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# Where to Patent? Theory and Evidence on International Patenting

Joachim Inkmann, Winfried Pohlmeier and Luca Antonio Ricci

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## Non-technical Summary

This paper builds on the repeatedly documented empirical observation that flows of international patent applications are closely related to international trade relationships. In the first part of this paper we provide additional evidence for this empirical phenomenon using aggregated trade and patent data of the contracting states of the European Patent Office. From this lesson we conclude that a firm's decision to apply for patent protection for a particular location is likely to be driven by the same factors that determine the firm's international trade activities with this location.

In the subsequent part of this paper we try to formalize this relationship between international trade and patenting along the lines of a simple model of new trade theory. We explicitly account for the probability that a firm may not fully appropriate the monopolistic advantage implied by patent protection because of the disclosure of relevant knowledge through the patent which facilitates imitation. This setup yields a simple decision rule which determines a firm patenting in a particular location if its expected net profits from patenting abroad are positive. The econometric counterpart of this decision rule is a threshold crossing binary choice model.

Empirical evidence is given in the final part of this paper using a sample of 887 German manufacturing firms from the first wave of the Mannheim Innovation Panel (MIP) collected in 1992. The data set contains information on patent applications at the German and European Patent Offices and the United States Patent and Trademark office leading to a system of three patent equations to be estimated. The three equations are likely to be correlated because a single invention can be filed with different offices. We therefore estimate a trivariate probit model by full information maximum likelihood.

While conventional determinants of patenting behavior as firm size and R&D expenditures turn out significantly, factors which are usually considered as crucial determinants of a firm's export designation have only a limited impact on the firm's decision of patenting abroad.

# Where to Patent?
# Theory and Evidence on International Patenting*

**Joachim Inkmann,**[+] **Winfried Pohlmeier,**[+] **Luca Antonio Ricci**[+]

**Abstract:** This paper investigates both theoretically and empirically the location choice of patenting and its dependence on the determinants of international trade flows. A model of firms' benefits of patenting abroad is developed along the lines of a simple new trade theory setup. The model implies an econometric specification of the firms' patenting decisions in terms of a discrete choice problem. The empirical evidence is based on patent applications of 887 Germany based firms at the German Patent Office, the European Patent Office, and the U.S. Patent and Trademark Office. The results indicate that factors which are usually considered as crucial determinants of a firm's export designation have only a limited impact on the firm's decision of patenting abroad.

**Keywords:** International patents; new trade theory; discrete choice; multivariate probit

**JEL Class.:** C35, F12, O34

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+ Joachim Inkmann, SFB 178, University of Konstanz, Box D124, 78457 Konstanz, Germany;
Winfried Pohlmeier, SFB 178, University of Konstanz, Box D124, 78457 Konstanz, Germany und ZEW, L7,1, 68161 Mannheim, Germany
Luca Antonio Ricci, Research Department, International Monetary Fund, 700 19th St. N.W., Washington DC 20431, USA

## 1. Introduction

The international diffusion of new products and processes is often regarded as a major driving force of world economic growth. According to estimates by Eaton and Kortum (1996) more than 50 % of the productivity growth in every OECD country other than the U.S. results from ideas originated abroad. Due to the public good character of knowledge, the speed and the quality of the diffusion process of innovations is strongly influenced by the patenting strategies of globally operating firms. A firm patenting in a foreign country seeks protection against imitators that would produce there (and sell domestically or abroad) or export there from a third market. Hence international patenting not only reveals valuable information on the international competitiveness of firms but also signals where innovations are most likely to be used.

A large body of the theoretical and empirical work on patenting centers around patenting as an instrument to enforce (temporal) appropriation of the returns to private R&D investments. Numerous empirical studies try to quantify the determinants of patenting by treating patents as an intermediate innovative output which contributes to technical progress and productivity growth (for an overview, see Griliches, 1990). However, only a few studies consider patenting behavior in an international context. Slama (1981) offers an explanation of patent flows between countries based on a 'gravity' model of international trade theory. According to his findings a significant fraction of the variation in international patent flows can be explained by the size of the two economies ('mass') and their physical distance apart. Using cross-section data from 1974 on international patent applications, Putnam (1996) shows that a country's percentage of the total value of patent rights granted worldwide conforms closely to the relative size of its domestic economy measured in terms of GDP. The value of a single patent is defined by its present discounted value of future returns based on a theory of optimal patent renewal. Using international patent data as an indicator of technology transfer, Bosworth (1984) finds for the case of the U.K. a strong association between patenting and foreign direct investments. In a related work Dosi et al. (1990) estimate trade and patent flows among OECD countries. A somewhat different approach is taken by Eaton and Kortum (1996) who develop a model of innovation and international diffusion of technology to explain relative productivity and growth among countries. Looking at a Grossman-Helpman-type quality ladders model of innovation two estimating equations are derived for a country's productivity growth rate and the number of patent applications from a given country i to a target country j.

None of the studies quoted above explicitly takes trade theoretic aspects of international patenting into account in the sense that relative factor prices, demand conditions and transportation costs are not only decisive determinants of a firm's export decision but also reflect the relative benefits of patenting abroad. Table 1 provides descriptive evidence on the link between the structure of trade flows and patenting for Germany, France and the U.S. There is a high correlation between the geographic composition of their patent applications at the European Patent Office (EPO) and the geographic composition of their exports to and imports from the set of EPO contracting states. Such correlations are particularly high for France and Germany, ranging between 80 and 90 percent, while for the U.S. the corresponding correlations are less pronounced, but still well above 60 per cent.

