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By

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ABSTRACT

INNOVATION, NETWORK EXTERNALITY, AND INTERNATIONAL TRADE

By

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The dissertation consists of three essays exploring the effects of innovation on the extensive margin, the intensive margin, and the duration of exports, as well as the influence of network externality and products compatibility on firms' FDI decisions.

An important prediction of international trade theories is that countries which innovate more will export more. However, these theories have very different implications for how innovation would increase exports. In the first chapter, I empirically investigate the extent to which innovation increases the number of products (the extensive margin) and the export value of each product (the intensive margin). Using data on patents granted by the United States and data on manufacturing exports from 105 countries to the U.S. market over the period 1975-2001, I find that innovation has positive and significant effects on both the extensive and intensive margins. The intensive margin contributes about 70% of the effects, and the extensive margin accounts for the remaining 30%. The estimated results indicate that the effect of innovation on exports is stronger in low-income countries than in high-income countries. It is also stronger in industries which have relatively more differentiated products than homogeneous products. Finally, more innovative countries export larger quantities at higher prices, suggesting that innovation increases the product quality of exports.

The second chapter continues studying the impact of innovation on exports, but

the focus is switched to the dynamic pattern of trade. I use the survival analysis to investigate the effect of innovation on the duration of exports at the product level. The estimated results show that countries which have more innovations can sustain their export relationships for a longer period of time. The findings are consistent with the implication of the product cycle model, which stresses the role of innovation on dynamic trade patterns. The estimates also display that the duration of exports increases with country size and decreases with trade costs and barriers.

Traditional trade theories explaining different FDI patterns across firms and sectors seek answers from the production side, such as the proximity-concentration trade-off and the factor-proportions hypothesis. The third chapter provides a new explanation for FDI (foreign direct investment) patterns from demand-side properties. I develop a differentiated-product duopoly model to analyze the effects of network externality (demand-side economies of scale) and product compatibility on firms' FDI decisions. The model is able to explain the following facts in FDI. First, firms producing compatible products are more likely to undertake FDI in the same location than firms producing incompatible products. Second, FDI is more prevalent in industries with strong network externality effects. This explains why FDI is more important in high technology industries. Third, a firm is more likely to undertake FDI if it has a larger installed base (more existing customers) in the foreign market. This is consistent with the fact that larger firms or firms with longer history are more likely to undertake FDI.

To my parents

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1 Introduction

An important prediction in international trade theories is that innovation improves countries' export performance. However, these theories differ in their predictions about *how* innovation increases exports. The first strand of the literature predicts that innovation can introduce new products to the market or expand the range of products that a country exports (Krugman, 1979; Jenson and Thursby, 1986; Dollar, 1986; Grossman and Helpman, 1989). These studies emphasize the role of innovation in increasing the number of products, which will increase the *extensive margin* of exports. The second strand of the literature stresses that innovation can increase productivity (Eaton and Kortum, 1997a, 1997b, 1999, 2001, 2002) or improve product quality (Flam and Helpman, 1987; Grossman and Helpman, 1991a). Innovation enhances countries' competitiveness and leads to a higher export value of each product, which will increase the *intensive margin* of exports.

Although the effect of innovation on trade has been examined extensively in the theoretical literature, very little empirical work has been done to find the evidence for the role of innovation in affecting export performance for a wide range of countries and industries. Inspired by these trade theories, in this chapter I will assess the importance of innovation in determining export performance using a sample of 105 countries and 12 manufacturing industries. My work is also motivated by the firm-level studies that find ample evidence that good firms export, but scant evidence for the learning-through-exporting effect (Bernard and Jensen, 1999; Clerides, Lach, and Tybout, 1998; and Tybout, 2001). However, these firm-level studies mostly focus on the U.S. or a few developing countries (e.g. Mexico and Columbia). It is unclear whether the positive effect of productivity and innovation exists for a wider range of countries. In addition, my work is complementary to the literature that focuses on the effect of international trade on technology diffusion and productivity (Coe and Helpman, 1995; Keller, 1998; Xu and Wang, 1999).

The main object of this chapter is to estimate the effect of innovation on exports and to decompose the effect into the extensive margin and the intensive margin. In empirical trade literature, the extensive margin represents the *width* of exports, and the intensive margin represents the *depth* of exports. In this chapter, the extensive margin is measured by the number of products exported from a country, and the intensive margin is measured by the export value of each product from a country. I calculate the extensive and intensive margins of exports using detailed data on 105 countries' exports to the U.S. market over the period 1975-2001, and use the data on patents granted by the U.S. as a proxy for innovation. My estimates show that innovation has a positive and significant effect on both the extensive margin and the intensive margin, and the intensive margin accounts for a larger proportion of the impact. This result holds for various specifications. In the benchmark estimation, a country with 10% more patents will export 5.4% more to the U.S. The effect can be decomposed into 1.6% higher extensive margin and 3.8% higher intensive margin. The intensive margin accounts for 70% of the greater exports from more innovative countries, and the extensive margin accounts for the remaining 30%. I further decompose the intensive margin into the price and quantity indices, and find that more innovative countries export higher quantities at slightly higher prices, which suggests that innovation increases the quality of exports.

The decomposition of innovation's effect has important welfare implications. An increase in the extensive and intensive margins may lead to different terms-of-trade effects. If innovation increases the number of products in exports (an increase in the extensive margin), the terms-of-trade move in the innovating country's favor and innovation unambiguously increases the welfare of the innovating country. If innovation makes countries export more of each product (an increase in the intensive margin), the terms-of-trade effects can be ambiguous or even negative. The estimates of this paper suggest that more innovative countries export more varieties of products and have higher export prices. Thus, my results imply that innovation improves the innovating countries' welfare not only by increasing the number of varieties, but also by improving their terms of trade.

In this paper I also investigate how the effect of innovation on exports differs across countries, industries, and years. First, North-South trade models (e.g. Krugman, 1979; Flam and Helpman, 1987) show that technological progress may impose asymmetric impacts on developed and developing countries. I include the interaction between patent counts and GDP per capita to allow innovation's effect to vary with countries' income levels. The estimates show that the impact of innovation on exports is stronger and the contribution of the extensive margin is also larger for lower-income countries. This result is different from existing literature which largely makes a simplified assumption that developing countries do not innovate. My estimates suggest that innovation is an important factor of developing countries' technology catch-up. Second, the effect of innovation may be larger for industries with a higher share of differentiated goods, because innovation should be more important in the production of differentiated products than that of homogeneous products. Using Rauch's (1999) classification of differentiated and homogenous products to categorize industries, my estimates reveal that innovation has a stronger impact on exports in industries with a higher share of differentiated products, such as instruments, electronics, and transportation equipment. Third, the effect of innovation and the composition of the effect may change over time. The year-by-year estimation shows that the effect of innovation decreases over time, which is mainly due to a decline in the contribution of the extensive margin.

The method of decomposition used in this paper is closely related to Hummels and Klenow (2005). They analyze the relationship between country size (measured by GDP per worker and employment) and the extensive, intensive, and quality margins of exports. They find that the extensive margin accounts for 60% of the greater exports from larger economies, and the intensive margin is dominated by higher quantities rather than higher unit values. My paper extends their work in the following ways. First, in addition to country size, I include innovation as an important factor determining countries' trade performance in different margins. My estimated results show that innovation has significantly positive impacts on different margins of exports, even after controlling for the country size and income level. Second, I construct the indices of export performance at the industry level, while Hummels and Klenow (2005) construct these indices at the country level. Using industry-level trade data enables me to compare the effect of innovation on exports in different sectors. My results show that the impact of innovation on overall export performance and the relative contributions of the extensive and intensive margins differ significantly across sectors. Finally, I use panel data which contains 105 countries' exports to the U.S. from 1975 to 2001, while Hummels and Klenow (2005) use a cross-sectional sample for the year 1995. Using the panel data allows me to control for the unobserved country and industry fixed effects, and to compare the change in the effects of innovation over time. Furthermore, using the panel data allows me to estimate a dynamic model that takes into account the persistence of exporting (Roberts and Tybout, 1997).

