on patent flows. As it seems in figure 1, both margins of trade may have a positive but possibly unequal effect on patent flows. It may even be the case that trade margins are a more powerful instrument to explain patent flows than it is trade, which would mean it is not sufficient to look only at variances in the overall trade volume when explaining patent flows, but at the variations in the composition of trade instead.

5.1 Theoretical framework and hypotheses

In order to understand the impact of trade margins on patent flows, it is important to understand what determines trade margins in the first place. The most decisive determinant from our perspective is innovation, because international patent applications only occur if patentable products or processes have been invented. Besides, if we assume that protection of exports is the only motivation behind such applications, then innovation has only an impact on patent flows through trade. International trade theory predicts that innovation helps to improve export performance and thus positively affects trade volumes. Consequently, inventive activity must also affect at least one of the trade margins. Hence, the question is to which degree innovation influences the extensive and intensive margins of trade. In order to answer this question, let us first have a look at innovation-based models developed within the trade as well as the endogenous growth theory.

One strand of the literature deals with horizontal innovation, i.e. innovation that generates new varieties of horizontally differentiated products. In the endogenous technological change model of Romer (1990), innovation leads to a new but not necessarily improved intermediate product variety. Innovation is the result of R&D which uses only labor as input. The model starts from the production function derived by Dixit and Stiglitz (1977) which exhibits diminishing returns to inputs. Consequently, more product variety increases total production as the given stock of capital is allocated more optimally and thus leads to long-run economic growth. The idea is that more intermediate product varieties intensify specialization through the division of labor and thus sustain economic growth. Hence it is rather a sort of process innovation (Acemoglu, 2009). An endogenous growth model with product innovation was formulated by Grossman and Helpman (1991b). In their set up, new product varieties expand the set of goods available to the consumer, and as the latter has a love for variety, the consumer's utility increases with product innovations. Their demand for varieties ultimately spurs the innovation process.

The second strand of the literature regarding endogenous growth focuses on quality-improving innovations, referred to as the Schumpeterian growth theory since it is based on Schumpeter's idea of creative destruction. Departing from this idea, Aghion and Howitt (1992) set up a quality ladder model where innovations have the form of qualitatively improved products. Alternatively to increased quality, vertical innovation can also result in reduced production costs, such as proposed in Shleifer (1986) and thus describes primarily process innovations.

The trade literature provides some models which use similar types of innovations and analyze their effect on international trade. For instance, Krugman (1979) formulated a simple general-equilibrium model with innovating North and non-innovating South where research leads to new varieties and where the rate of innovation is exogenously determined. His model shows that such horizontal innovations induce trade and increase the extensive margin, because North exports new varieties to and imports old ones from South but only if innovative activity is performed. Similarly, Grossman and Helpman (1989) set up a dynamic general-equilibrium model with horizontal product innovation. They conclude that innovation of new product varieties spurs trade and the creation of multinational firms. If this is the case, the extensive margin increases as a consequence of horizontally differentiated product innovations, while the implication for the intensive margin is ambiguous. However, when the model allows for the emergence of multinational enterprises, innovation of horizontally differentiated goods not only increases the extensive margin but also production and trade of single product varieties which results in a higher intensive margin.

Models with vertical innovations allow better predictions for the intensive margin. In Grossman and Helpman (1991a) firms invest in research to climb up the quality ladder regarding their products. The world is similar as in Krugman (1979) with innovating North and imitating South. Again, innovation spurs the trade volume, but this time it is especially the intensive margin that is positively affected by the innovative effort of North, since this effort increases quality and thus competitiveness of the same product variety. To complete the picture, there are also models focusing on productivity-increasing innovations such as in Eaton and Kortum (2001; 2002). Such innovations could represent inventions reducing production costs, for example, and thus would describe process innovations. In Eaton and Kortum (2001) technological advantage in form of higher productivity increases the trade volume for single product varieties and thus again we expect such innovations to raise the intensive margin of trade.

In sum, theory predicts that horizontal innovations positively affect the extensive margin while vertical innovations increase the intensive margin of the source country. The closest empirical analysis was conducted by Chen (2013) who estimated the impact of general innovation on trade margins without making the distinction between horizontal and vertical innovation and finds that 70 percent of the effect of innovation on the trade volume is explained by intensive margin and 30 percent by the extensive margin. In other words, innovation increases trade both by raising the number of export varieties and the export volume of each variety. Other determinants that are found to explain trade margins are income and country size (Hummels & Klenow, 2005), distance (van Hove, 2010) or similarity of demand structures between the trade partners (Bernasconi, 2013).

The evidence that innovation increases both the extensive and the intensive margin allows constructing hypothesis about their impact on patent flows. One the one hand, innovation might increase the extensive margin because it creates new product varieties such as in Grossman and Helpman (1991b) that can be exported. A higher number of patentable products among exports that are exposed to imitations consequently call for more patent protection in the destination country. On the other hand, innovation might increase the intensive margin because innovative products are more competitive in international markets if they evolve from an innovation process as Aghion and Howitt (1992) proposed. In this case, export markets become more valuable to innovating firms and thus increase their willingness to patent abroad.

> **Hypothesis 1.1**: Both the extensive and intensive margin of bilateral trade increase the number of patents that the innovative country applies in the destination country.

The intensive margin is the product of the average price and the export quantities of the corresponding good. This means the positive effect of the intensive margin on patent flows can be either attributed to higher export prices, larger quantities or both. On the one hand, the average export price can be approximated by the unit value, i.e. the trade value per item, which is commonly considered to be related to the quality of goods (Hummels & Klenow, 2005). As quality improving innovations are exported at higher prices compared to non-innovative products, unit values may increase patent flows. As for export quantities, such innovations may increase the number of exported items if they replace domestic products or imports from elsewhere, but may also stay constant if they just replace former imports from the same source country. On the other hand, cost reducing innovations could also decrease unit values without affecting the product quality, while the export quantities would probably increase. This would lead to the opposite effect of unit values on patent flows. As these cost reducing innovations are more likely to be process innovations which are less protected by patents, one can assume that the former case with quality enhancing innovations dominates among patents.

Hypothesis 1.2: Higher unit values and larger quantities in trade raise the number of patent flows.

Although we generally expect both trade margins to increase the number of patents applied abroad, their effect is less evident once we try to explain differences in international patenting by variations in trade margins for country pairs with similar trade volumes. A glance at the data reveals that exports of similar volume to different trade partners may consist of considerably different trade margins. For instance, in 2005 Switzerland exported goods worth USD 1.2 billion to both Russia and Malaysia. However, Switzerland counted 1'932 different product categories among its exports to Russia, while only 1'605 to Malaysia. In return, its average trade volume per product category amounted to around USD 644'000 to Russia, while USD 764'000 to Malaysia. In comparison, Swiss residents filed 265 patent applications in Russia but only 37 in Malaysia.

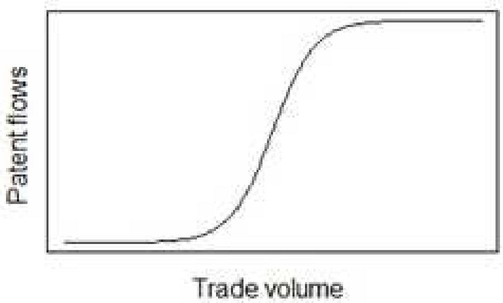


Figure 2: Within an industry, the effect of trade on patent flows is assumed to resemble a logistic curve.

The difference in the number of patent flows when trade volumes are equal may be affected by the different combinations in trade margins, which implies that different values of trade margins would favor patent flows more than others do. For example, in a narrowly defined industry we expect exporters not to patent if trade volumes are too low, because patenting costs are likely to exceed earnings from their exports. However, with higher trade we expect them eventually to patent abroad as earnings become important and patenting profitable, leading patent flows to strongly increase with intermediate trade. This increase in patent flows is gradually diminishing with higher levels of trade, as the number of patentable products in a specific industry is bounded above. Once the export volume of an industry is high and most patentable products in trade are patented abroad, patent flows become inelastic with regard to higher trade volumes. Hence, we may approximate the relationship between patent and trade flows on the industry level by means of an S-curve as in figure 2:

> **Hypothesis 2**: Within an industry, the number of patent flows is zero for low trade volumes, highly increasing with intermediate trade volumes and converging to the upper bound of existing patents with high trade volumes.

The same relationship is true for the intensive margin as long as the extensive margin is maximized for all exporters. This is the case if an industry trades the whole range of product varieties existing in its sector. In sum, patent flows are expected to be small if the intensive margin is too low, independently of the extensive margin. With intermediate levels of the intensive margin, both trade margins increase patent flows, while for high levels of the intensive margin, the number of patent applications depends primarily on the extensive margin.