**Table 1.**
**Patterns of International Patent Applications and International Trade in 1992**

| | **Germany** | | | **France** | | | **USA** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Patents | Imports | Exports | Patents | Imports | Exports | Patents | Imports | Exports |
| Austria | 7.54 | 7.02 | 8.78 | 5.72 | 1.35 | 1.35 | 5.73 | 1.24 | 1.13 |
| Belgium | 10.96 | 11.22 | 10.87 | 12.55 | 13.43 | 13.50 | 11.89 | 4.45 | 9.01 |
| Denmark | 5.00 | 3.60 | 2.86 | 5.13 | 1.47 | 1.23 | 5.48 | 1.58 | 1.32 |
| France | 13.03 | 19.12 | 19.11 | - | - | - | 1.39 | 14.02 | 13.08 |
| Germany | - | - | - | 12.63 | 29.11 | 25.76 | 14.21 | 27.26 | 19.05 |
| Greece | 3.19 | 0.92 | 1.66 | 4.35 | 0.43 | 1.20 | 3.97 | 0.35 | 0.80 |
| Ireland | 0.77 | 1.54 | 0.65 | 0.94 | 1.75 | 0.64 | 0.85 | 2.14 | 2.56 |
| Italy | 11.68 | 14.64 | 13.69 | 11.42 | 16.56 | 15.98 | 10.87 | 11.63 | 7.80 |
| Netherld. | 8.50 | 15.32 | 12.25 | 7.94 | 7.91 | 7.16 | 8.45 | 5.00 | 12.32 |
| Portugal | 2.88 | 1.48 | 1.56 | 3.94 | 1.76 | 2.43 | 2.06 | 0.63 | 0.92 |
| Spain | 8.33 | 4.31 | 6.12 | 9.39 | 8.40 | 10.58 | 7.37 | 2.84 | 4.92 |
| Sweden | 7.32 | 3.53 | 3.21 | 7.06 | 2.31 | 1.48 | 7.10 | 4.46 | 2.55 |
| Switzerld. | 8.38 | 6.36 | 7.83 | 6.95 | 3.51 | 5.12 | 6.57 | 5.37 | 4.08 |
| U.K. | 12.43 | 10.93 | 11.42 | 11.98 | 12.01 | 13.57 | 14.04 | 19.05 | 20.46 |
| Σ | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | corr(P,I) | corr(P,E) | | corr(P,I) | corr(P,E) | | corr(P,I) | corr(P,E) | |
| | 0.85 | 0.90 | | 0.83 | 0.88 | | 0.64 | 0.68 | |

Note: 'Patents' represent the shares of German, French, and U.S. patent applications at the European Patent Office (EPO) for the 14 EPO contracting states listed in the first column. Similarly, 'Imports' and 'Exports' represent the shares of the respective country's trade flow with the 14 countries. Source: EPO (1993) and OECD (1993a). Corr(P,I) and corr(P,E) denote the coefficients of correlation between patent applications and imports and exports, respectively.

More evidence on the relationship between trade flows and patenting activity abroad is presented in Table 2 which summarizes the results of two fixed effects panel data estimations. Country i's patenting activity in country j is well explained by bilateral export and import flows as well as the size of market in target country j. On the other hand, the size of the applying country i does not significantly contribute to the explanation of patenting of the applying country i in target country j.[1] As GDPs are traditionally considered as explanatory variables for trade flows ('gravity equations'), it is no surprise that GDP[i] is not significant, while GDP[j] may capture an additional strategic effect: the larger the market of country j, the larger the incentives of a firm of country i to protect its exports to j via patenting (ceteris paribus, i.e. controlling for export levels).

**Table 2.**
**Determinants of Aggregated Patent Applications in 1987-1994**

| | ln(Imp.[i←j]) | | ln(Exp.[i→j]) | | ln(GDP[i]) | | ln(GDP[j]) | | Specification | |
|---|---|---|---|---|---|---|---|---|---|---|
| | coeff. | t-value | coeff. | t-value | coeff. | t-value | coeff. | t-value | H-test | F-test |
| 1) | 0.13 | 4.12 | 0.15 | 5.41 | - | - | - | - | 72.42 | 199.68 |
| 2) | 0.09 | 2.71 | 0.11 | 3.82 | -0.04 | -0.69 | 0.18 | 3.25 | 251.67 | 112.81 |

Note: The observational unit is a pair of EPO contracting states (14 states given in the first column of Table 1). The dependent variable is the log of the annual number of patents applied by country i in country j. The estimated coefficients result from fixed effects panel estimation using 1239 observations. A random effects specification is rejected by the Hausman test (H-test) at the 1% level in both regressions. At the same level the hypothesis of a common intercept is rejected by the F-test in both equations. The data was collected from various issues of EPO's annual report (patent applications; e.g. EPO, 1993), OECD's foreign trade statistics (imports and exports; e.g. OECD, 1993a) and OECD's main economic indicators (GDP; e.g. OECD, 1993b).

In this paper we argue that international patenting is an intrinsic part of a firm's export strategy. Along the lines of a simple model of new trade theory we model the export decision of a firm and the relation with its patenting choice. The theoretical setup is used as a guide-line to model the firm's patenting decision econometrically in terms of a binary choice problem. Our empirical evidence is based on patent applications of 887 German firms at the German Patent Office, the European Patent Office, and the U.S. Patent and Trademark Office. Parameter estimates are based on trivariate probit estimates for the three patent decisions at the three major patent offices.

1 More empirical evidence on the similarities between the structure of trade and patterns is presented by Sirelli (1987) for the case of Italy and Licht and Zoz (1998) for Germany.