This paper also contributes to the following two strands of empirical literature. The first strand of literature looks into the composition of trade. Traditional international trade studies usually focus on the total value of trade between countries. However, recent research looks more deeply into the composition and the different dimensions of trade, such as the number of varieties, the volume of exports, the quality of exports, and the duration of export relationships (Funke and Ruhwedel, 2001; Hummels and Klenow, 2005; Schott, 2004; Hallak, 2006; Besedeš and Prusa, 2007). Many variables (such as the country size, growth rate, income level, and distance) have been linked with these different margins in exports, but the impact of innovation on the extensive and intensive margins has not been explored yet. The second strand of literature examines the correlation between innovation and exports empirically. These studies find a positive correlation between innovation and export performance either within a country (Gruber et. al., 1966; Keesing, 1967) or across countries at the aggregate level (Soete, 1987; Fagerberg, 1988, 1996; Wakelin, 1998). However, they do not estimate in which margin innovation has the largest impact, which is the focus of my paper.

The remainder of this chapter is organized as follows. Section 2 provides a theoretical background of the empirical model. Section 3 describes the data source and the construction of both the exports and innovation variables. Section 4 shows the models of estimation and presents the estimated results. Section 5 decomposes the effect on the intensive margins into price and quantity. Section 6 concludes.

2 Theoretical Framework

This section reviews two strands of trade theories which motivate the empirical estimations in this paper. These papers stress the role of innovation and technological progress on exports. Nevertheless, they differ in the predictions about how innovation affects exports.

To help explain the impact of innovation on the different margins of exports, consider the following simple model. Suppose consumers in the U.S. can purchase products from C countries. Each country has a large number of firms producing different products. Consumers have a CES utility function over products. They face the following maximization problem

$$max_{q_{cj}} \; U = (\Sigma_{c=1}^{C} n_c \theta_{cj} q_{cj}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} \tag{1}$$

$$s.t.\ \Sigma_{c=1}^{C} n_c p_{cj} q_{cj} = I \tag{2}$$

where subscription c is country, j is product variety, n_c is the number of products produced by country c, θ_{cj} is the quality of product j from country c, q_{cj} is the export quantity of product j from country c, and p_{cj} is the unit price of product j from country c. $\sigma > 1$ is the elasticity of substitution between any two products, and I is consumers' income levels. Equations 1 and 2 imply that firms in the same country are symmetric: they produce products of equal quality ($\theta_{cj} = \theta_c$) and charge the same price ($p_{cj} = p_c$). By solving the maximization problem in equation 1 and 2, I get the export value of each product from country c

$$p_c q_c = (p_c)^{1-\sigma} \theta_c^{\sigma} \Phi \tag{3}$$

where $\Phi = \Sigma_{c=1}^{C} (n_c {p_c}^{1-\sigma} \theta_c^{\sigma})$. Consumers buy every variety produced in country c, and the export value of country c is

$$n_c p_c q_c \tag{4}$$

This total value of exports can be decomposed into the extensive margin and the intensive margin. The extensive margin measures the width of export. In equation 4, it is captured by n_c, which is the number of products exported by country c. The intensive margin measures the depth of export. In equation 4, this margin is measured by $p_c q_c$, which is the export value per product from country c. In equation

3, quality works as a demand shifter, and the intensive margin of exports is increasing with product quality.

In trade literature, innovation is predicted to have important influence on both the extensive margin and intensive margin.

(1) **The extensive margin**

The link between innovation and the extensive margin is introduced by theories like Krugman (1979), Dollar (1986), Jensen and Thursby (1986), and Grossman and Helpman (1989). These studies emphasize the role of innovation in increasing exports by creating new products or expanding the range of products exported. For instance, Krugman (1979) develop a North-South trade model in which technological progress determines exports. In equilibrium, the relative number of products a country exports is increasing with its rate of technological progress. More innovations enable a country to export a wider range of goods, which increase the extensive margin of exports. In terms of equation 4, innovation will increase exports by increasing n_c.

(2) **The intensive margin**

Two strands of trade literature stress the ability of innovation in increasing the intensive margin of exports. First, innovation can raise product quality, which increases consumers demand of these goods. Grossman and Helpman (1991a) develop a quality-ladder model in which successful innovations can improve quality of products. Other studies such as Flam and Helpman (1987) and Grossman and Helpman (1991b) also assume that innovation is an important determinant of exports quality. In equation 3, the intensive margin ($p_c q_c$) increases with quality (θ_c), and thus a higher quality leads to a higher intensive margin of exports. Second, innovation can improve production efficiency. Eaton and Kortum (1997a, 1997b, 1999, 2002) develop a series of Ricardian models which link innovation, technology, and trade. Eaton and Kortum (2001) provide a unified framework in which innovation takes the form of extending the technology frontier and raising productivity. Higher productivity will reduce the production cost and decrease the export price p_c. From equation 3, the export value of each product decreases with price, as long as the elasticity of substitution $\sigma > 1$. This means an increase in productivity will reduce the unit price and increase the intensive margin of exports. In summary, these two strands of studies predict that innovation enhances producers' competitiveness by improving product quality or raising productivity, which leads to higher intensive margins of exports ($p_c q_c$).

According to these theories, if innovation increases the number of products, we expect to find a positive correlation between innovation and the extensive margin of exports. If innovation increases the quality of products or productivity, we expect innovation to be positively correlated with the intensive margin of exports. Despite the various predictions of theoretical works, empirical studies have not, to the best of my knowledge, tried to estimate and compare the relative importance and contribution of the different margins of exports regarding innovation's influence, and this motivates the estimations in this paper.

3 Data

An empirical study which estimates the relation between innovation and export performance requires data that fall into two categories. The first is a variable which measures countries' innovations or technological changes. The second is detailed information of exports which can be decomposes into the extensive margin and the intensive margin. Variables of a gravity equation, such as country size, distance, language and border are also included in my estimation. This section describes the data source and the construction of both the exports and innovation variables.

3.1 Innovation Data

The key explanatory variable in this paper is each country's innovation at the industry level. Patents granted by the U.S. are used as the proxy for innovations. The patent data come from Hall, Jaffe and Trajtenberg (2001).[1] The data comprise detailed information on about 3.5 million patents granted between 1963 and 2002 by the United States Patent and Trademark Office (USPTO).

In economic literature, a patent is an indicator of an innovation or invention. Some studies find a positively correlation between patents and new products, while others associate patents with the competitiveness or comparative technology advantage (see a survey by Griliches, 1990). These works show that patent count is a valid proxy for innovation which covers the concepts of both product and process innovations in the trade theories discussed in this paper. A potential problem is that patents vary

[1] Data after 1999 is updated by Hall.

enormously in their technological and economic significance, and thus simple patent counts cannot precisely measure innovative outputs. It has been shown in empirical studies that patent counts weighted by citations are more closely associated with their value and importance (Trajtenberg, 1990; Jaffe et al., 2000; Hall et al., 2000, 2001). In this paper, patents are weighted by the number of citations received, and the *weighted patent counts* (WPC) are used to assess the innovations or innovative capabilities of countries. The linear weighting scheme which follows Trajtenberg (1990) is applied to construct the weighted patent count index:

$$WPC_{cit} = \Sigma_{j=1}^{n_{cit}}(1 + g_j) \tag{5}$$

where subscription c is country, i is industry, t is year, n_{cit} is the number of patents issued to country c in industry i during year t, and g_j is the number of citations received by patent j. The natural log of the weighted patent count in equation 5 is the key regressor in this paper.