Assuming industries are symmetric across countries, hypothesis 2 has direct implications on how trade margins influence patent flows on the aggregate level. This is because for a given aggregate trade volume, the trade margins are directly linked to each other, as they are defined such that the product of the trade margins equals the trade volume V. They work against each other, because the derivative of EM on IM is negative for fixed trade volumes:

$$V = EM \cdot IM \leftrightarrow d\bar{V} = dEM \cdot IM + EM \cdot dIM = 0 \leftrightarrow \frac{dIM}{dEM} = -\frac{IM}{EM} < 0 \qquad (10)$$

This relationship is illustrated in figure 3 for a given trade volume $\bar{V}$. The curve is the set of all possible combinations of EM and IM. There are two extreme cases for any given positive trade volume. The first case describes the upper end of the curve, where a country pair trades only in a few industries but at large quantities. One would expect the exporters to have a high incentive to patent the few innovative products contained in trade, since its trade volume is substantial. However, hypothesis 2 states that the number of patents within an industry is limited and thus we expect overall patent flows between these countries to be rather small. In

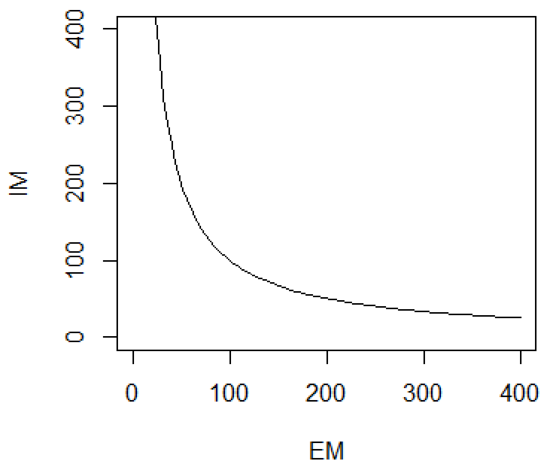


Figure 3: Possible combinations of trade margins for $\bar{V}$=10’000.

the second case (the lower end of the curve), many industries trade and thus the number of product varieties in trade is large, but the individual trade volume is low. According to hypothesis 2, exporters have little incentive to patent abroad as long as the individual trade volume is below a certain level, since patenting is not profitable for such low levels of trade. So in both extreme cases we expect few patent flows. In contrast, patent flows can be expected to be higher for balanced extensive and intensive margins, where trade of patentable goods is numerous and the trade volume of each product high enough to justify patenting costs.

In order to model the relationship between the extensive margin and patent flows, an inverted U-shaped function as illustrated in the top right corner in figure 4 is assumed. It originates from the following equation:

$$PF = \beta_0 + \beta_1 \cdot EM + \beta_2 \cdot EM^2 + \beta_3 \cdot EM \cdot V \quad (11)$$

where PF is the number of patent flows. This function requires a continuous distribution of extensive margins and patent flows. It should have the desired property that patent flows are highest for balanced trade margins and lowest for very unequal trade margins. For this reason, the model’s coefficients must meet some conditions. Specifically, the number of patent flows increase with the extensive margin as long as the EM is small (and thus the IM high), i.e. smaller than the level EM^* for which patent flows are maximized (condition I). In addition, this effect is diminishing and eventually becomes negative as the function should be concave for all values of EM (II):

I. $\partial PF/\partial EM = \beta_1 + 2 \cdot \beta_2 \cdot EM + \beta_3 \cdot V > 0$ if $0 < EM < EM^*$

II. $\partial^2 PF/\partial EM^2 = 2 \cdot \beta_2 < 0$

From the second condition we know that $\beta_2 < 0$. Thus, rearranging the first condition gives $\beta_1 + \beta_3 \cdot V > -2 \cdot \beta_2 \cdot EM > 0$. Therefore, for relatively small values of EM, it must hold that $\beta_1 + \beta_3 \cdot V > 0$.

This way, patent flows converge to the constant β_0 either if the EM approaches zero or the threshold level EM''. The first minimum is obvious, while the second one refers to the threshold level for the IM, below which patenting is not profitable. These threshold levels are obtained by setting patent flows in equation 11 to zero and solving for the extensive margin. For simplicity let us assume that $\beta_0 = 0$:

$$PF = 0 \rightarrow EM' = 0, EM'' = (\beta_1 + \beta_3 \cdot V)/(-\beta_2).$$

According to equation 10, the IM is explicitly defined by the trade volume and the EM. Consequently, patent flows can also be expressed by the IM:

$$PF = \beta_0 + \beta_1 \cdot (V/IM) + \beta_2 \cdot (V/IM)^2 + \beta_3 \cdot (V/IM) \cdot V \qquad (12)$$

Figure 4 combines equations 10, 11 and 12 and illustrates the relationship between the trade margins and their impact on patent flows.

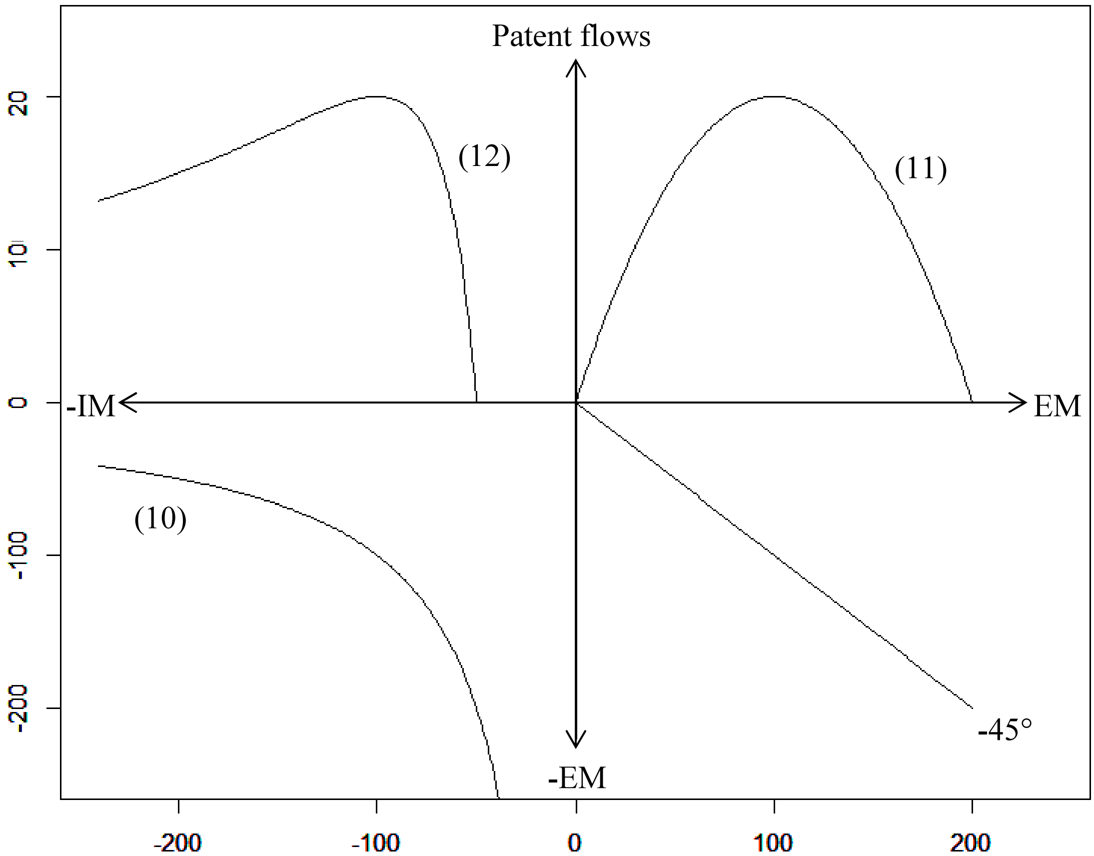


Figure 4: Combinations of extensive and intensive trade margins and their impact on patent flows ($V = 10'000, \beta_0 = 0,\ \beta_1 = 0.3, \beta_2 = -0.002, \beta_3 = 0.00001$). Note: For illustrative purpose, the vertical axis is scaled up for values in the positive range.

Contrary to the EM, the range of IMs for which patent flows are positive does not have an upper limit, because as the EM approaches zero, the IM converges to infinity. This is a result of the specification of function 11. We obtain the corresponding threshold values for the intensive margin using equation 10 and assuming β_0 equals zero:

$$IM' \rightarrow \infty, IM'' = \frac{-\beta_2 \cdot V}{\beta_1 + \beta_3 \cdot V}$$

Patent flows are maximized for the combination of EM^* and IM^*, with EM^* being calculated from equation 11:

$$\frac{\partial PF}{\partial EM} = \beta_1 + 2 \cdot \beta_2 \cdot EM + \beta_3 \cdot V \rightarrow \frac{\partial PF}{\partial EM} = 0 \leftrightarrow EM^* = \frac{\beta_1 + \beta_3 \cdot V}{-2 \cdot \beta_2} \quad (13)$$

From equation 10 we can infer that $IM^* = -2 \cdot \beta_2 \cdot V / (\beta_1 + \beta_3 \cdot V)$. At the maximum, the number of patent flows is $PF^* = ((\beta_1 + \beta_3 \cdot V)/2)^2 / (-\beta_2)$. As all of these optima have positive but finite values, we can formulate the following hypothesis:

> **Hypothesis 3.1**: For a given trade volume, patent flows are highest for moderate values of EM (and IM), since the effect of the extensive margin on patent flows follows an inverted U-shaped function.

Now we would like the number of patent flows as well as the trade margins that maximize patent flows to be increasing in the trade volume V, i.e. the peak of function 11 should shift North-East with higher V. This leads to three additional conditions, namely

III. $\partial PF^* / \partial V = (\beta_1 + \beta_3 \cdot V)\beta_3 / (-2 \cdot \beta_2) > 0$

IV. $\partial EM^* / \partial V = \beta_3 / (-2 \cdot \beta_2) > 0$

V. $\partial IM^* / \partial V = (-2 \cdot \beta_1 \cdot \beta_2) / (\beta_1 + \beta_3 \cdot V)^2 > 0$

Given the negative sign of β_2, condition IV requires β_3 to be positive, while condition V requires the same for β_1. As a consequence, conditions I and III are automatically fulfilled.

> **Hypothesis 3.2**: The values for the combinations of trade margins that maximize patent flows as well as the maximum number of patent flows that can be attained increase with trade flows.