The limited role of patents as a tool of enhancing appropriation has been pointed out by a number of studies, e.g. Levin et al. (1987), for the U.S., or König and Licht (1995), for Germany. Mechanisms like secrecy, lead time or long term employment contracts are often seen by firms as being more valuable instruments to preserve a firm's competitive edge. In our empirical analysis, we will therefore control for some of these factors which complement the patenting strategy (secrecy, long-term employment, complexity of product design, temporal lead).

The outline of our paper is as follows: Section 2 presents the theoretical model and the econometric implementation. Section 3 provides the reader with some background information on the international patenting system. Section 4 describes the data and the econometric technique being used. Our empirical findings are discussed in Section 5, while the final section concludes and presents an outlook on future research.

## 2. The Model

Theoretical models on patenting choice mostly focus on the game-theoretic interaction among firms (usually two). Our main objective is to provide a framework encompassing the insights of new trade and location theory which could guide our econometric analysis based on the new database on German firms. A natural starting point is the usual setup offered by new trade theory (e.g. Helpman and Krugman, 1985) which will help us in organizing our thinking on patenting choices. As the database includes information on the number of firms and R&D expenditures, we will let such variables enter exogenously our model, in order to estimate empirically their impact on patenting, instead of forcing the variables to be determined endogenously by the few parameters of the model.[2]

In a first step we derive a stylized framework of trade in an environment where firms are natural monopolists (as usual in new trade theory) given the firms' innovation and patenting decisions from an earlier stage of the decision process. This would allow us to identify the firms' benefits of being able to fully appropriate their innovation, and to analyze in particular the beneficial effects of the following variables which are crucial in new trade and location theory (e.g. Krugman, 1991): market sizes, trade costs, concentration of firms, wage differen-

[2] It is left for future work to explore both theoretically and empirically the simultaneous endogenous determination of patenting, R&D, and the number of firms.

tials, and so on. Then we will discuss the benefits and costs of patenting, stressing in particular the factors which make it more likely that a firm enjoys a natural monopoly, and under what circumstances patenting increases the degree of monopoly. As the database on German firms reports patents requested at the patent offices of Germany, Europe, and the U.S., we will analyze, for a given sector, the behavior of one representative firm selling to three markets from one location, focusing in particular on its patenting choices in each market.

## 2.1 The case of natural monopoly

*Consumer behavior*

Assume the existence of three locations, which, for convenience, we will call: G for Germany, E for Europe, and U for the U.S.; $k \in (G, E, U)$ is the index of location. Consumers of all locations share Cobb-Douglas preferences over goods of different sectors, and the same Dixit-Stiglitz (1977) subutility function $(W)$ over all differentiated product varieties of sector s produced in the three locations. As consumers' expenditure shares on each sector are given (by the Cobb-Douglas assumption), we just need to focus on a typical sector. Within a sector, purchases of varieties produced in different countries will be dictated by the maximization of the aforementioned subutility:[3]

$$W = \left( \sum_{j=1}^{n} c_j^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad \text{s.t.} \quad \sum_{j=1}^{n} p_{kj} c_j = H_k , \qquad \sigma > 1 , \tag{2.1}$$

where $n$ is the total number of differentiated varieties, $c_j$ is each consumer's consumption of variety j, $\sigma$ is the elasticity of substitution, $p_{kj}$ is the price of variety j in location k (which includes trade costs), and $H_k$ represents the expenditure level in location k. Trade costs are of the usual Samuelson iceberg type. For our purposes we can assume a very simple trade cost matrix (a more general one would not add significant insight): $\tau_E$ is the cost of trade between G and E, while $\tau_U$ is the cost of trade both between G and U, and between E and U. Assuming that all firms of location k, within the typical sector, are symmetric, we can derive the sales of a typical firm located in G to location k $(S_{Gk})$:

$$S_{GG} = \frac{p_G^{1-\sigma}}{n_G p_G^{1-\sigma} + n_E (p_E \tau_E)^{1-\sigma} + n_U (p_U \tau_U)^{1-\sigma}} H_G , \tag{2.2}$$

[3] We drop subscript s for subutility, number of varieties, consumption, prices and expenditures.

$$S_{GE} = \frac{(p_E \tau_E)^{1-\sigma}}{n_G (p_G \tau_E)^{1-\sigma} + n_E p_E^{1-\sigma} + n_U (p_U \tau_U)^{1-\sigma}} H_E,$$

$$S_{GU} = \frac{(p_U \tau_U)^{1-\sigma}}{n_G (p_G \tau_U)^{1-\sigma} + n_E (p_E \tau_U)^{1-\sigma} + n_U p_U^{1-\sigma}} H_U.$$

*Process-innovating R&D and operating profits*[4]

As usual in new trade theory, firm i has to bear fixed costs $(F_i)$ and constant marginal costs in terms of labor. In this model we depart from the usual setup by assuming that the labor input requirement of a firm is inversely related to the quality of its production process. Assume that the quality of the production process of firm i, as measured by $m_i$, depends on the research and development expenditures of the firm $(R_i)$ and on the expenditures of the other firms $(R_{-i})$ in the sector:

$$m_i = R_i^{\gamma} R_{-i}^{\delta}, \qquad \gamma > 0, \; 0 < \delta < \gamma, \tag{2.3}$$

where $\gamma$ and $\delta$ measure the degree of returns to scale in the respective R&D; $\gamma > \delta$ is meant to represent a stronger effect of the firm's own R&D than of spillovers. As mentioned above, we assume R&D expenditures to be given instead of deriving their optimal level.[5] Our assumption of symmetry across local firms implies that all firms in location k have the same quality of production process $(m_k)$.