Except patent, R&D expenditure is also used as a proxy for innovation in trade literature. I use patent counts for the following considerations. First, patents are the output of innovative activities, but R&D expenditure is the input. In trade theories, it is the results of innovation rather than the efforts of innovation that improve countries' export performance. Second, the time that an innovation is created is more accurately measured by the application year of patents than by the year of R&D expenditures. There is a time lag between R&D expenditure and innovation output. Third, patent data from a single source can reflect countries' innovative capabilities on a relatively comparable base.[2] R&D expenditures from different countries can have different measurements and efficiency. The patent data from USPTO cover a wider range of countries in a longer time span (1963-2002). On the contrary, industry-level R&D data are available only among a limited set of countries (such as OECD member countries), and the time span is shorter. Using R&D expenditure as the proxy for innovation will restrict the scope of this paper in a small group of countries with similar properties. Another drawback of using R&D expenditure is that it tends to underestimate the innovation contribution of small firms which do not have a separate research department.[3]

Two points should be emphasized when using weighted patent counts as the proxy for innovation. First, there is no natural scale or value measurement for patents and citations.[4] The number of patents granted and citations made depend largely on the examination process of Patent Office, which can be different by year and industry. This issue can be solved by including industry and year fixed effects in the regressions, which is a method similar to the fixed-effects approach used by Hall, et. al. (2001) to compare the citation intensity of patents from different cohorts. Second, each patent has two indices of time: the application year and the grant year. I classify

[2] I use patents granted by the U.S. rather than other countries, because intuitively U.S. is the technologically most advanced country in the world. It also has the largest market, which should attract most inventors in the world to apply for patents from (see Mahnood and Singh, 2003). Empirically, Soete (1987) finds that a patent granted by U.S. is indeed a superior measurement of international innovation than a patent granted by other countries like Japan, France, U.K. and Germany.

[3] Wakelin (1998) uses R&D expenditure and patent numbers separately as proxies of relative innovation performance, and she finds that the patent proxy captures it better than R&D expenditure, especially in high technology industries.

[4] For example, it is not clear whether a country having 100 patents in the year 1990 is more or less innovative than a country having 300 patents in the year 2000.

patents according to the application year because innovation outcomes are reflected on the year patents are applied rather than the year they are granted. However, patent counts are truncated when classified by the application year, especially in the last few years of the data. Hall, et. al. (2001) show that the average lag between the application and grant year in the sample is 1.97 years, and more than 95% of patents are granted within three years after they are applied. For the time being, I drop observations of the last three years (2000-2002) from the data to mitigate this problem. The truncation issue will be addressed in section 4.4 with a year-by-year estimation. More details about the patent data and the construction of weighted patent counts are discussed in appendix A.

3.2 Export Data

The data of exports at the product level for 1975-2001 are constructed by Feenstra (1996) and Feenstra, Romalis and Schott (2002). The data contain the quantity and value of each product that U.S. imports from other countries. Products are classified according to the 7-digit Tariff Schedule of the United States Annotated (TS7) in 1975-1988, and are classified according to the 10-digit Harmonized System (HS10) in 1989-2001.[5] The data also include U.S. Standard Industrial Code (SIC) of each product variety, which enables me to identify the extensive and intensive margins of exports at the industry level.

[5] These are very disaggregated data sets. In 1988, there are 11,198 commodities classified in TS7 exported to the U.S., and in 2001 there are 16,293 commodities based on HS10.

3.3 Method of Export Decomposition

To find out how innovation affects exports, I decompose trade values into the extensive and intensive margins. The decomposition method is similar to Hummels and Klenow (2005), but I calculate the two margins of each country at the industry level, instead of at the country level as in Hummels and Klenow (2005).

To suppress the notation, consider export data of products in the same industry and year. In equation 4, the export value of country c is $n_c p_c q_c$. The empirical counterpart of country c's export value is made relative to the *world* export value (i.e., the total export value of all products from all countries in the sample), and so country c's overall export share is

$$export_c = \frac{\Sigma_{j \in S_c} (p_{cj} q_{cj})}{\Sigma_{j \in S} (p_{wj} q_{wj})} \tag{6}$$

Subscription c is country, j is product variety defined by TS7 or HS10, w indicates *world* which represents all countries in the sample. $p_{cj}q_{cj}$ is the export value of product j that country c exports to the U.S. $p_{wj}q_{wj} = \Sigma_c p_{cj} q_{cj}$ is the *world* export value of product j to the U.S. S is the set of products that the world exports to the U.S. S_c is a subset of S in which country c has positive exports to the U.S. ($p_{cj}q_{cj} > 0$). The sum of all countries' export shares equals one ($\Sigma_c export_c = 1$).

The empirical counterpart of the extensive margin is an index which measures the relative number of products a country exports. If each product has a equal weight, the extensive margin is the fraction of products in which country c has positive exports (i.e., n_c/n_w,where n_c is the number of products exported by country c ($j \in S_c$), and

n_w is the total number of products exported to the U.S. from all countries ($j \in S$)). If each product is weighted by its world export value, $p_{wj}q_{wj}$, country c's extensive margin of exports will be

$$extensive_c = \frac{\Sigma_{j\in S_c}\,(p_{wj}q_{wj})}{\Sigma_{j\in S}\,(p_{wj}q_{wj})} \tag{7}$$

The extensive margin increases with the number of products that country c exports ($j \in S_c$).

The empirical counterpart of the intensive margin in equation 4 is defined as

$$intensive_c = \frac{\Sigma_{j\in S_c}\,(p_{cj}q_{cj})}{\Sigma_{j\in S_c}\,(p_{wj}q_{wj})} \tag{8}$$

It equals the ratio of country c's export value relative to world's export value of those products that country c has positive exports.[6]

From equations 6, 7 and 8, country c's export share equals the product of its extensive margin and intensive margin:

$$\underbrace{\frac{\Sigma_{j\in S_c}\,(p_{cj}q_{cj})}{\Sigma_{j\in S}\,(p_{wj}q_{wj})}}_{export_c} = \underbrace{\frac{\Sigma_{j\in S_c}\,(p_{wj}q_{wj})}{\Sigma_{j\in S}\,(p_{wj}q_{wj})}}_{extensive_c} \times \underbrace{\frac{\Sigma_{j\in S_c}\,(p_{cj}q_{cj})}{\Sigma_{j\in S_c}\,(p_{wj}q_{wj})}}_{intensive_c} \tag{9}$$

Equation 9 indicates that the overall export share can be decomposed linearly into

[6] As the export share, the extensive margin and intensive margins are smaller than one. Nevertheless, the sum of *extensive* and the sum of *intensive* do not equal 1. Consider an extreme case: if every country exports all varieties to the U.S., $extensive = 1$ for all c, and thus the sum of $extensive \neq 1$.

the extensive and intensive margins after taking natural logs:

$$\ln export_c = \ln extensive_c + \ln intensive_c \tag{10}$$

In the estimations of this paper, I construct the logs of overall export, the extensive margin, and the intensive margin of each country-industry-year according to equations 6, 7 and 8. These three variables will be the dependent variables in the estimations. An advantage of decomposing exports as in equation 10 is that when I regress each margin on the same regressors using a linear estimator (such as OLS), the estimated coefficients of each regressor will also have a linear relation: the coefficient of the overall export regression equals the sum of the coefficient of the extensive margin regression and that of the intensive margin regression. I can estimate the relative contribution of each margin regarding the impact of each regressor.