5.2 Data

Patent flows are in the following defined as patent applications from country A in another patent office in country B. As the goal is to explain the existing pattern of applications at foreign patent authorities, it is important to identify the country of the owner(s) of an invention on the one hand, and the countries of the patent offices where they patent on the other hand. Two different definitions of patent flows are separately applied in the analysis. The main dataset uses the applicator criterion, i.e. the applicator's country of residence of the priority filing to determine the source country, while the second dataset (APA) defines the source country of a patent flow as the location of the patent office where the initial filing takes place. The destination countries and the corresponding year are derived from all subsequent filings which refer to the same invention. To this end I use the October 2012 release of the PATSTAT database which relies on the EPO's master documentation database (DOCDB) and consists of patent families of more than 100 patent offices. A patent family constitutes of all patent applications which protect the same technical content. Hence, a priority filing is only considered as the head of a patent family if it protects a new technical content. However, sometimes there exist multiple priority filings within a patent family, because the patent was applied as a priority filing at various patent offices. In such cases, the patent flow from one of several source countries to a destination counts only as a fraction of one, which leads to non-integer values for patent flows.

The advantage of the main dataset over the APA is that sometimes the owner of the invention does not apply his first patent at the patent office where he resides and from where he possibly exports the invention, but applies first at a patent office located in a large (potential) export market instead. The downside of this method is the existence of missing values for the applicator's residence country.[14] For robustness tests, I conduct the relevant analysis on the aggregate also for the APA dataset. For both methods, the patent count includes normal patents and international patents (PCT) but no utility models, design patents or special intellectual property rights such as the Gebrauchsmuster. In the following, information corresponding to the APA dataset is reported in parenthesis.

[14] In case of a missing value regarding the residence country of the applicator in a specific patent flow, an algorithm was applied to replace it by information given in a patent flow of the same DOCDB family, a near relative within the same INPADOC family or the country of the application authority - in this very order.

The focus of this analysis is on the effect of bilateral trade on patent flows. The main explanatory variables of interest are therefore trade flows (*V*) as well as their extensive (*EM*) and intensive (*IM*) margins. Trade data is from the World trade database (BACI) developed by CEPII and based on original data from the United Nations Statistical Division (COMTRADE database). It contains bilateral trade data on goods (no services) broken down to the HS 6-digit product level for over 200 countries.[15] On this level of disaggregation, 5'018 product categories are observable. I define trade flow as the total value of traded goods between two countries within one year and aggregated over all product categories. In order to calculate the trade margins, I use the definition of "unnormalized aggregate bilateral trade margins" developed in Bernasconi (2013):

$$V_{ij} = \sum_{p \in P} v_{ijp}\,,\ EM_{ij} = \sum_{p \in P} 1\left(v_{ijp} > 0\right),\ IM_{ij} = \frac{V_{ij}}{EM_{ij}} \tag{14}$$

where p is a single product category and P the set of all product categories within the HS 6-digit product disaggregation. For further analysis, the intensive margin is decomposed into unit values (*UV*) and average quantity per product category (*AQ*), where $UV_{ij} = V_{ij}/Q_{ij}$ and $AQ_{ij} = Q_{ij}/EM_{ij}$.

The main dataset is further broken down to different levels of industries, in order to account for their substantial differences with respect to trade and patent flows. The industries are defined according to the second review of the Standard International Trade Classification (SITC), since corresponding concordance tables are available to merge data from COMTRADE and PATSTAT. The United Nations Statistics Division provides a one-to-one map between the Harmonized System and the SITC.[16] PATSTAT data in turn is organized by the 4-digit IPC classification. I use the ALP concordance derived by Lybbert and Zolas (2012) with weights according to the probability of an IPC class being matched to a specific SITC class.[17] The disaggregation is done on each of the 1, 2 and 4-digit SITC levels.

The control variables measure certain aspects of the gravity forces explained earlier. This includes GDP, GDP per capita and the population size of both the source and the recipient country. I use the data from the World Bank Indicators, which also provide data for public

---

[15] For more information see http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=1
[16] http://unstats.un.org/unsd/trade/conversions/HS%20Correlation%20and%20Conversion%20tables.htm
[17] http://www.wipo.int/econ_stat/en/economics/publications.html

spending on education and total expenditure for R&D relative to GDP. The latter variables allow controlling for innovative and imitative capabilities. Unfortunately, there are many missing values. Contrary to some previous studies, I do not include geographical distance into the regression, because its effect on patent flows was often reported to be ambiguous.

The samples cover the time period of 1995-2009 as the BACI database is limited to this sequence. Within this time frame, the selection of countries is predetermined by the availability of patent, trade and country-specific data. Countries reported in the PATSTAT database match well the COMTRADE database such that only a few countries have been dropped.[18] A bigger issue is the fact that regional patent offices with initial or subsequent filings (such as the EPO) cannot be assigned to a specific source or destination country and thus these observations were also dropped from the sample.[19] On the aggregate, the regional patent offices amount to a total of 4'766 (4'278) observations, which represent roughly 11 (16) percent of total observations in the PATSTAT database. Patent flows of Belgium and Luxembourg were added up in order to match with the trade data. On the other hand, many destination countries or regions from the COMTRADE database were ignored as they are not considered in PATSTAT (with the APA dataset many source countries were affected, too). The sample is further limited to country pairs for which gravity forces are available. However, most of the ignored observations concern very small countries or regions.[20]

The final aggregate sample contains 187 source and 82 destination countries which all reported at least once a positive in and/or outflows of a patent (the APA dataset is balanced with respect to source and destination countries with 84 each, as only countries with patent offices are included). The maximum possible number of country pairs or observations is therefore 15'170 (6'972) per year and 227'550 (104'580) over the period of 15 years, since intra-national flows are ignored. For both patent and trade flows, only country pairs with positive flows are reported, while the values for the rest of the country pairs must be either zero or unknown. Following Lybbert and Zolas (2012), country pairs which neither report

[18] Countries with positive patent flows but not considered in the COMTRADE database are mostly of transitional nature. Partly or entirely dropped source countries include Czechoslovakia, Democratic Republic of Congo, Democratic Republic of Germany and Soviet Union. A few very small countries were also ignored. The only missing destination country is Montenegro. In the APA database Serbia was additionally dropped.

[19] The concerned regional patent offices for both databases include the African Regional Intellectual Patent Office (ARIPO), the Eurasian Patent Office, the EPO, the Cooperative Council for the Arab States of the Gulf (CCASG), the International Bureau of WIPO, as well as the Organisation Africaine de la Propriété Intellectuelle (OAPI).

[20] A total of 20'964 (5'252) observations were dropped of which 3'271 (918) contain positive patent flows.

patent nor trade flows are dropped from the sample in the corresponding year, but observations with either positive trade or patent flows are kept as information. The dataset finally consists of 166’445 (94’672) observations, of which 165’134 (94’533) report positive trade flows and 29’698 (19’178) show positive patent flows. Observations with both a positive patent and trade flow amount to 28’387 (19’039). Descriptive statistics for all variables can be found in appendix 2 (appendix 3).

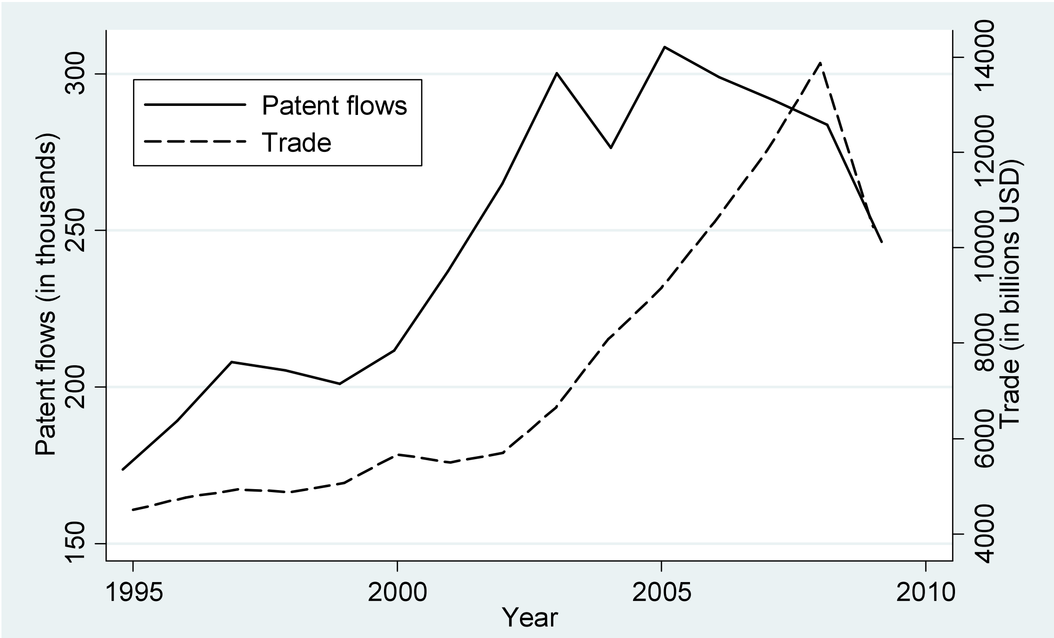


Figure 5: Total annual patent flows and trade (1995-2009).

For the analysis, I divide the samples into three periods of five years each, being 1995-1999, 2000-2004 and 2005-2009. According to figure 5, the earliest period is characterized by low and slowly increasing patent and trade flows, the second period by strong growth in both flows while the third period experienced fluctuating patent flows and a substantial drop in both flows towards the end of the period due to the economic crisis. Due to this latter event, I prefer the second subsample for the regressions. It turns out that the results from the following regressions are qualitatively equal across all three periods such that only the results for the second period are reported.