A representative firm located in k selling $x_{kk'}$ units of output to location k', faces input requirements $(l_{kk'})$ which are inversely related to the quality of the production process $(m_k)$ and directly related to the firm's output $(x_{kk'})$. Therefore

$$l_{kk'} = \frac{\beta x_{kk'}}{m_k} \tag{2.4}$$

where $\beta$ is just a parameter measuring the labor input requirements for a unit of quality of the production process[6]. If the firm can fully appropriate the benefits of its development of a pro-

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4 Assuming product innovation R&D and heterogeneity of firms would give analogous reduced form, which is all that matters for our purposes.

5 Let us note that R&D expenditures are likely to be affected in a similar way as patenting from the exogenous variables of the model and that such expenditures have a positive effect on patenting. Hence our inference on the patenting choice is likely to be reinforced.

6 One could allow for different $\beta$ across locations (as in Ricci, 1997, 1998) in order to represent other location specific factors affecting the marginal costs, such as subsidies, infrastructure, industrial policies, rental prices and externalities other than R&D.

duction process, we can naturally assume the usual large group monopolistic competition market structure. Firm's profit maximization will deliver the following optimal price $(p_k)$:

$$p_k = \frac{\sigma}{\sigma - 1} \frac{\beta w_k}{m_k}, \tag{2.5}$$

where $w_k$ is the wage prevailing in the location of the firm and $\sigma$ is approximately equal to the perceived elasticity of demand. From (2.2) and (2.5) we can then derive how variables are likely to affect the sales to location k of the representative firm located in G

$$S_{Gk} = p_k x_{Gk} = S_{Gk}\left[\overset{+}{H_k},\ \overset{-}{n_k},\ \overset{-}{n_{-k}},\ \overset{-}{\tau_k},\ \overset{+}{\tau_{-k}},\ \overset{-}{w_G},\ \overset{+}{w_E},\ \overset{+}{w_U},\ \overset{+}{\frac{m_G}{m_E}},\ \overset{+}{\frac{m_G}{m_U}}\right]. \tag{2.6}$$

The sales to location k will increase with the expenditure of location k $(H_k)$, with the trade costs between G and the other location $(\tau_{-k})$, with the wage levels in E and U $(w_E, w_U)$, and with the relative quality of the production process in G with respect to the two other locations ($m_G / m_E$, $m_G / m_U$); these variables are likely to increase with the firm R&D expenditures, with the spillovers from other German firms, and are likely to diminish with foreign R&D expenditures. The sales to location k are instead likely to decrease with the number of firms in location k $(n_k)$ and, although to a lesser extent, with the number of firms in other market $(n_{-k})$. They also decrease with the trade costs between G and k $(\tau_k)$, and with the wage prevailing in G $(w_G)$.

The operating profits (sales minus total variable costs) that the representative firm of G derives from selling to market k $(\pi_{Gk})$ can easily be obtained as a fraction of sales to k:

$$\pi_{Gk} = S_{Gk} - \frac{w_G \beta x_{Gk}}{m_G} = \frac{S_{Gk}}{\sigma}. \tag{2.7}$$

## 2.2 Patenting Choice and Econometric Implementation

The operating profits have been derived under the assumption of full appropriation of a firm's monopolistic position. As argued above a firm may not always be able to appropriate fully the returns of its R&D investments in which case we will assume that the firm will enjoy a lower level of profits than the one described by equation (2.7). One way in which the firm can protect its interests is by patenting. However, since patenting implies disclosure of information, competitors may have the chance to invent around the patented product. In order to account for the idea that patent coverage may not exclude profitable imitation, assume that a firm can only fully appropriate the benefits of a patent and gain profits in (2.7) with a certain probability. In case of imitation assume for simplicity that profits take on the value of profits if the firm had decided not to file the patent. Hence, the expected operating profits when patenting in location k are:

$$E\left[\pi_{Gk}^{(1)}\right] = \Phi_{Gk}(z_k)\pi_{Gk}^{(1)} + \left(1 - \Phi_{Gk}(z_k)\right)\pi_{Gk}^{(0)}, \tag{2.8}$$

where $\pi_{Gk}^{(j)}$, j = 0,1, denote operating profits of the firm selling to market k in the case of patenting (j=1) and non-patenting (j=0) as defined by (2.7). The probability of complete appropriation is given by $\Phi_{Gk}(z_k)$ with $z_k$ a vector of determinants of appropriation and imitation.

The representative firm of G would patent in location k if patenting generated expected operating profits that exceed operating profits under non-patenting plus the costs $C_k$ of patenting in location k:

$$E\left[\pi_{Gk}^{(1)}\right] - \pi_{Gk}^{(0)} = \Phi_{Gk}\left(\pi_{Gk}^{(1)} - \pi_{Gk}^{(0)}\right) \geq C_k, \tag{2.9}$$

where we have assumed that the fixed costs of production are covered under both patenting strategies (i.e. $E\left[\pi_{Gk}^{(1)}\right] - C_k \geq F_k$, $\pi_{Gk}^{(0)} \geq F_k$).[7]

The left hand side represents the extent to which patenting raises operating profits, while the right hand side represents the fixed costs of patenting. The benefits and the cost of patenting have been extensively analyzed in the literature and we will just describe which factors play a crucial role. The advantage of patenting in location k as measured by $\Phi_{Gk}\left(\pi_{Gk}^{(1)} - \pi_{Gk}^{(0)}\right)$ increases with the quality of enforcement of property rights and with the length of the patent (for the good produced by the firm) in location k. Patenting is less relevant if the firm's industry in location k is characterized by a high level of secrecy, by firm specific human capital and skills, by long term employment, by complexity of design, and if patenting produces an adverse effect of allowing easier imitation by forcing disclosure of important information. The cost of patenting in location k ($C_k$) is likely to be affected by location specific variables. It increases with the fee charged in country k, and it is higher if G and k have different languages[8] or different legal

7 In our econometric study we restrict our attention to export firms only. Therefore this condition is satisfied.
8 In our analysis this will always be the case unless German firms apply for a patent in Austria or Switzerland.

systems. The cost is lower if the firm has already patented in k, or has the ability to influence the decision regarding the acceptance of the patent (lobbying). Patenting activity is generally likely to face increasing returns to scale, suggesting that large firms should face lower costs for each patent.