3.4 Other Controls

Five other controls are included alongside with the patent data in the benchmark estimation. Population and GDP per capita are included to control for country size. The data are from Penn World Table 6.2. I also include distance, common language, and common border in the estimation, which represent trade costs and resistances. These data are from Jon Haveman's International Trade Data.

3.5 The Sample

The complete sample of my empirical analysis contains observations of 105 countries in 12 manufactured industries (2-digit SIC) over the period 1975-2001. Lists of these countries and industries are in tables 1.1 and 1.2. Since the focus of this paper is to analyze the effect of innovation on different margins of exports, the sample only contains country-industry-years which have positive export flows to the U.S. The complete sample is thus an unbalanced panel which has 27,450 observations. To mitigate the truncation problem of patent counts as mentioned earlier, observations after 1999 are dropped in the benchmark estimations, and the sample used in the benchmark estimations has 25,268 observations.

4 The Extensive and Intensive Margins: Empirical Models and Estimated Results

4.1 Benchmark Estimation Model

The model of estimation in this section is an extension to Hummels and Klenow's (2005) model in the sense that innovation is considered as an additional and important determinant of export performance. The motivation comes from the theoretical literature reviewed in section 2. Nevertheless, the object of the empirical work here is not to formally test each model. These theoretical models are polar cases, and it is not surprising if none of them can individually cover the complete effect of innovation in the real world. The intension of this section is to *estimate* the relative impact of innovation on the extensive and intensive margins. The benchmark model of estimation is:

$$\ln(trade_{cit}) = \beta_0 + \beta_1 \ln(patent_{cit}) + \beta_2 \ln(pop_{ct}) + \beta_3 \ln((\frac{GDP}{pop})_{ct}) \quad (11)$$
$$+\beta_4 \ln(dist_c) + \beta_5 lang_c + \beta_6 bord_c + \beta_7 \mu_i + \beta_8 \lambda_t + \varepsilon_{cit}$$

$\ln(trade_{cit})$ in equation 11 represents the three export variables: the natural logs of the overall export, extensive margin, and intensive margin of exports. I will run three separate regressions to estimate the effect of innovation on each margin. These variables are defined in equations 6-8, and are calculated on the industry-year base. These dependent variables may change with industries and years,[7] and thus industry-specific effects (μ_i) and year-specific effects (λ_t) are included in the model.[8] The key explanatory variable, $\ln(patent_{cit})$, is the natural log of weighted patent counts (WPC) in equation 5. As discussed in section 3, weighted patent counts can change systematically by industry and by year because of the classification system and the examination process of U.S. Patent Office. The patent counts should also be adjusted by industry and year to be comparable in different industries and years. This adjustment is taken into account in a log linear model once industry and year fixed

[7] Although these variables are calculated relatively in a industry-year base, they can still change with time and industry. For example, in earlier years there were fewer countries export to the U.S. than in later years, and thus export shares in earlier years are likely to be higher than that of later years. Similarly, the number of countries which have positive exports can differ by industry.

[8] A complete control should include an interaction between industry and year fixed effects. It turns out the estimated results are almost identical, and thus I include industry and year dummies separately in the estimation without taking interactions.

effects are included.[9] $\ln(pop_{ct})$ and $\ln((\frac{GDP}{pop})_{ct})$ are natural logs of population and GDP per capita of country c in year t, and these two variables will change over time. Similarly, the inclusion of year dummy variables controls for this effect. $\ln(dist_c)$ is the natural log of the distance between country c and the U.S. $lang_c$ is a binary variable, which equals one if country c uses English as its primary language. $bord_c$ is a binary variable, which equals one if country c has a common border with the U.S. These three variables are included in the estimation as proxies for trade costs.

The coefficients on $\ln(patent_{cit})$ and other log variables are interpreted as the elasticity of different margins in exports with respect to these regressors. An advantage of taking natural logs is: because OLS is a linear operator, the regressions can decompose the impact of each regressor on overall exports into different margins additively: $\widehat{\beta_i}^{ex} = \widehat{\beta_i}^{em} + \widehat{\beta_i}^{im}$, where $\widehat{\beta_i}^{ex}, \widehat{\beta_i}^{em}$ and $\widehat{\beta_i}^{im}$ are the coefficients in the three equations using the overall export share, extensive margin, and intensive margin as the dependent variable, respectively. The relative contribution of the extensive and intensive margins can be measured by calculating $\frac{\widehat{\beta_i}^{em}}{\widehat{\beta_i}^{ex}}$ and $\frac{\widehat{\beta_i}^{im}}{\widehat{\beta_i}^{ex}}$, respectively. Because innovation is supposed to improve exportss, the coefficients on $\ln(patent_{cit})$ should be positive. According to Hummels and Klenow (2005), coefficients on country size (i.e., $\ln(pop)$ and $\ln(\frac{GDP}{pop})$) should be positive, too. The coefficients on common language and common border are supposed to be positive, and that on the distance is expected to be negative.

[9]To measure the relative innovation of a country in an industry-year, the weighted patent count of each country should be divided by the total number of weighted patent counts of all countries in the same industry-year. Observations from a same industry-year will be divided by a same number, and after taking log this will be obsorbed by the industry and year fixed effects.

Equation 11 is estimated using OLS.[10] This estimation is referred to as the *two-way-fixed-effects* case since it controls for industry-specific and year-specific fixed effects. Standard errors are made robust to heteroskedasticity and are clustered by country. The estimated results are presented in table 1.3: the estimates of the export share regression, the extensive margin regression, and the intensive margin regression are reported in columns (1), (2) and (3), respectively. The key explanatory variable, $\ln(patent)$, has positive and significant effects on overall export as well as on both the extensive and intensive margins. The coefficient in column (1) reveals that a country which has 10% more patents will export 5.4% more. This effect can be decomposed into different margins: a 10% increase in patent counts will raise the extensive margin by 1.6%[11] and the intensive margin by 3.8%. This means 30% of the higher export from more innovative countries occurs on the extensive margins, and 70% occurs on the intensive margins.[12]

The next two rows in table 1.3 verify that large countries export more. A country which has 10% more population will on average export 5.5% more varieties and

[10] Since by definition export shares, extensive margins, and intensive margins are between zero and one, $\ln(trade)$ must be non-positive. Because I use OLS to estimate the model, the fitted values can be positive. It turns out that only a very small proportion of the fitted values has this problem. For instance, only 103 observations (out of 25,268, which is less than 0.05% of the sample) have positive values in log export. And these observations are from 3 countries: Canada, Germany, and Japan. For the extensive margin, about 6% of observations have positive fitted values. For the intensive margin, no observation has a positive value.

[11] The definition of the extensive margin used in this paper actually represents the products coverage share of each country in each industry-year. It cannot, nevertheless, reflect an increase in the absolute number of products. For example, suppose in 1975 there are in total 100 varieties, and each variety has a equal weight. If Germany exports 90 varieties in 1975, the extensive margin is 90%. If in the year 2000, the total number of varieties in this industry increases to 1,000 and Germany exports 800 of them, the extensive margin of Germany will drop to 80%. Although Germany exports more products in the year 2000 than 1975, its relative coverage share of products falls and thus the extensive margin decreases.

[12] The contribution of the extensive margin is (0.160/0.537) = 30%, and the contribution of the intensive margin is (0.378/0.537) = 70%.