5.3 Estimation techniques

Hypothesis 1 is tested with a modified gravity equation similar to Lybbert and Zolas (2012) or Yang and Kuo (2008), while a count data model is applied to compute the regressions. I use the Pseudo (Poisson) Maximum Likelihood (PPML) estimator as proposed by Silva and Tenreyro (2006). Its advantage compared to traditional estimators is that it assumes the dependent variable to follow a Poisson distribution and thus having only non-negative values. This is often the case with count data and, as appendix 4 reveals, also with patent flows. The PPML estimator helps to deal with the excessive amount of zero values in our matrix of country pairs and with the fact that the distribution of patent count data is likely to be over dispersed, i.e. that the conditional variance exceeds the conditional mean. PPML estimates $y_i = e^{\alpha + x_i \beta}$ which is equivalent to $\log(y_i) = \alpha + x_i \beta$. Appendix 4 shows that trade data follow also rather a Poisson than a normal distribution. The same is true for the control variables, although less pronounced. Hence, a log-linear model is preferred for testing the first hypothesis with the convenient consequence that the coefficients report elasticities. The first equation verifies that trade volume actually has a positive impact on patent flows:

$$log(PF_{ijs}) = \alpha_0 + \alpha_1 \cdot log(V_{ijs}) + \boldsymbol{c}' \cdot \boldsymbol{\theta} + \varepsilon_{ijs} \tag{15}$$

where vector $\boldsymbol{c}$ stands for selected combinations of control variables regarding the source and destination country and ε_{ijs} is the error term. The subscript *s* refers to the industry in case the data is disaggregated.[21] From specification 14 we can proof that the product of the extensive and intensive margin of trade equals total trade volume, i.e.

$$V_{ijs} = EM_{ijs} \cdot IM_{ijs} \tag{16}$$

Hence, in a regression analysis one can substitute trade volume by the product of the trade margins. This is particularly useful in a log-linear model, because

$$log(V_{ijs}) = log(EM_{ijs}) + log(IM_{ijs}) \tag{17}$$

This means the sum of the logarithmic values of the trade margins can replace the logarithmic value of trade volume without significantly changing the results of the regression analysis:

$$log(PF_{ijs}) = \alpha_0 + \alpha_1 \cdot log(EM_{ijs}) + \alpha_2 \cdot log(IM_{ijs}) + \boldsymbol{c}' \cdot \boldsymbol{\theta} + \varepsilon_{ijs} \tag{18}$$

[21] I also experimented with adding time fixed effects. However, even for the period of the highest growth (the 2nd subsample), controlling for time seems to have only a negligible effect on the estimates on the variables of interest.

It can be shown that the intensive margin equals the product of the average value of an exported product and the average quantities exported within a product category. Therefore, I estimate also equation 19:

$$log(PF_{ijs}) = \alpha_0 + \alpha_1 \cdot log(EM_{ijs}) + \alpha_2 \cdot log(UV_{ijs}) + \alpha_3 \cdot log(AQ_{ijs}) + \boldsymbol{c}' \cdot \boldsymbol{\theta} + \varepsilon_{ijs} \quad (19)$$

The correlation matrix in appendix 5 indicates that there is an increased likelihood of multicollinearity if certain control variables are jointly used in the regression analysis. Expenditure in R&D as a percentage of GDP correlates strongly with GDP per capita and thus they should not be included both to the equation. Less severe but still high are the correlations of public expenditure in education with expenditures in R&D and with GDP per capita.[22]

While selecting the control variables we need to take into account that trade variables may become endogenously determined, since trade volume and trade margins can be explained by these control variables. For this reason I alternatively suppress the control variables and use origin country fixed effects instead. This way the regression controls better for the innovativeness of the origin country and the patentability of its export products, but does no longer control for destination country characteristics. This is less of an issue since we then assume that the trade variables are already determined by the size and wealth of the destination country. For robustness test, I additionally estimate selected equations on the 1-digit SITC level because this allows including broad industry fixed effects.

Regressions for testing hypothesis 2 are computed by OLS, since the presumed relationship between the dependent and explanatory variables is no longer linear in logs. The choice for the OLS estimator requires limiting the sample to observations with positive patent flows. In order to test whether the data confirms an S curve as assumed in hypothesis 2, it would be best to use a logistic model. However, as patent flows are not binary but count data, the logistic model is not applicable in that case. Instead, I estimate two concave functions by taking logs and using quadratic values of trade, respectively:

$$PF_{ijs} = \gamma_0 + \gamma_1 \cdot \log(V_{ijs}) + A_s + \mu_{ijs} \quad (20)$$

$$PF_{ijs} = \gamma_0 + \gamma_1 \cdot V_{ijs} + \gamma_2 \cdot V_{ijs}^2 + A_s + \mu_{ijs} \quad (21)$$

[22] Correlations are comparable with the APA database (see appendix 6).

where the subscript s refers to the 4-digit SITC product category. Following Lybbert and Zolas (2012), with A_s I include industry fixed effects on the 2-digit SITC level. The error term is denoted by μ_{ijs}. Equations 20 and 21 test whether the number of patent flows is limited above for high levels of trade. The assumption of a lower threshold level of trade is tested by means of a Probit model with the null hypothesis that the probability of observing a patent flow does not increase with low levels of trade.

Additionally, I test a cubic function as it models an S-shaped relationship for certain values of trade in case the estimates are of a specific sign:

$$PF_{ijs} = \gamma_0 + \gamma_1 \cdot V_{ijs} + \gamma_2 \cdot V_{ijs}^2 + \gamma_3 \cdot V_{ijs}^3 + A_s + \mu_{ijs} \quad (22)$$

For this function to have an S-shape and to provide evidence for a lower threshold level as well as well as for a concave relationship with higher values of trade, it must increase monotonically until it reaches its maximum. This implies for the signs of the coefficients in equation 22 that γ_1 and γ_2 have to be positive and γ_3 negative.

The hypotheses 3 are tested on the aggregate and disaggregate level with equation 23, which is a straightforward derivation from equation 11:

$$PF_{ijs} = \beta_0 + \beta_1 \cdot EM_{ijs} + \beta_2 \cdot EM_{ijs}^2 + \beta_3 \cdot EM_{ijs} \cdot V_{ijs} + A_i + A_s + \omega_{ijs} \quad (23)$$

It includes origin country fixed effects A_i instead of the usual control variables as well as industry fixed effects A_s in regressions with disaggregated data, while ω_{ijs} is the error term. Equation 23 is performed on the aggregate as well the disaggregate 1 and 2-digit SITC level, because again the disaggregated data allows accounting for broad industry differences. The effect of the IM on patent flows for a given trade volume does not have to be estimated separately, as the IM can be directly derived from the EM and trade as illustrated in figure 4.

5.4 Empirical results

The results regarding hypothesis 1 are reported in table 1. The results for the baseline regression in column 1 are of the expected sign and size, and correspond to the estimates obtained by Lybbert and Zolas (2012) who performed such a regression with a similar dataset. One percent higher trade is on average associates with a 0.45 percent increase in patent flows if we control for GDP and GDP per capita of both trade partners. The market size of both countries has a strong and comparable impact on patent flows. Wealth seems to be highly important as well, although only in the case of the source and not the destination country. The latter country's estimate has a negative sign even if the analysis is broken down to the industry level and therefore remains a puzzle. Other combinations of control variables were also successfully tested as appendix 7 reveals. The coefficient for trade increases if the regression includes only origin country FE.

Table 1: Determinants for international patent applications.

PF_{iis}	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Disaggr.:	None	None	None	None	1-dig SITC	None	None	1-dig SITC
V_{ijs}	0.446***	1.014***						
	(0.034)	(0.116)						
EM_{ijs}			0.795***	0.785***	1.760***	0.887***	1.073***	1.761***
			(0.073)	(0.202)	(0.423)	(0.062)	(0.194)	(0.363)
IM_{ijs}			0.348***	1.068***	0.656***			
			(0.048)	(0.123)	(0.123)			
UV_{ijs}						0.685***	1.535***	0.656***
						(0.055)	(0.148)	(0.173)
AQ_{ijs}						0.399***	1.053***	0.656***
						(0.045)	(0.078)	(0.109)
GDP_{is}	0.676***		0.645***			0.599***		
	(0.032)		(0.033)			(0.030)		
GDP_{js}	0.835***		0.858***			0.797***		
	(0.033)		(0.034)			(0.031)		
$GDPPC_{is}$	0.594***		0.557***			0.481***		
	(0.032)		(0.035)			(0.034)		
$GDPPC_{js}$	-0.225***		-0.226***			-0.284***		
	(0.035)		(0.036)			(0.033)		
Constant	-23.00***		-25.16***			-26.15***		
	(0.733)		(0.767)			(0.566)		
Origin FE	No	Yes	No	Yes	Yes	No	Yes	Yes
Indust. FE	No	No	No	No	Yes	No	No	Yes
Obs.	55'319	51'127	55'319	51'127	213'736	55'319	51'127	213'736
Pseudo R^2	0.860	N/A	0.862	N/A	N/A	0.870	N/A	N/A
Wald χ^2	4'076***	77***	7'053***	80***	139***	8'559***	219***	147***

Note: PPML estimates with explanatory variables in logarithmic values. Robust SE in parenthesis. Significance levels: 10% > * 5% > ** > 1% > ***.

Column 3 to 5 confirm hypothesis 1.1 as both trade margins have a positive impact on patent flows. According to the baseline regression in column 3, the elasticity of the EM on patent flows is approximately 0.8, while the elasticity of the IM amounts to roughly 0.3. However, their relative importance remains ambiguous as the coefficients' size vary between models. There is also evidence for hypothesis 1.2 in column 6 to 8 where the intensive margin is split up into the unit value and the average quantity traded. Both have a positive influence on patent flows, although unit values tend to be slightly more important. All regressions calculate robust standard errors, as we have strong indication for heteroscedasticity.[23] The coefficients obtained for the other time periods and the APA database (on the aggregate level) are of comparable size and significance. As expected, the OLS estimator delivers less significant and partly even contradicting results.