Equation (2.9) can serve as a specification device for a standard threshold crossing binary choice problem. Denote the latent variable $y^*_{Gk} = E[\pi^{(1)}_{Gk}] - \pi^{(0)}_{Gk} - C_k$ as the expected returns to patenting. Hence we observe a patenting firm if $y^*_{Gk}$ exceeds zero and we observe a non-patenting firm otherwise.

## 3. International Patent Procedures

The necessity to coordinate national patent protection laws on the international level has lead to several conventions which determine today's institutional framework for international patent applications. The Convention for the Protection of Industrial Property ('Union Convention') signed in Paris on March 20, 1883, established the principle of the priority year. This principle states that a patent initially filed with a national patent office of a signatory country (a 'priority patent') can be submitted within one year to any patent office of other countries that have ratified the treaty. As of January 1, 1993, 108 countries signed the convention (cf. OECD, 1994a). Revisions of the Union Convention led to the establishment of the World Intellectual Property Organization (WIPO) in 1967 in Geneva and to the Patent Co-operation Treaty (PCT) signed in Washington on June 19, 1970. Since the PCT went into force on June 1, 1978, a single patent application filed with WIPO and designated to different contracting states and regions has the same effect as a number of national applications for the same countries (cf. OECD, 1994a). A comparable standard for Europe has been achieved by the European Patent Convention (EPC) that was signed in Munich on October 5, 1973, and also went into force on June 1, 1978. A single patent applied at the European Patent Office (EPO) - a so called Europatent - can be designated to any number of signatory countries.[9] In 1992 (the year of origin of the data described in the next section) the following 17 countries were covered by the EPC: Austria, Belgium, Denmark, France, Germany, Greece, Ireland (since August 1),

9 The patent protection law remains under national concern. Patent protection under European law was introduced with the Luxembourg Convention on December 15, 1975. However, this convention is not in force yet because it has not been ratified by all signing countries.

Italy, Liechtenstein, Luxembourg, Monaco, Netherlands, Portugal, Spain, Sweden, Switzerland, and the United Kingdom (cf. European Patent Office, 1993). The EPO also receives applications from the WIPO which are submitted under the PCT and designated to EPC contracting states. When these patents 'enter the regional phase' they are labeled EURO-PCT applications (EPO, 1993). In 1992 the EPO received a total of 58,900 applications including 12,800 EURO-PCT applications. On average, 7.8 countries were designated per application. The majority of applications were initially filed with national offices but 7.8 % were priority patents. EPO membership states accounted for slightly more than every second application with an average of 8.7 designations and Germany as the dominating contributor with a share of 40 % (EPO, 1993).

In general, patent applications are published by the WIPO 18 months after the date of the priority application. This holds for the vast majority of national applications (e.g. with the German Patent Office, GPO) as well as for patents filed with EPO. The important exception are patents filed with the United States Patent and Trademark Office (UPO) which are published at the time they are granted which can take up to five years after the date of priority (cf. OECD, 1994a).

Another remarkable difference between European and U.S. patents is related to the maximum life of patents which is limited to 20 years after the date of application in Europe and to 17 years after the date the patent is granted in the U.S. (cf. Kaufer, 1988, p.12). Most patent offices (including GPO, EPO, UPO) do not automatically grant protection for the maximum permissible duration but require periodic patent fees to be paid to extend the life of a patent. These renewal fees may increase sharply over time, as for example in Germany, to refrain from protecting inventions with marginal value. Early calculations for European patents indicate that a patent application for three countries with the EPO is less expensive than two direct national applications taking application and renewal fees into account (cf. Kaufer, 1988, p.15). However, this calculation can only serve as a rule of thumb and depends heavily on the designation, as the following exemplary calculation for a French company in 1993 given in OECD (1994a) clearly reveals: an application designated to Sweden is more expensive (FF 30,900) than designations to both Germany and the U.K. (FF 29,100). Part of these fees are due to translation costs which make designations to countries with the same official language more attractive (cf. footnote 8). According to calculations of the EPO in Munich in November 1996, translation costs account for 37 % of the total costs (DM 61,200) of the average German application at the EPO with 10 years protection for 8 designated countries and 6 necessary translations.[10] This is the largest cost share followed by 27 % recurring fees such as renewal costs and 18 % each non-recurring fees and other costs (e.g. for lawyers).

## 4. Data and Econometric Approach

For our empirical work we use the first wave of the *Mannheim Innovation Panel* ('Mannheimer Innovationspanel', MIP) collected in 1992 by the Centre for European Economic Research (ZEW, Mannheim). This data source contains detailed information on the patenting behavior of German firms. The questionnaire follows the guidelines proposed by OECD (1992) in the so called 'Oslo-Manual' for the standardization of innovation surveys. The database serves as Germany's contribution to the European Community Innovations Surveys (CIS) established to facilitate a comparison of innovation behavior in the EC. Each firm reporting a patent application in 1992 is asked to give the exact number of patents applied at the German, European, and U.S. patent offices. Other locations are combined to a fourth category 'other patent office', which is omitted in our analysis because of the impossibility to match location specific variables to this rather broad category. In following with our theoretical setup we use, for our empirical work, only the binary information of whether a firm applies for patent protection at a particular patent office or not. Unfortunately, our data do not allow us to identify whether the applications at different locations refer to the same patent or patent family. If they do, the dependent variables are correlated across equations. Hence, unlike previous single equation estimates by König and Licht (1995) and Licht and Zoz (1998) for count data, we use full information maximum likelihood probit.