5.0% higher value in these varieties. A 10% increase in GDP per capita will raise the extensive margin by 8.9% and the intensive margin by 6.1%. With regard to population and GDP per capita, the extensive margin accounts for a larger part (52% with respect to population and 59% with respect to GDP per capita) than that of the intensive margin (48% with respect to population and 41% with respect to GDP per capita). The relative contribution of the two margins with respect to country size in this paper is similar to Hummels and Klenow (2005), in which they use cross-sectional data at the country level and find that the extensive margin accounts for about two thirds of the increased exports from larger countries.

The remaining part of table 1.3 shows that countries located close to the U.S., using English as the primary language, and sharing a common border with the U.S. have higher overall exports to the U.S. Among these variables, only the coefficient on distance is significantly different from zero. All coefficients have correct signs except that of border in the intensive margin regression.[13] Most of these coefficients on trade costs are individually insignificant, but they are jointly significant in each of the three regressions.

In addition to the industry-specific and year-specific effects, there can be unobserved country characteristics which are related to export performance. A *three-way-fixed-effects* model controlling for industry, year, and country-specific effects is estimated using OLS:

[13]In this sample only two countries, Canada and Mexico, have common border with the U.S. and thus the variation of this variable could be small.

$$\ln(trade_{cit}) = \beta_0 + \beta_1 \ln(patent_{cit}) + \beta_2 \ln(pop_{ct}) + \beta_3 \ln((\frac{GDP}{pop})_{ct}) \quad (12)$$
$$+\beta_4\mu_i + \beta_5\lambda_t + \beta_6\delta_c + \varepsilon_{cit}$$

where δ_t is the country fixed effect, and all other variables are as defined in equation 11. Since distance, language, and border are country-specific characteristics, they are dropped out once the country fixed effect is included. Standard errors are again made fully robust. The estimates of this three-way-fixed-effects case are presented in table 1.4. The effects of innovation on overall export shares and the two margins remain statistically significant, and the effects are stronger than in the two-way-fixed-effect case. A country which has 10% more patents exports 2.0% more varieties and 3.9% higher value of these varieties on average, leading to a 5.9% higher overall export share. The relative contribution of the two margins is similar to the two-way-fixed-effects case. The extensive margin accounts for 34% and the intensive margin accounts for 66%. The coefficients on country size are different from that of the two-way-fixed-effects case. The intensive margin now accounts for a slightly larger proportion than the extensive margin, but the effect on the intensive margin is insignificant. An explanation is that countries' *relative* sizes do not change much across years. Once the country fixed effect is included, the variation in country size becomes small and leads to insignificant coefficients. The bottom line is the effect of innovation on exports is significant in both cases, and the relative importance of the two margins is also similar.

The results in tables 1.3 and 1.4 reveal that trade theories predicting innovation can improve exports through only one margin do not explain the full effects of innovations. Models like Krugman (1979) which assume that innovations can only increase the number of varieties but not productivity or quality fail to explain the high intensive margins from more innovative countries. Models which assume that innovation only increases productivity or quality capture the higher intensive margins, but they miss the effect on the extensive margin, which contributes nearly one third of the total impact. From this point of view, a theoretical model which reconciles innovations' ability in expanding the number of varieties as well as in increasing productivity or quality is required to explain the complete influence of innovation on exports.

According to theoretical works reviewed in the introduction, the contribution of the extensive margin will raise exporting countries' welfare. The welfare change caused by the intensive margins depends on whether innovation increases export quantities or product quality. If the high intensive margin is mostly induced by higher export quantities, the expansion in export volume may be at the cost of a terms-of-trade loss. If the higher intensive margin is mainly driven by an increase in product quality, the terms of trade can improve and welfare will be higher. To identify the welfare impact and terms of trade effect, a further decomposition of the intensive margin will be discussed in section 5.

4.2 Interaction between Patent and GDP per capita

The benchmark estimations in the previous section assume that the effect of innovation on exports is the same across countries. However, trade theories which use North-South models display that technological progress can impose asymmetric impacts on developed and developing countries (e.g. Flam and Helpman, 1987). To explore this issue, I estimate a different version of equation 11 which adds an interaction between patent counts and GDP per capita.

$$\begin{aligned}\ln(trade_{cit}) = {} & \beta_0 + \beta_1 \ln(patent_{cit}) + \beta_2 \ln(patent_{cit}) \times \ln((\widetilde{\frac{GDP}{pop}})_{ct}) \quad (13)\\ & + \beta_3 \ln(pop_{ct}) + \beta_4 \ln((\frac{GDP}{pop})_{ct}) + \beta_5 \ln(dist_c)\\ & + \beta_6 lang_c + \beta_7 bord_c + \beta_8 \mu_i + \beta_9 \lambda_t + \varepsilon_{cit}\end{aligned}$$

GDP per capita in the interaction term is divided by the mean of all countries' GDP per capita of the same year (i.e., $\ln((\widetilde{\frac{GDP}{pop}})_{ct})$ is the demeaned log GDP per capita). In equation 13, the elasticity of export with respect to the patent is $\beta_1 + \beta_2 \ln((\widetilde{\frac{GDP}{pop}})_{ct})$, which varies with countries' income levels. This model is estimated by OLS and the estimates are reported in table 1.5. The coefficients on $\ln(patent)$ are positive in all regressions, and the coefficients on the interaction term are all negative. This means the influence of innovation on the different margins of export decreases with countries' income levels. Though the coefficient on the interaction term in the intensive margin regression is individually insignificant, the impact of patents is jointly significant with the coefficient on ln(*patent*).

To have a better quantitative intuition about how elasticities of exports vary by countries' income levels, consider three countries which are identical in all aspects except their GDP per capita: the *high-income country*'s GDP per capita is twice as much as the sample average; the *middle-income country*'s GDP per capita equals the average; and the *low-income country*'s is half as much as the average. Using the estimates in table 1.5, I can calculate the elasticity of each margin with respect to innovation of these countries, and the results are reported in table 1.6.[14] In each margin, the low-income country has the highest elasticity, followed by the middle-income country, and then the high-income country. For example, a 10% increase in patent counts will increase the low-income country's overall exports by 7.9%; but it will increase the middle-income country's overall exports by 6.6%, and the high-income country's exports by only 5.4%.

The composition of the higher exports led by innovation also changes with income levels. In table 1.5, the coefficient on the interaction term in the extensive margin regression is larger in absolute value and statistically more significant than that in the intensive margin regression. Though the impact of innovation falls with the income level in both margins, it falls more quickly in the extensive margin than in the intensive margin, and thus the relative importance of the extensive margin also

[14] The estimated elasticity of export with respect to innovation equals $\widehat{\beta}1 + \widehat{\beta}2 \ln(\textit{demeaned GDP per capita})$. For example, the high-income country's elasticity of overall export is $0.663 - 0.178 \times \ln 2 = 0.540$. We can calculate the elasticity of countries with any income level. For example, in 1999 Norway's GDP per capita is $32,355, and the mean GDP per capita is $10,609. This means Norway has *demeaned GDP per capita* = 3.05, or ln(*demeaned GDP percapita*) = 1.12. The estimated elasticity of export with respect to innovation for Norway will be $0.663 - 0.178 \times 1.12 = 0.464$.

declines with GDP per capita. In table 1.6, the extensive margin accounts for 40% of innovation's impact in the low-income country, while it accounts for 30% of the effect in the high-income country. These findings are also presented in figure 1.1. The height of each bar is the elasticity of overall exports with respect to innovation, and the composition of each bar shows the relative contribution of the extensive and intensive margins.