On the 4-digit SITC level, the regressions for hypothesis 2 report only significant results for equation 20 as showed in table 2. The estimated coefficient implies that a 1 percent increase in trade volume increases patent flows by 0.37 percentage points, so the relationship is concave as expected. The results for the quadratic function suggest a concave relationship, while the estimates in the case of the cubic function exhibit signs contrary to expectation. However, the results are insignificant for all exponential terms.

Table 2: Patent flows and trade on the industry level.

PF_{ijs} Disaggregation:	(9) 4-digit SITC	(10) 4-digit SITC	(11) 4-digit SITC
$log(V_{ijs})$	0.369*** (0.064)		
V_{ijs}		0.003*** (0.001)	0.005*** (0.002)
V_{ijs}^2		-3.42e-8 (3.87e-8)	-4.21e-7 (2.76e-7)
V_{ijs}^3			9.88e-12 (6.44e-12)
Constant	1.19*** (0.009)	1.30*** (0.022)	1.26*** (0.035)
Origin FE	No	No	No
Industry FE	Yes	Yes	Yes
Observations	145’195	212’365	212’365
F	33.38***	2’091***	N/A
R^2	0.019	0.005	0.005

Note: OLS estimates with robust SE in parenthesis. Industry fixed effects are on the 2-digit SITC level. Only observations with positive patent flows considered. Significance levels: 10% > * 5% > ** > 1% > ***.

The R-squared in column 9 indicates that the model explains only 1.9 percent of the variation in patent flows. A glance at the data for combinations of trade and patent flows on the

[23] In fact, a modified Wald statistic for testing groupwise heteroskedasticity in fixed effects regression models reveals that the null hypothesis, which assumes homoscedasticity within groups, is highly rejected.

industry level reveals that dispersion is high throughout the vast majority of industries. For example, appendix 9 shows combinations in patent flows and trade for the product category “cocks, valves and similar appliances for pipes boiler shells”, an industry which ranks among those with the most international patent applications. Dispersion of patent flows is relatively high, especially for higher values of trade. The histogram for the extensive margin reveals that most countries exporting in this industry trade the whole set of product varieties but that the dispersion in patent flows is also highest for those countries (see appendix 10). As it turns out, in 43 percent of observations with positive trade and patent flows, the exporter trades the whole set of product varieties, while the average country pair trades 75 percent of the maximally reported export variety in the corresponding industry. Hence, the effect of trade on patent flows may also be true for the intensive margin. In fact, the results for the regressions in table 2 are equivalent when replacing the trade volume by the intensive margin. Besides, a Probit test[24] confirms on a high confidence level that the probability of applying patents abroad increases with low levels of trade. The z-score increases by 0.11 with each million of the trade volume as long as trade is positive but below USD 10 million.

Table 3: Patent flows and the extensive margin for a given volume of trade.

PF_{iis} Disaggregation:	(12) None	(13) 1-digit SITC	(14) 2-digit SITC
EM_{ijs}	0.124 (0.170)	0.050*** (0.015)	0.069*** (0.011)
EM_{ijs}^2	-3.08e-5 (5.69e-5)	-4.55e-5** (2.16e-5)	-1.90e-4*** (5.05e-5)
$EM_{ijs} \cdot V_{ijs}$	1.08e-5* (5.59e-6)	9.38e-6*** (3.43e-6)	5.6e-5*** (1.6e-5)
Constant	-36.46 (86.23)	-2.34 (2.57)	-0.47 (0.63)
Origin FE	Yes	Yes	Yes
Industry FE	No	Yes	Yes
Observations	10’403	37’408	97’055
F	4.56***	6.51***	13.27***
R^2	0.238	0.131	0.053

Note: OLS estimates with robust SE in parenthesis. Industry fixed effects are on the corresponding disaggregation level. Only observations with positive patent flows considered. Significance levels: 10% > * 5% > ** > 1% > ***.

[24] The Probit test was conducted with robust standard errors and used the same observations as in the regression of column 9, i.e. only observations with positive trade flows were considered.

The results regarding the effect of the extensive margin on patent flows with given trade volume provide evidence for hypotheses 3.1 and 3.2. Table 3 shows that all coefficients have the expected sign, although the coefficients are more significant if the analysis controls for broad industries. As expected, the effect of the extensive margin on patent flows for a given trade volume is concave with a positive slope for low and a negative slope for high levels of the extensive margin. Figure 6 simulates the function with the estimates obtained using broad industry fixed effects on the 1-digit SITC level for the average trade partners with positive patent flows, which have a trade volume of USD 601 million, an extensive margin of 260 and consequently an intensive margin of USD 2.3 million. The estimated model predicts 9.0 patent flows for the average trade partner which is slightly higher than the actual number of patent flows of approximately 7.8 in the average case but clearly below the predicted maximum of 14.6. In case the trade volume doubles to USD 1'202 million, the predicted maximum flow of patents is raised to roughly 18.2 and the corresponding maximizing extensive margin increases from 611 to 673, which is all in line with hypothesis 3.2. The estimated model also suggests that the same average trade partner with equal trade volume but a higher extensive and a lower intensiver margin would patent more often. Generally, by means of equation 13 we can calculate the predicted level of EM for each trade partner which maximizes patent flows according to its trade volume. It turns out that 33'283 observations or 89 percent of all 37'408 observations with positive patent flows have an extensive margin below the maximizing level. In other words, the combination of trade margins is in most cases such that a higher EM (and consequently a lower IM) would increase their patent flows. The R-squared of 13.1 percent on the 1-digit SITC level indicates that the model explains only a rather small fraction of the variation.

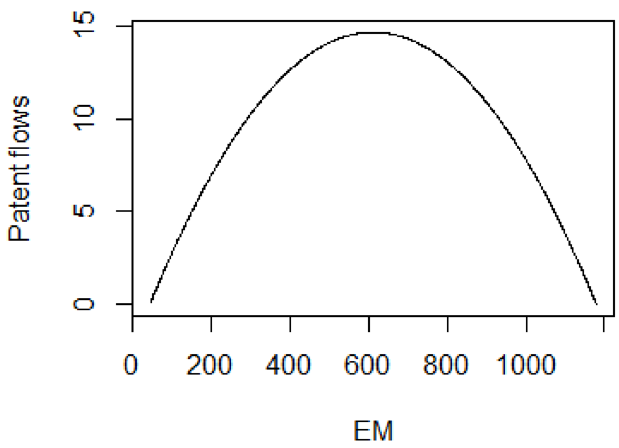


Figure 6: Simulated effect of the EM on patent flows on the 1-digit SITC level with a trade volume of USD 601 million with the results in column 13.

5.5 Discussion

We have evidence on the aggregate and disaggregate level that patent flows are positively associated with trade via the number of export varieties and the average trade value per product category. In other words, the aggregate number of international patent applications depends on both trade margins. Note that the coefficient for trade is substantially larger and the ones for trade margins change if destination characteristics are ignored in the regression. This indicates that the market size of the destination country affects trade and its margins positively. Despite the larger estimates for trade when the destination's market size is suppressed, it may not fully account for the positive effect of market size on patent flows, like the attractiveness for licensing or conducting FDI, or the need for building patent fences against competitors. Still, the results are qualitatively consistent for those regressions which include control variables for both countries and those which only use origin country fixed effects. This let us believe that we do not have a serious issue with trade variables being endogenously determined by characteristics of the destination country. The estimated positive and strong effect of unit values on patent flows provides evidence that exports of qualitatively superior products are patented more often abroad, a result which may be driven by the fact that inventive activity focuses generally more on industries with relatively high-priced goods. However, the estimate for unit value on the level of broad industries is lower but still positive, suggesting that quality-enhancing innovations actually increase international patenting. The positive but lower effect of the average quantity on the number of patent flows confirms that incentives to patent abroad increase with larger export quantities. Despite evidence for a positive influence of trade, trade margins, unit value and the average quantity on the number of patent flows, one should interpret the size of the estimates carefully, because the assumption of a constant elasticity over all values of the dataset is unlikely to be true. This concern is justified as trade and patent flows between most country pairs are quite small or zero, while some exhibit flows of enormous size. On the disaggregated broad industry level, large differences between country pairs persist despite controlling for industry-specific effects. As a consequence, there is high dispersion among observations which causes reasonable doubt that the same effect holds for the whole range of values.

The results obtained in table 2 support partially hypothesis 2. The regression in column 9 predicts that trade has a concave but always a positive effect on patent flows. Clearly, the model explains only a small fraction of all variation as dispersion is high for patent flows on the industry level. In addition to actual dispersion among patent flows, its cause may also be of technical nature, since the applied concordance table assigns weighted patent flows to SITC categories and thus leads to many positive but unrealistically low numbers of patent flows. The analysis on industry level with patent data is generally problematic as it is often difficult to find out in which industry and where in the production chain patented products are finally used or to which product category (e.g. SITC) they should be assigned to. Nevertheless, the Probit test confirms that the probability of applying any patent is increasing with low levels of trade, indicating that there might be a threshold level below which exporters do not patent at all. In reality, this threshold level is likely to depend on the industry and the involved countries, while the analysis accounts only for industry-specific differences. In sum, there is weak indication that patent flows are most elastic for intermediate levels of trade and the intensive margin, which is an important assumption for hypothesis 3.

The insignificant results for the regression in column 11 could be associated with the generally high dispersion. In addition, the signs of the estimated coefficients for the exponential terms contradict hypothesis 2, since the estimated function does not shape an S-curve. In either case, the cubic function may not be the most adequate model for estimating an S-curve, as even with the correct signs the effect of trade on patent flows would eventually become negative, which is not realistic. Note that the results may also be distorted as the OLS estimator required limiting observations to those with positive patent flows. Therefore, it is difficult to identify the exact causes for the puzzling results in column 11.