The original data source includes about 3,000 firms in manufacturing, construction and service (cf. Harhoff and Licht, 1994, for details on the data composition). We focus on manufacturing because the sectoral information on some crucial variables (R&D, value added, and wages) is not available for the remaining sectors. We also exclude firms without R&D and export activities from the sample because they do not coincide with our theoretical model.[11] After deleting missing values, our final sample consists of 887 firms.

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10 Information kindly provided informally by the EPO.

11 This exclusion does not introduce a bias in out analysis of patenting choice, as only 3 of the excluded firms applied for a patent.

**Table 3.**
**Descriptive Statistics**

| | Type | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| *patents applications at* | | | | | |
| German Patent Office | D | 0.4295 | 0.4953 | 0.00 | 1.00 |
| European Patent Office | D | 0.3224 | 0.4677 | 0.00 | 1.00 |
| U.S. Patent and Trademark Office | D | 0.1962 | 0.3973 | 0.00 | 1.00 |
| *size of firm and sector* | | | | | |
| number of employees | L | 5.6207 | 1.6193 | 1.10 | 12.06 |
| number of firms in domestic sector | L | 3.6458 | 0.6967 | 2.43 | 4.57 |
| *research and development* | | | | | |
| R&D expenditures of firm | L | -0.0505 | 2.1254 | -6.91 | 7.74 |
| R&D expenditures of domestic sector | L | 8.2186 | 1.1979 | 5.89 | 9.54 |
| R&D department | D | 0.5919 | 0.4918 | 0.00 | 1.00 |
| R&D cooperation in Germany | D | 0.3168 | 0.4655 | 0.00 | 1.00 |
| R&D cooperation in Europe | D | 0.1488 | 0.3561 | 0.00 | 1.00 |
| R&D cooperation in the U.S. | D | 0.0654 | 0.2474 | 0.00 | 1.00 |
| *sector characteristics of designation* | | | | | |
| relative market size of Germany | L | 1.4820 | 0.4600 | 0.38 | 1.82 |
| relative market size of Europe | L | -2.9414 | 0.3589 | -3.89 | -2.30 |
| relative market size of the U.S. | L | 2.6114 | 0.4639 | 2.12 | 3.96 |
| relative wage of Germany (·10) | L | 5.1090 | 0.4736 | 4.35 | 6.15 |
| relative wage of Europe (·10) | L | -4.4713 | 0.9321 | -6.35 | -3.29 |
| relative wage of the U.S. (·10) | L | 2.6739 | 1.4601 | 1.10 | 5.54 |
| *innovative restraints* | | | | | |
| missing external capital | D | 0.2627 | 0.4403 | 0.00 | 1.00 |
| innovations imitable | D | 0.3393 | 0.4738 | 0.00 | 1.00 |
| *efficient protection mechanisms* | | | | | |
| secrecy | D | 0.2773 | 0.4479 | 0.00 | 1.00 |
| complexity of product design | D | 0.2007 | 0.4007 | 0.00 | 1.00 |
| temporal lead | D | 0.5536 | 0.4974 | 0.00 | 1.00 |
| long term employment contracts | D | 0.4972 | 0.5003 | 0.00 | 1.00 |
| *provenance of firm* | | | | | |
| located in eastern part of Germany | D | 0.2097 | 0.4073 | 0.00 | 1.00 |
| subsidiary of foreign firm | D | 0.0620 | 0.2413 | 0.00 | 1.00 |

Note: The data source is the first wave of the Mannheim Innovation Panel (MIP, 1993) containing 887 firms located in Germany and engaged in export activities. R&D expenditures of the domestic sector are taken from SV-Stifterverband (1995). The type of the variables is either D for dummies or L for variables transformed in logs. Relative sector characteristics are computed from OECD (1994b), converted in German marks, and defined as the log of the quotient of the respective variable of the designated location and the mean of the remaining two locations. Market size is defined in terms of value added and wages in terms of monthly gross earnings. European values are calculated as the average value of the EPO contracting states in 1992 excluding Germany.

Table 3 contains descriptive statistics of the covariates being used in the empirical work. Our explanatory variables include the number of employees within the firm and the number of firms within the sector taken from OECD (1994b). While the former variable should reflect economies of scale and scope the latter should reflect domestic market structure. Due to missing data we were not able to construct a similar measure for the markets abroad.

The data source contains several indicators of the firm's research and development activities. We use R&D expenditures as a measure of current R&D efforts. Dummy variables for the existence of an R&D department and a R&D cooperation with a firm in the designated location are also introduced to capture the firm's economies of scale in R&D and foreign R&D spillovers. R&D spillovers are assumed to increase a firm's product quality in our theoretical model and are captured empirically by total R&D expenditures of the firm's domestic sector which are taken from SV-Wissenschaftsstatistik (1995).

Using sector information obtained from OECD (1994b) we generate two variables reflecting the market size and the wage level of each designation. Market size is defined in terms of value added and wages in terms of monthly gross wages and salaries. Using this information we construct relative measures of the market size and wage level for the three locations defined as the log of the ratio of the respective variables to the average value of the remaining two locations. In our definition, Europe consists of the EPO contracting states in 1992 excluding Germany which serves as a separate location. We refrain from using separately the level information on sector size and wage of the three locations in each patent equation because these sector variables do not vary much across the firms in the sample. Out procedure yields a single variable which contains the information of all three locations.