This section is concluded by the following two points. First, patents have stronger effects on low-income countries than on high-income countries. This difference is significant in the overall exports and the extensive margins but relatively insignificant in the intensive margins. Second, the extensive margins in low-income countries contribute a higher proportion than that in high-income countries to an increase of exports caused by innovations.

4.3 Differentiated and Homogeneous Products

The estimations up to this point implicitly assume that the effect of innovation on exports is identical across industries. In this section, I estimate an alternative model specification which allows innovation's effect on exports and the composition of this effect to differ by industry. More specifically, I investigate whether innovation imposes different impacts on differentiated products and homogeneous products.

Rauch (1999) classifies products into two types: homogeneous products which have a reference price and differentiated products which have no reference price. Based on Rauch's classification, I calculate a *differentiated-product share* of each industry, which equals the number of differentiated products divided by the number of total products in each industry. Industries with higher differentiated-product shares have relatively more differentiated products than homogeneous products compared with industries with lower shares. The differentiated-product shares of the 12 manufacturing industries in my sample are listed in table 1.2. I then categorize industries into two groups. The first group contains six industries which have differentiated-product shares higher than the sample median. These industries are defined as the differentiated-product industries, including electronics, instrument, transportation, machinery, fabricated metal, and glass-stone-clay. The second group includes six industries which have differentiated-product shares lower than the sample median. These industries are food, textile, plastic, chemicals, rubber, and primary metal, and are defined as homogeneous-product industries.

To explore whether innovation imposes asymmetric effects on the export performance of differentiated-product and homogeneous-product industries, I estimate the following model:

$$\begin{aligned} \ln(trade_{cit}) &= \beta_{0i} + \beta_1 \ln(patent_{cit}) + \beta_2 \ln(patent_{cit}) \times differentiated_i \\ &\quad + \beta_3 \ln(pop_{ct}) + \beta_4 \ln((\frac{GDP}{pop})_{ct}) + \beta_5 \ln(dist_c) \\ &\quad + \beta_6 lang_c + \beta_7 bord_c + \beta_8 differentiated_i + \beta_9 \lambda_t + \varepsilon_{cit} \end{aligned} \quad (14)$$

The variable $differentiated_i$ is a dummy variable which equals one if industry i is a differentiated-product industry and equals zero if industry i is a homogeneous-product industry. The interaction between ln(*patent*) and *differentiated* allows innovation's impact on exports to be different across industry groups. The elasticity of exports with respect to innovation in the differentiated industries is $\beta_1 + \beta_2$, while that in the homogeneous industries is β_1. We expect that innovation has a stronger impact on exports in differentiated industries than in homogeneous industries, because the production of differentiated products requires more innovations to create new varieties or to increase the quality of products than that of homogeneous products.

I estimate equation 14 using OLS, and the estimated results are presented in table 1.7. The coefficients on the interaction term (β_2) are positive and significant in all three regressions, indicating that innovation has stronger impacts in differentiated industries than in homogeneous industries. The estimated elasticities of exports with respect to innovation of differentiated-product and homogeneous-product industries are reported in table 1.8. A 10% increase in patents will increase the overall exports of differentiated-product industries by 6.5%, and will increase the overall exports of homogeneous-product industries by only 2.6%. The elasticity of overall exports with respect to innovation of differentiated industries is more than twice as large as that of homogeneous industries. Next, I compare the effects of innovation on the extensive and intensive margins in the two types of industries. The elasticity of the extensive margin in differentiated and the homogeneous industries are 0.15 and 0.12, respectively. The difference is statistically significant but economically not large (only 0.03). This is in contrast to the intensive margin, in which the elasticities of the two types of industries differ greatly (0.50 for differentiated industries and 0.15 for homogeneous industries). In differentiated industries, the intensive margin accounts for 77% of innovation's effect on exports, which is higher than that in homogeneous industries (56%). These results can also be found in figure 1.2.

In summary, the estimates of this section show that innovation has different degrees of impacts on export performance across sectors. The impact is much stronger in industries which have relatively more differentiated products, and the difference in the intensive margin is the primary reason which causes the large difference in innovation's impact on exports across industries.

4.4 Estimation by Year

In this section I split the sample by year to carry out a separate estimation of each year. This work has two objects. First, the magnitude of innovation's effect on exports may change over time, and a year-by-year estimation helps to detect it. Second, as mentioned in section 3, patent counts calculated according to the application year are truncated especially in the last few years of the sample. In previous sections I drop observations from the last three years to reduce the possible bias. By estimating the model by year, I can use observations of these dropped years to find out if they generate very different estimates. I can also compare the results using patent counts calculated by the application year and the grant year (which does not have the truncation problem) to see if the two measurements lead to different conclusions.

A version of equation 11 is estimated separately by year t:

$$\ln(trade_{cit}) = \beta_{0t} + \beta_{1t}\ln(patent_{cit}) + \beta_{2t}\ln(pop_{ct}) + \beta_{3t}\ln((\frac{GDP}{pop})_{ct}) \quad (15)$$
$$+\beta_{4t}\ln(dist_c) + \beta_{5t}lang_c + \beta_{6t}bord_c + \beta_{7t}\mu_i + \varepsilon_{cit}$$

The estimates will contain twenty-seven sets of coefficients. I list the coefficients on $\ln(patent)$ in table 1.9, and depict the elasticities of each margin against year in figure 1.3. The change in estimates with time does not show a consistent pattern. To summarize the changes in elasticities over time, I separate observations into three periods and estimate the average elasticities of exports with respect to innovation in each period: the seventies (1975-1979), the eighties (1980-1989), and the nineties (1990-1999). The results are given in the second panel of table 1.9. The average elasticity of overall exports in the seventies is 0.65; this average drops to 0.53 in the eighties, and then slightly drops to 0.52 in the nineties. Innovation's influence on overall exports falls through the late eighties, but it fluctuates during the nineties and climbs up after 1998. Figure 1.4 summarizes these results of estimation.

How can the change of innovation's effect on exports be explained? First, the falling influence may be related to the foreign direct investment (FDI). Compared with domestic firms, a subsidiary of a multinational firm depends less on the host country's technology level. For instance, a subsidiary of Dell in Mexico can produce more advanced products than domestic Mexican firms. As the proportion of exports accounted for by multinational firms increases with time, the explanatory power of innovation becomes weaker, because innovation and export do not always take place in the same country. However, this answer cannot explain why the elasticity stopped falling in the nineties, while FDI kept increasing during that period. The second explanation is the increased pace of knowledge and technology transfer. The central concept of technology gap theory is that innovation gives countries a temporary advantage in competition. If technology and knowledge transfer more quickly and more easily, the advantage created by innovation fades more quickly and becomes relatively impotent. To identify whether or not the decreasing effect of innovation on exports is driven by these two reasons, we need data of multinational firms' exports and technology transfer, which will be explored in future research.

In table 1.9, the average elasticities of the extensive margin with respect to innovation in the seventies, eighties, and nineties are 0.23, 0.16 and 0.14, respectively. The average elasticities of the intensive margin in these three periods are 0.42, 0.37, and 0.38, respectively. The decrease in the elasticity of overall exports from the seventies to the eighties occurs primarily on the extensive margin, and the change in the intensive margin is comparatively small. This indicates that the relative importance of the extensive margin regarding the effect of innovation decreases over time.