On the aggregate, there is evidence for an inverted U-shaped relationship between the extensive margin and patent flows for a given level of trade, which confirms that balanced trade margins favor patent flows. The estimated model has the reasonable property that it predicts more patent flows for a country pair with higher trade volume as long as trade margins remain balanced. However, the coefficients are insignificant unless the regression uses disaggregated data with broad industry fixed effects. The fact that the results are insignificant on the aggregate indicates that there may be large differences between industries not only regarding patent flows but also the extensive margin. The estimates on the 1-digit SITC level seem plausible as they suggest that most country pairs have an extensive margin which is below the predicted maximizing level. High performing industries with valuable innovations may export their innovations at volumes highly above the threshold level for which patenting becomes profitable, corresponding to the upper end of an industry’s S-curve.

As a consequence, the intensive margin is proportionally higher than the extensive margin compared to the predicted maximizing trade margins. Note that the analysis was again limited to observations with positive patent flows. With data of this limited sample, the model explains only a fraction of the variation in patent flows and even decreases with the level of disaggregation. A possible reason could be again the application of a concordance table using weights or the choice of the wrong estimator.

6 Conclusion

In this thesis I compare existing theoretical and empirical evidence regarding the determinants of international patent applications, while focusing primarily on trade-related factors. The literature provides ample evidence that trade exerts a positive influence on patent flows. I proceed by decomposing trade into its trade margins and testing the trade margins' effects on patent flows by using a modified gravity equation as applied in Lybbert and Zolas (2012) or Yang and Kuo (2008). Determining the impact of the trade margins on patent flows improves our understanding of causes and effects of the relationship between trade and international patent applications.

Patent flows between two countries are explained by three groups of factors: source country characteristics, destination country characteristics and the relation between these two countries. On the one hand, the results of most regressions confirm the importance of non-trade-related factors, such as market size and wealth of both countries, as they account for the origin country's innovativeness and the destination country's imitative capabilities, respectively. On the other hand, the economic involvement of two countries seems to play a large role as well, since trade is found to have a positive and significant effect on patent flows These findings indicate that protection of exports against imitations are a major motivation for international patent applications. The empirical analysis concludes that the extensive and intensive margins have both a positive influence on patent flows. This is in line with expectations, since international patent applications are expected to be positively associated with the number of product varieties in trade and the trade volume of each variety. However, no conclusion can be given with respect to their relative importance. Decomposing the intensive margin reveals that patent flows increase with the average quantities in trade and even more with the unit value and thus the quality of a product variety. This thesis analyzes also how trade influences patent flows in narrowly defined industries. In fact, there is weak evidence for patent flows being most elastic within an industry when trade and the intensive aggregate patent flows to be maximized if trade margins are balanced. The empirical results confirm this hypothesis and predict a concave relationship between the extensive margin and patent flows for a given level of trade.

This thesis provides evidence for a positive effect of both trade margins on patent flows, but their relative importance could not be established. For more consistent and thus conclusive results, an analysis using a modified gravity equation needs more evidence regarding the appropriate combination of determinants. Further research is also required to establish the effect of trade on patent flows on the industry level in order to make sure the hypothesis that patent flows are maximized for balanced trade margins is based on justified assumptions. To this end one might reconsider the choice of the classification for disaggregating the data as well as the specification of the empirical model and the estimator for its estimation.

7 References

Acemoglu, Daron (2009). Introduction to Modern Economic Growth: Princeton and New York; Princeton University Press.

Aghion, P. & Howitt, P. (1992). A MODEL OF GROWTH THROUGH CREATIVE DESTRUCTION. *Econometrica,* 60 (2), 323–351.

Arundel, A. (2001). The relative effectiveness of patents and secrecy for appropriation. *Research Policy,* 30 (4), p. 611.

Bernasconi, C. (2013). Similarity of Income Distributions and the Extensive and Intensive margin of Bilateral Trade Flows. Working Paper Series / Department of Economics No. 115. University of Zurich.

Bosworth, D. L. (1984). Foreign patent flows to and from the United Kingdom. *Research Policy,* 13 (2), 115–124.

Cardwell, R. & Ghazalian, P. L. (2012). The Effects of the TRIPS Agreement on International Protection of Intellectual Property Rights. *International Trade Journal,* 26 (1), 19–36.

Caviggioli, F. (2011). Foreign applications at the Japan Patent Office – An empirical analysis of selected growth factors. *World Patent Information,* 33 (2), 157–167.

Chan, H. P. (2010). The Determinants of International Patenting for Nine Agricultural Biotechnology Firms. *Journal of Industrial Economics,* 58 (2), 247–278.

Chang, C.-L., Chen, S.-P. & McAleer, M. (2013). Globalization and knowledge spillover: international direct investment, exports and patents. *Economics of Innovation & New Technology,* 22 (4), 329–352.

Chen, W.-C. (2013). The Extensive and Intensive Margins of Exports: The Role of Innovation. *World Economy,* 36 (5), 607–635.

Coe, D. T. & Helpman, E. (1995). International R&D spillovers. *European Economic Review,* 39 (5), 859–887.

Cohen, W. M., Nelson, R. R. & Walsh, J. P. (2000). Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). NBER Working Paper No. 7552.

De Prado, G. & Nepelski, D. (2012). International patenting strategies in ICT. JRC-IPTS Working Papers No. 79479. Institute for Prospective and Technological Studies, Joint Research Centre.

Dixit, A. K. & Stiglitz, J. E. (1977). Monopolistic Competition and Optimum Product Diversity. *American Economic Review,* 67 (3), 297–308.

Eaton, J. & Kortum, S. (1996). Trade in ideas. *Journal of International Economics,* 40 (3/4), 251–278.

Eaton, J. & Kortum, S. (2001). Technology, Trade, and Growth: A Unified Framework. *European Economic Review,* 45 (4-6), 742–755.

Eaton, J. & Kortum, S. (2002). TECHNOLOGY, GEOGRAPHY, AND TRADE. *Econometrica,* 70 (5), 1741–1779.

Eaton, J., Kortum, S. & Lerner, J. International Patenting and the European Patent Office: A Quantitative Assessment. In : OECD 2004 – Patents, innovation and economic performance, 27–52.

Eto, H. & Lee, J. H. (1993). Foreign patenting and trade with regard to competitiveness. *Technovation,* 13 (4), 221–233.

Furman, J. L., Porter, M. E. & Stern, S. (2002). The Determinants of National Innovative Capacity. *Research Policy,* 31 (6), 899–933.

Ginarte, J. C. & Park, W. G. (1997). Determinants of Patent Rights: A Cross-National Study. *Research Policy,* 26 (3), 283–301.

Girma, S., Gorg, H. & Hanley, A. (2008). R&D and Exporting: A Comparison of British and Irish Firms. *Review of World Economics/Weltwirtschaftliches Archiv,* 144 (4), 750–773.

Grossman, G. M. & Helpman, E. (1989). Product Development and International Trade. *Journal of Political Economy,* 97 (6), p. 1261.

Grossman, G. M. & Helpman, E. (1991a). Quality ladders and product cycles. *Quarterly Journal of Economics,* 106 (2), p. 557.

Grossman, Gene M.; Helpman, Elhanan (1991b). Innovation and growth in the global economy: Cambridge, Mass. and London; MIT Press.

Grupp, H. & Schmoch, U. (1999). Patent statistics in the age of globalisation: new legal procedures, new analytical methods, new economic interpretation. *Research Policy,* 28 (4), 377–396.

Han, Y.-J. & Lee, W.-Y. (2007). The Effects of the Characteristics of Korean Firms on the Patent Production Function. *Economics of Innovation and New Technology,* 16 (3-4), 293–301.

Harhoff, D., Hoisl, K., Reichl, B. & van Pottelsberghe de la Potterie, B. (2009). Patent Validation at the Country Level--The Role of Fees and Translation Costs. *Research Policy,* 38 (9), 1423–1437.

Hu, A. G. (2010). Propensity to Patent, Competition and China's Foreign Patenting Surge. *Research Policy,* 39 (7), 985–993.

Huang, C. & Jacob, J. (2013). Determinants of quadic patenting: Market access, imitative threat, competition and strength of intellectual property rights. *Technological Forecasting and Social Change*.

Hummels, D. & Klenow, P. J. (2005). The Variety and Quality of a Nation's Exports. *American Economic Review,* 95 (3), 704–723.

Kortum, S. & Lerner, J. (1999). What is behind the recent surge in patenting? *Research Policy,* 28 (1), 1–22.

Krugman, P. (1979). A Model of Innovation, Technology Transfer, and the World Distribution of Income. *Journal of Political Economy,* 87 (2), p. 253.

Kumazawa, R. & Gomis-Porqueras, P. (2012). An Empirical Analysis of Patents Flows and R&D Flows around the World. *Applied Economics,* 44 (34-36), 4755–4763.

Licht, G. & Zoz, K. (1998). Patents and R&D: An Econometric Investigation Using Applications for German, European and US Patents by German Companies. *Annales d'Economie et de Statistique* (49-50), 329–360.

Lybbert, T. & Zolas, N. (2012). Getting Patents and Economic Data to Speak to Each Other: An'Algorithmic Links with Probabilities' Approach for Joint Analyses of Patenting and Economic Activity. *US Census Bureau Center for Economic Studies Paper No. CES-WP-12-16* (CES-WP-12-16).

Maskus, K. E. & Penubarti, M. (1995). How Trade-Related Are Intellectual Property Rights? *Journal of International Economics,* 39 (3-4), 227–248.

Nepelski, D. & De Prado, G. (2012). Does the Patent Cooperation Treaty work? A global analysis of patent applications by non-residents. JRC-IPTS Working Papers No. 79541. Institute for Prospective and Technological Studies, Joint Research Centre.

OECD (2009). OECD Patent Statistics Manual: OECD Publishing.

Park, W. G. (2013). International Patenting, Patent Rights, and Technology Gaps. *Review of Economics and Institutions,* 4 (1).