The firms in the data set were asked to name potential constraints to their innovative success which includes the danger of imitation. We add a dummy variable with value one for firms stressing the importance of imitation. This variable measures directly the probability that a firm appropriates the returns of patent protection used in our theoretical model.

Firms may not have an incentive to apply for patent protection if there exist other sufficiently efficient protection mechanisms. To detect potential substitutes of patent protection we include four dummy variables for other protection mechanisms with value one if they are claimed to work efficiently for process innovations. These mechanisms are secrecy, complexity of product design, temporal lead in the development of new processes and long term employment contracts in order to secure the loyalty of qualified employees.

Finally we account for differences in the patenting behavior of firms located in the eastern and western part of Germany assuming that the former are less likely to engage in international trade and patenting. A dummy variable for a firm located in East Germany should reflect this assumption. A second dummy variable indicates if a firm is a subsidiary of a foreign company, which may reduce its fixed costs of international patenting by reducing e.g. the translation costs.

## 5. Estimation Results

Table 4 contains the results of the trivariate ML probit estimates for the probability of applying for a patent at the three patent offices under consideration. Due to data limitations we have to restrict our attention to firm and sector specific determinants of patenting. Choice specific factors such as location specific application costs and the quality of granted protection are depicted by the intercepts. A positive coefficient on a firm specific variable indicates that the impact of this variable on profits increases in the case of patenting. To put it differently, if the increase (decrease) in profits due to the change in the explanatory variable is larger (smaller) when patenting, we would expect the firm's propensity to patent to rise. Thus the estimated coefficients reveal information on how patenting affects demand and production costs. Note that coefficient estimates that do not turn out to be significantly different from zero do not necessarily conflict with our theoretical model, instead they rather indicate that the impact of this variable on profits is independent of the firm's patenting strategy.

Focussing only on coefficients that are significantly different from zero we find an identical sign pattern for the three equations. Hence the impact of the explanatory variables on a firm's propensity to patent is qualitatively the same for each of the locations.

We use firm size and the number of firms in the domestic sector as a proxy for the firm's market power in each of the locations. Both measures are admittedly crude, however, if the industrial structure is not too different in the three locations such that the number of firms in the foreign sectors is approximately proportional to the number of firm's in the domestic sector the latter variable reflects the effects of the number of firms in the foreign sector as proposed by our theoretical setup. While the number of firms does not have a significant impact on the propensity to patent we find a significant positive association between firm size (measured in terms of the number of employees) and patenting. The results with respect to the impact of the number of firms do not change if the firm size variable is dropped from the equation. If firm size is a proxy for market power we would expect firms with more market power (or a lower aggregate price elasticity of demand) to extract larger gains from patenting. The significantly positive coefficient is therefore in accordance with the theoretical reasoning. However, firm size may also depict economies of scale and scope with respect to patenting. Large firms are likely to be able to reduce their application costs per patent.

In our theoretical framework a firm can reduce labor input requirements by R&D investments. Since larger R&D efforts imply a downward shift of marginal costs, the relative benefits of patenting increase with reduced marginal costs. The same argument holds for the R&D expenditures of the domestic sector which serve to approximate the R&D efforts of the competitors in the sense of information externalities (R&D spillovers). For all three equations the two coefficients are positive as expected and significant in five out of six cases.

The existence of an R&D department does not enhance the firm's patenting activity regardless of the destination of the patent. Given the level of R&D expenditures there are no additional gains in terms of patent activity if a firm coordinates its R&D activities through an R&D department. However, having R&D cooperation with an U.S. based firm increases the probability of patenting at the U.S. Patent and Trademark Office. An obvious explanation for this finding is that R&D cooperation may reduce the access costs of patent applications in the U.S. (information costs, or translation costs etc.). In addition, external effects of R&D are internalized by R&D cooperation which increases the probability of appropriation, $\Phi(\cdot)$.

In accordance with the evidence on aggregate data presented in the introduction we find that the relative size of the U.S. sector increases the probability to patent. For the two other locations we cannot find empirical support for the demand hypothesis at the micro-level. Since we use relative sector wages, our relative wage cost measure is rather crude and strongly correlated with sector heterogeneity. Thus it comes with no surprise that our wage measure has no significant impact on the probability to patent.

Restraints to innovation are picked up by the variables *'innovation imitable'* and *'missing external capital'* which in our theoretical framework affect the firm's propensity to patent via the probability of successful appropriation. Both variables do not have a significant impact on patenting: Firms which regard their products as easily imitable rely on patenting as much as firms whose products are less imitable.