Finally, I implement the year-by-year estimation again, but now patents are classified according to the grant year rather than the application year. Classifying patents by the grant year does not have the truncation problem, but it measures countries' innovation capabilities with lags. The export elasticities with respect to patent using grant year are reported in table 1.10. In most years, estimations using grant-year patents have higher elasticities than that of using application-year patents, but the differences are not large. More interestingly, the elasticity of overall exports starts to climb after 1998 in both cases. Since the reverse trend occurs in both cases, I am cautious to attribute it to the data truncation and need data of more recent years to reach a conclusion. In summary, table 1.10 basically tells us the same story as table 1.9: the impact of innovation on exports decreases until late eighties, and the contribution of the extensive margin falls with time.

4.5 Sensitivity Analysis

In this section, the robustness of the main findings is checked by estimating models under different specifications and data construction methods: (1) considering the persistency in exporting, (2) taking the endogeneity of innovation into account, (3) including factor endowment and factor intensity, (4) controlling for tariffs and freight costs, (5) using lag patents instead of current patents as the proxy for innovation, (6) using different citation weights to calculate the weighted patent counts, (7) using variables in level forms rather than in log forms, (8) constructing export variables under different levels of aggregation. The estimates are stored in tables 1.11, 1.12 and 1.13. None of these variations alters the main conclusions of this paper. More innovations induce countries to export more products and higher values of these products, and the intensive margin accounts for a greater proportion of the effect than the extensive margin.

4.5.1 Persistency in exporting

Trade literature shows that prior exporting experience affects later decisions of participating in foreign markets. The persistency in trade patterns is related to the sunk cost of exporting (Roberts and Tybout, 1997; Bernard and Jensen, 2004; Das et. al., 2007). Although most of the evidence is presented at the firm level, the persistency in exporting can still exist at more aggregate levels. I consider the following dynamic model:

$$\begin{aligned}\ln(trade_{cit}) &= \alpha + \gamma \ln(trade_{ci,t-1}) + \beta_1 \ln(patent_{cit}) + \beta_2 \ln(pop_{ct}) \\ &\quad +\beta_3 \ln((\frac{GDP}{pop})_{ct}) + \beta_4 \ln(dist_c) + \beta_5 lang_c \\ &\quad +\beta_6 bord_c + \beta_7 \mu_{ic} + \beta_8 \lambda_t + \varepsilon_{cit}\end{aligned} \tag{16}$$

Compared with the benchmark model (equation 11), the dynamic model includes the lag export variable ($\ln(trade_{ci,t-1})$) in the regression as an additional regressor.[15] Using OLS or regular panel data estimators to estimate this model will generate inconsistent estimates, because the lag dependent variable is endogenous. I use the Generalized Method of Moment (GMM) estimator for dynamic panels proposed by Arellano-Bover (1995)/Blundell-Bond (1998) to estimate this model. The *system GMM estimator* uses lag dependent variables in level or difference forms dated $t-2$ or earlier as instruments for period t, to account for the endogeneity of lag dependent variable.[16]

[15]This model is more flexible than equations 11 and 12, because it allows each country-industry to have its fixed effect.

[16]A necessary condition for lag variables to be valid instruments is that there is no autocorrelation of order 2 or above in the idiosyncratic error term. Using the Arellano and Bond autocorrelation test, my sample shows symptoms of AR(2) but not of AR(3). So only variables dated t-3 or earlier are used as instruments.

The estimated coefficients on lag exports and patents are recorded in panel (A) in table 1.11. The coefficient on lag export variable of each regression is positive and significant. This finding verifies the persistency in exporting at the industry level. The coefficients on ln(*patent*) are smaller than that of the benchmark estimation. But the result shows that even after controlling for lag export variables, the effect of patents on each margin remains positive and very significant, and the elasticity of the intensive margin is larger than that of the extensive margin.

4.5.2 Endogeneity of innovation

This section takes the endogeneity of innovation into account. Innovation can be endogenous due to reverse causality or simultaneity. Changes in trading opportunities can alter the motivation of innovation, and it can even change the incentive to apply inventions to be patents.[17] I estimate equation 16 without including $\ln(trade_{ci,t-1})$ and considering innovation to be endogenous. The model is estimated using GMM estimator, and current innovation is instrumented with lag innovations. Panel (B) in table 1.11 shows the estimated coefficients on ln(*patent*). The result is very similar to the benchmark case, which indicates that considering the endogeneity of innovation does not change the main conclusion of this paper.

[17]First, there can be variables which are not controlled in the model, but can affect innovation and export simultaneously (e.g. change in government policies). Second, export and innovation can affect each other. On one hand innovation can improve competitiveness and increase exports; but on the other hand trade can induce the transfer of knowledge (Coe and Helpman, 1995) which motivates more innovations.

4.5.3 Factor endowment and factor intensity

The Heckscher-Ohlin model (H-O model) predicts that trade patterns are determined by factor endowments of countries. In this section I estimate a version of equations 11 and 12 which controls for the factor endowments of countries. I calculate each country's skilled labor, unskilled labor, and capital endowment proportions (made relative to land). The interactions between factor endowment proportions of each country and the factor intensity of each industry are included in the model of estimation. More details about the data source and how I calculate the factor endowments and factor intensities are discussed in appendix B. The estimated coefficients of $ln(patent)$ are displayed in panel (A) of tables 1.12 and 1.13. The result indicates that including factor endowments does not change the main conclusion of this paper.

4.5.4 Tariffs and freight costs

In this estimation tariffs and freight costs are included to control for trade barriers. The trade data described in section 3 have information of freight costs and duties paid at U.S. custom of each product. Similar to Hummels and Klenow (2005), I define an index of trade barrier which equals the sum of duty and freight divided by the total export value of each country-industry in a given year. The benchmark models in equations 11 and 12 are estimated by OLS with the inclusion of this index of trade barrier ($\ln(duty\ freight\ trate)_{cit}$). The coefficients on $ln(patent)$ are displayed in panel (B) of tables 1.12 and 1.13. The magnitude and the composition of patent's effect do not alter after including the duty-freight rate.

4.5.5 Replace current patent counts by lag patent counts

In this specification, I use lag patent counts instead of current patent counts as the proxy for innovation. Producers may need some time to adjust their production in response to a change in the technology level, and the effect on exports can take even longer. Furthermore, it is more convincing that lag patent counts are exogenous to current exports, and thus using lag patent counts can mitigate the possible simultaneity problem. $ln(patent_{cit})$ in the benchmark models (equations 11 and 12) is replaced by $ln(patent_{cit-1})$ and $ln(patent_{cit-2})$, separately, and the model is estimated by OLS. The sample size becomes smaller because some observations are dropped out when lag patent counts are used instead of current patent counts. The coefficients of $ln(patent_{cit-1})$ and $ln(patent_{cit-2})$ are shown in panel (C) in tables 1.12 and 1.13. Compared with the estimates using current patent counts, the coefficients in the two-way-fixed-effects case become smaller, but the main results in both cases remain very similar to that of using current patents.

4.5.6 Different weights of patent citations

In section 3, I discuss the importance of weighting patents by the number of citation received. The sample applies the linear weighting scheme of Trajtenberg (1990), in which the weight of each citation equals 100%. To make sure that the results are not sensitive to the selection of the citation weight, I calculate the weighted patent counts with alternative citation weights from 0 (simple patent counts) to 100%. Equations 11 and 12 are estimated with weighted patent counts using different citation weights.

Since elasticities with respect to country size and trade resistances are very similar to those in benchmark case in table 1.3, I only present the elasticities with respect to patents in panel (D) of tables 1.12 and 1.13. The elasticity decreases as the citation weight increases.[18] The decrease in the elasticity occurs on both the extensive margin and intensive margin, but patent's effects are significant and the relative importance of the two margins remains similar under different weights of citations.