Peeters, C. & van Pottelsberghe de la Potterie, B. (2006). Innovation strategy and the patenting behavior of firms. *Journal of Evolutionary Economics,* 16 (1/2), 109–135.

Picci, L. (2010). The Internationalization of Inventive Activity: A Gravity Model Using Patent Data. *Research Policy,* 39 (8), 1070–1081.

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy,* 98 (5), S71.

Shleifer, A. (1986). Implementation Cycles. *Journal of Political Economy,* 94 (6), p. 1163.

Silva, J. M. C. Santos & Tenreyro, S. (2006). THE LOG OF GRAVITY. *Review of Economics & Statistics,* 88 (4), 641–658.

Sláma, J. (1981). Analysis by means of a gravitation model of international flows of patent applications in the period 1967–1978. *World Patent Information,* 3 (1), 2–8.

Sun, Y. (2003). Determinants of foreign patents in China. *World Patent Information,* 25 (1), 27–37.

van Hove, J. (2010). Variety and quality in intra-European manufacturing trade: the impact of innovation and technological spillovers. *Journal of Economic Policy Reform,* 13 (1), 43–59.

van Pottelsberghe de la Potterie, B. & Francois, D. (2009). The Cost Factor in Patent Systems. *Journal of Industry, Competition and Trade,* 9 (4), 329–355.

Xu, B. & Chiang, E. P. (2005). Trade, Patents and International Technology Diffusion. *Journal of International Trade & Economic Development,* 14 (1), 115–135.

Yang, C.-H. & Kuo, N.-F. (2008). Trade-Related Influences, Foreign Intellectual Property Rights and Outbound International Patenting. *Research Policy,* 37 (3), 446–459.

Appendix

Appendix 1: Overview of theoretical and empirical studies on international patent applications.

Study	Sample	Countries	Years	Dep. variable	Explanatory variables	Model	Estimation	Research Question
Sláma (1981)	National patent application	27 countries	1967, 1971, 1975-1978	Patent flows	GDP, population, distance, membership in economic organizations	Log-linear model	N/A	Determinants of international flows of patent applications.
Bosworth (1984)	UK patent data	UK as source country with 50 destinations	1974	Patent flows from and to the UK	GDP, GDP p.c., exports, activities of subsidiaries with UK parents, differences of international patent laws	Linear and log-linear model	N/A	Factors influencing patent flows to and from the UK as an indicator for determinants of technology transfer.
Eto & Lee (1993)	WIPO	US, UK, West Germany, France, Japan	1976-1987	Patent flows	Industrial trade, direct investment, technology trade	Correlation coefficients	N/A	Relationship between patterns of patent flows and trade w.r.t. industrial competitiveness.
Eaton & Kortum (1996)	WIPO	19 OECD countries	1988	Patent flows per source country worker	R&D intensity, IPR, human capital, distance, import per GDP, patenting costs per GDP, relative GDP p.c.	Patent equation	Arellano-Bond GMM	Explain relative productivity and growth by innovation and international technology diffusion.
Eaton et al. (1998)	WIPO	5 dest., 17 source countries	1970, 1977	Patent flows	Destination country, source country, technology class, home effect, interaction terms	Log-linear model	ML	Main source and destination countries for innovation by classes of technology.
Kortum & Lerner (1999)	WIPO & OECD	Germany, France, U.K., Japan, US	1955-1993	Patent applications	Invention rate, diffusion rate, propensity to patent, set of dummy variables regarding source and destination countries,	Log-linear model	GLM	Determinants of the increase of US patent applications.
Sun (2003)	Statistics Bureau of China	54 countries	1985-1999	Patent flows to China	innovation capabilities (patents held in US), imports, distance	Linear regression model	OLS	Determinants of foreign patents in China.
Eaton et al. (2004)	EPO and WIPO	EPO, JP, US as source and 16 EPO countries as destination	1991-2000	Patent application flows	GDP, distance, cost and fees	Structural model	Simulated method of moments	Determinants of the international patenting behavior in Europe.
Xu & Chiang (2005)	WIPO	48 countries	1980-2000	Foreign patent inflow	IPR, trade, level of technology	Log-lin regression	N/A	Determinants of foreign patent inflows.
Han & Lee (2007)	Jaffe & Trajtenberg (2002)	Korea and US	1981-1999	US patents per labor	Export ratio, R&D expenditure per labor, foreign ownership, Chaebol membership	Linear regression model	N/A	Effects of characteristics of Korean firms on their patenting production function.

Appendix 1: Overview of theoretical and empirical studies on international patent applications (cont.).

Study	Sample	Countries	Years	Dep. variable	Explanatory variables	Model	Estimation	Research Question
Yang & Kuo (2008)	WIPO	30 WIPO member countries	1995-1998	Patent flows	R&D, IPR, FIPR, distance, schooling, relative market size, exports, outbound FDI, strong imitative abilities	Log-linear model	Type II negative binomial estimation	Influence of national characteristics, trade and FIPR on outbound international patenting.
Harhoff et al. (2009)	EPASYS 2006	EPO (EPC member states)	1995, 1999, 2003	Patent validation flows	GDP p.c., population size, distance, post-grant-fees, translation costs, technological specialization, EPC membership duration, languages	Log-linear model	Heteroskedasticity-robust regression analysis	The role of fees and translation costs on international patent applications.
Hu (2010)	SIPO & USPTO	China as destination country	1985-2004	Foreign patent applications in China	Own imports to China, competing imports, USPTO patents in same industry, SIPO patents by Chinese applicants	Log-linear model	OLS, GMM	What is behind the increasing propensity of foreign inventors to apply for Chinese patents?
Caviggioli (2011)	JPO	Japan as destination & 147 source countries	1991-2005	Patent flows to Japan	Population, GDP p.c., R&D expenditures, IPR, IPR difference, propensity to patent abroad, costs, export, FDI, technological distance	N/A	Negative binomial model	Reasons for the recent increase in foreign patenting in Japan.
De Prato & Nepelski (2012)	PATSTAT	180 patent offices	1990-2007	Patent flows in ICT	GDP, distance, common language, FDI, innovation capacities in ICT, PCT membership	Log-linear model	OLS	What macroeconomic factors influence the motivation protecting ICT inventions under foreign jurisdiction?
Kumazawa & Gomis-Porqueras (2012)	WIPO	29 OECD & 9 non-OECD countries	1981-2006	Patent flows p.c.	R&D expenditure flows p.c., lagged patent flows p.c.	N/A	Arellano-Bond GMM	The effect of R&D flows on patent flows.
Lybbert & Zolas (2012)	PATSTAT	68 countries	2001-2005	Patent flows	GDP, distance, border effects, bilateral trade, same language, colonial relationship	Log-linear model	PPML	The relation between bilateral patent flows and bilateral trade flows (on industry level).
Nepelski & De Prato (2012)	PATSTAT	59 patent offices	1970-2009	Patent flows	GDP, distance, common language, FDI, innovation capacities, PCT membership	Log-linear model	OLS	What factors determine a country's attractiveness for foreign patent applicants?

Appendix 1: Overview of theoretical and empirical studies on international patent applications (cont.).

Study	Sample	Countries	Years	Dep. variable	Explanatory variables	Model	Estimation	Research Question
Chang et al (2013)	OECD	37 countries	1994-2005	Triadic patents	overall export ratio, overall import ratio, FDI, IDI, R&D expenditures (lagged by 1 period)	N/A	Negative binomial model	Impact of FDI, IDI and export on domestic innovation.
Park (2013)	WIPO	25 source & 44 destination countries	1975-2005 (every 5 years)	Domestic and international patent applications per worker	GDP, IPR, imitative capacity, patenting costs, scientists per worker	Log-linear model	OLS	Determinants of international pateting behavior.
Huang & Jacob	PATSTAT	38 countries	1985-2004	Quadic patents	Manufacturing value added, manufacturing imports, technological capability, IPR, WTO membership, share of inventors residing in country	N/A	Negative binomial model	Determinants of quadic patent applications.