**Table 4.**
**The Probability to Patent - Trivariate Probit Estimates**

| | German Patent Office | | European Patent Office | | United States Patent Office | |
|---|---|---|---|---|---|---|
| | coeff. | t-value | coeff. | t-value | coeff. | t-value |
| intercept | -2.07 | -2.64 | -2.04 | -1.62 | -4.42 | -3.19 |
| *size of firm and sector* | | | | | | |
| number of employees in firm | 0.17 | 3.55 | 0.11 | 2.02 | 0.11 | 1.72 |
| number of firms in domestic sector | 0.04 | 0.46 | -0.05 | -0.30 | 0.06 | 0.35 |
| *research and development* | | | | | | |
| R&D expenditures of firm | 0.17 | 3.93 | 0.25 | 5.59 | 0.24 | 4.41 |
| R&D expenditures of domestic sector | 0.10 | 1.29 | 0.16 | 2.85 | 0.18 | 2.63 |
| R&D department | 0.20 | 1.81 | 0.08 | 0.66 | 0.13 | 0.81 |
| R&D cooperation in designation | 0.12 | 1.19 | 0.13 | 0.99 | 0.48 | 2.66 |
| *sector characteristics of designation* | | | | | | |
| relative market size of designation | 0.05 | 0.31 | -0.11 | -0.59 | 0.45 | 2.26 |
| relative wage of designation | -0.06 | -0.39 | 0.13 | 1.17 | -2.56 | -0.97 |
| *innovative restraints* | | | | | | |
| innovations imitable | 0.02 | 0.22 | -0.01 | -0.11 | 0.02 | 0.15 |
| missing external capital | 0.11 | 0.94 | 0.17 | 1.30 | 0.05 | 0.34 |
| *efficient protection mechanisms* | | | | | | |
| secrecy | 0.19 | 1.60 | 0.09 | 0.70 | 0.21 | 1.45 |
| complexity of product design | 0.09 | 0.73 | 0.28 | 1.89 | 0.25 | 1.52 |
| temporal lead | -0.18 | -1.64 | 0.02 | 0.18 | -0.17 | -0.82 |
| long term employment contracts | 0.25 | 2.36 | 0.00 | 0.01 | 0.01 | 0.04 |
| *provenance of firm* | | | | | | |
| located in eastern part of Germany | -0.57 | -4.06 | -1.30 | -5.62 | -1.53 | -4.50 |
| subsidiary of foreign firm | -0.37 | -1.92 | -0.35 | -1.78 | -0.19 | -0.91 |
| *coefficients of correlation* | corr(GPO, EPO) | | corr(GPO, UPO) | | corr(EPO, UPO) | |
| | 0.72 | 2.48 | 0.72 | 0.85 | 0.80 | 0.46 |
| prediction success in % | 73.62 | | 78.02 | | 84.78 | |
| McKelvey-Zavoina Pseudo-$R^2$ | 0.39 | | 0.50 | | 0.50 | |
| # of observations | | | 887 | | | |
| mean log-likelihood | | | -1.1374 | | | |

Note: See notes to Table 3 for information on the data source. The estimates are obtained by Maximum Likelihood estimation of a trivariate probit model using the Gauss-Legendre quadrature integration procedures contained in GAUSS.

The possibility of protecting process innovations by patents is limited since enforcement of the patent is cumbersome and costly, particularly for the case of process innovations. Hence keeping qualified personnel is a meaningful complementary tool to increase appropriation of R&D returns. Given that German based R&D personnel is mainly demanded for German competitors, the complementary effect between patents and long term contracts as determinants of appropriation is likely to be most pronounced for the German patent equation as evidenced by our regression results.

A well-known empirical finding that East German firms do not patent as much as their West German competitors is also confirmed by our study. This effect is particularly strong for U.S. patents and also quite substantial for patent applications at the EPO. Having in mind that our data were collected in 1992, two years after unification, the low propensity to patent reflects also the limited trade relationships between East Germany and Western economies.

Multinationally operating firms may have the chance to share costs and benefits from patenting such that patent applications of German subsidiaries are less frequent. For this hypothesis we can only find weakly significant evidence for applications at the German and European patent offices.

In order to assess the goodness of fit for the three equations we use the prediction success as well as the McKelvey-Zavoina Pseudo-$R^2$ measure. Both measures point in the same direction indicating that the fit is best for the U.S. equation and the European equation in terms of $R^2_{MZ}$, while the explanatory power for patent applications in Germany is less strong on the basis of both goodness of fit measures.[12] As expected the correlations between equations are very large and positive. However, while the Cholesky factors of the variance-covariance matrix of the error terms (not reported in Table 4), which are used to maximize the log-likelihood function, are highly significant, the correlation coefficients (evaluated using the delta method) are only significant for applications at the German and European patent offices.

12 The prediction success for the U.S. equation should not be overstated since this measure highly depends on the distribution of the dependent variable.

# 6. Conclusion

The goal of this paper is to investigate both theoretically and empirically the link between the geographic choice of patenting and trade patterns. From a simple trade theoretic framework we derive an econometric discrete choice model from which we gain empirical evidence on the basis of a cross-section of 887 German manufacturing firms.

Similarly to previous studies on the same data set, the size of the firm and the amount of R&D expenditures are significant in explaining the patenting choice. The geographic location of the patenting choice is well explained in the case of the USA by a trade variable, the relative market size between Germany and the USA, and by a strategic variable, R&D cooperation between the German and American firm. In general, however, trade variables as captured by relative market size and relative wage, do not substantially contribute to explaining the locational choice of patenting. Also, variables representing the constraint on the ability to innovate or the efficiency of the mechanism of protection of ideas are usually not significant. The low t-statistics of trade variables (market size and relative wage) may be due to the low variation of such macro variables, while the low t-statistics of the innovation and protection variables may be due to the high presence of noise in micro data. Due to the cross-sectional character of our data a number of interesting effects cannot be tested since they are time invariant or nearly time invariant. For instance, the effects of transportation costs and the number of firms abroad on patenting as time invariant factors are only depicted by the intercept or the error term.

One ambitious way of improving our database would be to extend it to firms located in different countries, and to include information on their patenting choice, on more countries (which may allow for a sufficiently high signal to noise ratio), on sector specific trade costs, and on the sectoral market structure in foreign markets. This would allow to investigate further the relation between patenting choice and trade determinants, as well as to access whether patenting is considered by firms as an alternative way of protecting ideas which are not subject to a natural protection mechanism (such as secrecy, temporal lead, and complexity of product design).

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