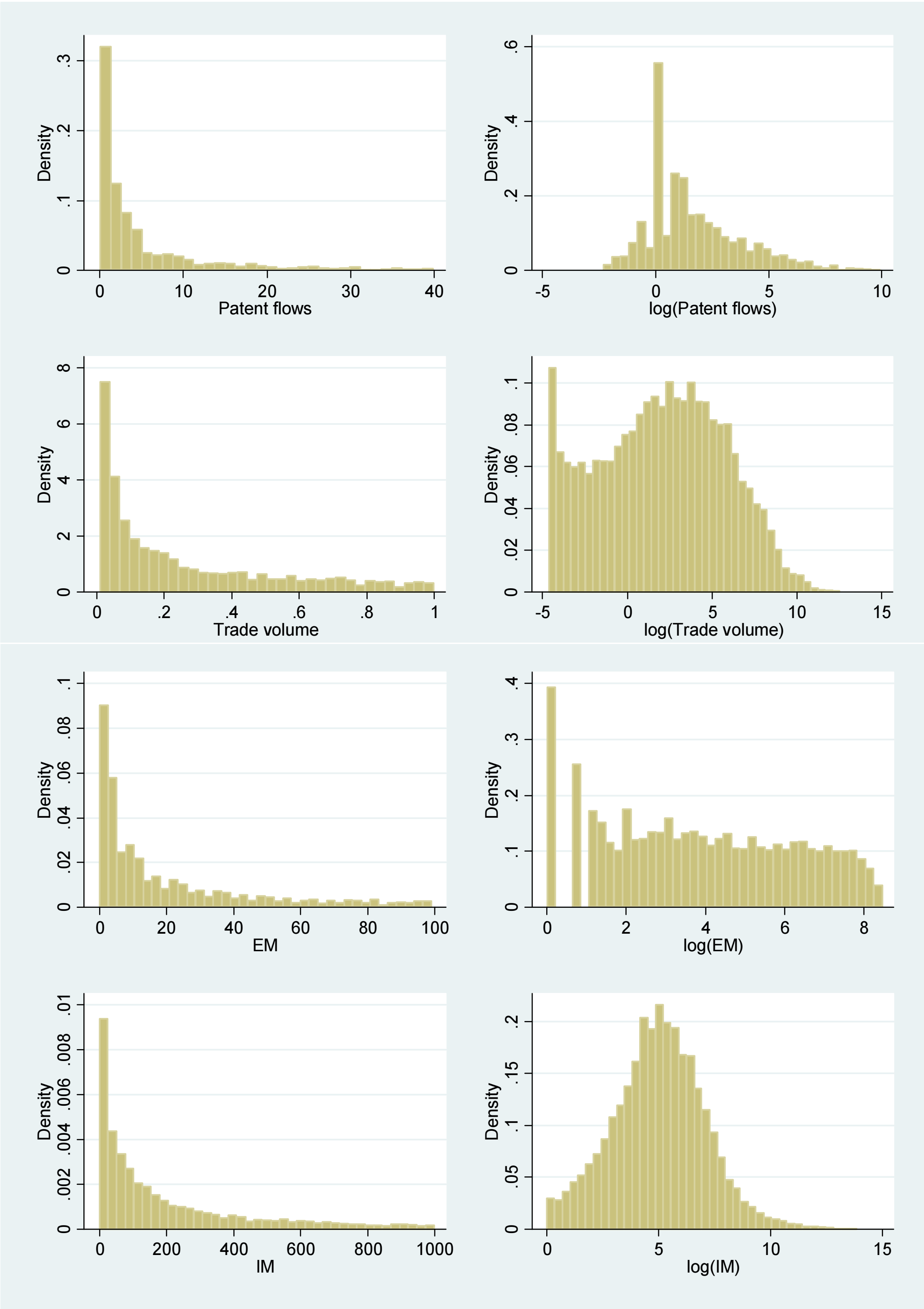
Appendix 2: Descriptive statistics of all variables on the aggregate in 2005.

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
PF	Number of patent applications	11’612	27	555	0	42140
V	Trade volume (million current USD)	11’612	788	5’741	0	282’029
EM	Ext. margin of trade	11’612	403	798	0	4’780
IM	Int. margin of trade (million current USD)	11’612	1.828	17	0	1’042
UV	Unit value (current USD / kilogram)	11’511	5’227	527’690	0.0002	5.66e+7
AQ	Average quantity per product category (tons)	11’522	6’980	182’632	0	1.83e+7
GDP	Gross domestic product (million current USD)	182	248’604	1’056’806	22	1.26e+7
GDPPC	GDP per capita (current USD)	182	12’068	20’034	144	125’599
POP	Total population (million)	182	35	132	0.010	1’304
EDU	Public education expenditure (perc. of GDP)	99	4.59	1.71	1.64	10.56
RD	R&D expenditure (perc. of GDP)	81	0.96	1.01	0.03	4.42

Appendix 3: Descriptive statistics of all variables on the aggregate in 2005 (APA).

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
PF	Number of patent applications	6’472	41	686	0	37’141
V	Trade volume (million current USD)	6’472	1322	7’591	0	282’030
EM	Ext. margin of trade	6’472	695	977	0	4’780
IM	Int. margin of trade (thousand current USD)	6’472	949	4’448	0	258’689
UV	Unit value (current USD / kilogram)	6’463	9.14	171.31	0	12’056.21
AQ	Average quantity per product category (tons)	6’464	2’557	53’910	0	4’113’434
GDP	Gross domestic product (million current USD)	84	515’580	1’516’237	1375	126’000’000
GDPPC	GDP per capita (current USD)	84	17’227	23’142	340	126’599
POP	Total population (million)	84	60.20	188.76	0.03	1’303.72
EDU	Public education expenditure (perc. of GDP)	60	4.98	1.62	2.26	10.56
RD	R&D expenditure (perc. of GDP)	65	1.14	1.05	0.03	4.42

Appendix 4: Histogram of patent and trade flows in 2005.



Appendix 5: Correlation matrix of potential control variables among source countries in 2005.

	GDP	*GDPPC*	*POP*	*EDU*	*RD*
GDP	1.0000				
GDPPC	0.2503	1.0000			
POP	0.2803	-0.1160	1.0000		
EDU	0.0059	0.3713	-0.1955	1.0000	
RD	0.3334	0.6686	0.0039	0.4096	1.0000

Appendix 6: Correlation matrix of potential control variables in 2005 (APA).

	GDP	*GDPPC*	*POP*	*EDU*	*RD*
GDP	1.0000				
GDPPC	0.2355	1.0000			
POP	0.2756	-0.1276	1.0000		
EDU	-0.0480	0.3397	-0.2377	1.0000	
RD	0.3095	0.6799	-0.0292	0.3473	1.000

Appendix 7: Baseline regression for different combinations of control variables.

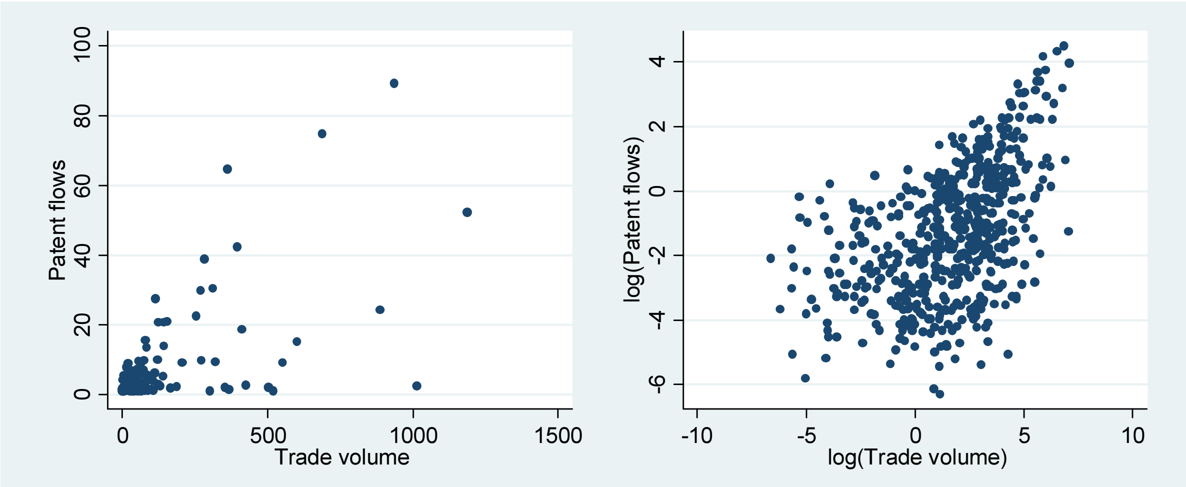
PF_{iis}	(1a)	(1b)	(1c)
V_{ijs}	0.446***	0.472***	0.375***
	(0.034)	(0.035)	(0.042)
GDP_{is}	0.676***		0.617***
	(0.032)		(0.034)
GDP_{js}	0.835***		0.878***
	(0.033)		(0.041)
POP_{is}		0.675***	
		(0.034)	
POP_{js}		0.824***	
		(0.035)	
$GDPPC_{is}$	0.594***	1.188***	
	(0.032)	(0.044)	
$GDPPC_{js}$	-0.225***	0.576***	
	(0.035)	(0.044)	
RD_{is}			1.600***
			(0.078)
EDU_{js}			-0.381**
			(0.179)
Const.	-23.00***	-22.08***	-19.15***
	(0.733)	(0.743)	(0.797)
Origin FE	No	No	No
Obs.	55’319	55’319	23’198
Pseudo R^2	0.860	0.853	0.872
Wald χ^2	4’076***	3’681***	3’332***

Appendix 8: Determinants for international patent applications (APA).

PF_{ij}	(1)	(2)	(3)	(4)	(6)	(7)
Disaggr.:	None	None	None	None	None	None
V_{ij}	0.464***	1.029***				
	(0.041)	(0.120)				
EM_{ij}			0.728***	0.807***	0.918***	1.060***
			(0.112)	(0.266)	(0.099)	(0.293)
IM_{ij}			0.396***	1.077***		
			(0.062)	(0.118)		
UV_{ij}					0.705***	1.558***
					(0.064)	(0.165)
AQ_{ij}					0.427***	1.073***
					(0.057)	(0.059)
GDP_i	0.783***		0.768***		0.724***	
	(0.039)		(0.039)		(0.036)	
GDP_j	0.822***		0.838***		0.780***	
	(0.038)		(0.038)		(0.036)	
$GDPPC_i$	0.490***		0.471***		0.398***	
	(0.036)		(0.039)		(0.040)	
$GDPPC_j$	-0.238***		-0.238***		-0.299***	
	(0.039)		(0.040)		(0.036)	
Constant	-23.50***		-25.35***		-27.37***	
	(0.825)		(1.076)		(0.808)	
Origin FE	No	Yes	No	Yes	No	Yes
Obs.	31’819	27’233	31’819	27’233	31’720	27’168
Pseudo R^2	0.838	N/A	0.838	N/A	0.846	N/A
Wald χ^2	3’673***	73***	6’152***	84***	6’699***	414***

Note: PPML estimates with explanatory variables in logarithmic values. Robust SE in parenthesis. Significance levels: 10% > * 5% > ** > 1% > ***.

Appendix 9: Trade and positive patent flows of "Cocks, valves and similar appliances, for pipes boiler shells" on the 4-digit SITC level in 2004.



Appendix 10: Extensive margin and positive patent flows of "Cocks, valves and similar appliances, for pipes boiler shells" on the 4-digit SITC level in 2004.