4.5.7 Variables in levels

In this case the benchmark models are estimated again but all variables are in level forms without taking logs. The patent count variable is made relative to the world level in each industry-year, and population and GDP per capita are made relative to the world level in each year.[19] The results are shown in panel (E) in tables 1.12 and 1.13. Without taking log on exports, I cannot decompose the impact of each explanatory variable on export performance into different margins additively. The bottom line is that all of the coefficients on innovation are still positive and statistically significant. Switching from a log-linear model to a linear model does not deny the impacts of innovation on exports.

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[18] A possible connection is as follows. High income countries generally have more patents, and thus their patents are more likely to be cited. This is related to the concept of "self-citation" mentioned in Hall, Jaffe and Trajtenberg (2001). Assigning higher weight to citations tend to assign higher weights to patents from rich countries. Since we already show the effect of patent on export is decreasing with countries' income level, the outcome in tables 1.12 and 1.13 is not too surprising.

[19] The proxy of innovation is a country's weighted patent counts divided by the total number of weighted patent counts of all countries in an industry-year. Population variable equals a country's population divided by total population of all countries in a year. GDP per capita variable equals a country's GDP per capita divided by the average of all countries' GDP per capita in a year.

4.5.8 Different aggregation levels in exports

Hummels and Klenow (2005) point out that the relative importance of the extensive margin and intensive margin is sensitive to the level of aggregation in export data. In the sample, the number of product categories exported from a country is identified by each TS7 or HS10 code. To precisely estimate the relative contribution of the two margins, it is critical to have a disaggregate product classification in the export data. If products are classified at a more aggregate level, it is more likely that different products are included in a same category. In this case, an increase in the number of products *within* each code cannot be observed, and the effect will be attributed to the intensive margin (an increased value of this product code). This type of within product variation is proved to exist and discussed in Schott (2004). By intuition, the contribution of the extensive margin should fall when the export variables are calculated at a more aggregate level. To check this effect in this paper, I follow Hummels and Klenow (2005) to estimate equation 11 and 12 with different levels of product aggregation.[20] Panel (F) in tables 1.12 and 1.13 show that the elasticities of the extensive margin with respect to innovation under different levels of aggregation. Using more aggregate product classification will decrease the elasticity and the contribution of the extensive margin, and will increase that of the intensive margin at the same time. Except the most aggregate case (3-digit), innovation's impacts on both margins remain statistically significant. By using the most disaggregated trade data (TS7 and HS10) available, this paper can estimate the contribution of the two

[20] Other than the TS7 and HS10 codes, I calculate $\ln(export)$, $\ln(extensive)$, and $\ln(intensive)$ with each variety j defined by 3 digit to 6 digit of TS or HS codes.

margins more accurately than studies using more aggregate data.

5 Decomposing the Intensive Margin: Innovation and Product Quality

In section 4 I show that the intensive margin accounts for a relatively larger part of innovation's effects than the extensive margin does. According to trade theories reviewed in section 2, innovation can increase the intensive margin in at least two ways: increasing productivity and/or improving the quality of products. Empirical studies have shown evidence of the positive correlation between innovation and productivity.[21] However, the relation between innovation and product quality has not been studied broadly.[22] A common difficulty faced by researchers is that product quality is not directly observable. In empirical trade literature, quality is usually inferred from unit values. Some literature uses the export unit price as an *index* of quality (Hummels and Skiba, 2004; Hallak, 2006): within each variety, a higher unit price is equivalent to higher quality. Others studies consider the export price as an *indicator* of quality (Hallak, 2006; Hummels and Klenow, 2005; Hallak and Schott, 2008): the unit price reflects product quality and other factors such as production costs.[23] These studies agree that product quality is an important, if not the only,

[21] Early studies are surveyed by Griliches (1979). Recent studies mainly use firm level data, such as Wakelin (2001) and Griffith et al., (2006).

[22] In empirical international trade literature, export quality has been connected to factor endowments (Schott, 2004), income levels (Schott, 2004; Hallak, 2006) and different types of export costs (Hummels and Skiba, 2004).

[23] Different export prices can also be caused by within variety differentiation. So it is very important to have disaggregate trade data to measure product quality more precisely. See Hallak (2006).

factor that affects export prices. In this section I assume that the unit price is possibly affected by both the product quality and production cost. The object of this section is to decompose the intensive margin into the price and quantity indices, and then to look for evidence of the link between innovation and product quality.

Consider two polar scenarios. First, suppose innovation increases productivity but has no influence on the quality of products. As shown by Schott (2004), countries with higher productivity will export at lower prices. In this case, we expect export prices to be lower and export quantities to be higher in more innovative countries. Second, suppose innovation enables producers to produce goods of higher quality (Grossman and Helpman, 1991), and higher quality is linked with higher production cost (Baldwin and Harrigan, 2007). Innovation induces producers to export goods of higher quality at higher prices, but the export quantities can increase as well.[24]

In summary, if innovation raises the intensive margin mainly by reducing production costs, we will observe more innovative countries export higher quantities at lower prices. On the other hand, if innovation increases the intensive margin primarily by improving product quality, countries with more innovations will export at higher prices. The logic is similar to Schott (2004), but my focus is on the impact of innovation, which is not taken into account in Schott (2004).

[24]In a model with differentiated-quality products such as Grossman and Helpman (1991a), the export quantity is determined by the quality-adjusted price. If the quality-adjusted price increases (prices increases more than quality), export quantity will decrease. If quality-adjusted price decreases, export quantity will increase.

5.1 Decomposition of Intensive Margin

As shown in section 2, the intensive margin of exports ($p_{cj}q_{cj}$) is measured by the export value of each product. To estimate innovation's effect on price and quantity separately, the intensive margin has to be further decomposed into the price (p_{cj}) and quantity (q_{cj}) components. I adopt the well known Fisher Index to construct the empirical counterparts of the price and quantity indices:[25]

$$P_c = [\frac{\Sigma_{j\in S_c} p_{cj}q_{cj}}{\Sigma_{j\in S_c} p_{wj}q_{cj}}]^{\frac{1}{2}}[\frac{\Sigma_{j\in S_c} p_{cj}q_{wj}}{\Sigma_{j\in S_c} p_{wj}q_{wj}}]^{\frac{1}{2}} \tag{17}$$

$$Q_c = [\frac{\Sigma_{j\in S_c} p_{cj}q_{cj}}{\Sigma_{j\in S_c} p_{cj}q_{wj}}]^{\frac{1}{2}}[\frac{\Sigma_{j\in S_c} p_{wj}q_{cj}}{\Sigma_{j\in S_c} p_{wj}q_{wj}}]^{\frac{1}{2}} \tag{18}$$

As in section 3, consider the price and quantity indices of different countries in the same industry and year. Subscription c, j, and w represent country, product, and world, respectively. p_{cj} is the unit price of product j from country c, and q_{cj} is the export quantity of product j from country c. p_{wj} is the average unit price of product j from all countries, and q_{wj} is the total export quantity of product j from all countries. The price index in equation 17 is the geometric average of two elements. The first element is the Paasche index: it is the sum of country c's export prices of products exported by c divided by the sum of world prices of the same products, with each product weighted by country c's export quantity, q_{cj}. The second element of price index is the Laspeyres index: it is the sum of country c's export prices divided by the sum of world prices of the same products, with each product weighted by its

[25] Hummels and Klenow (2005) use a modified Fisher Index to construct the price and quantity indices at the country level which considers the effect of new-entering products .

world export quantity, q_{wj}. Using the same method, the quantity index in equation 18 is the geometric average of the Paasche index and the Laspeyres index.[26]

The trade data (Feenstra, 1996 and Feenstra, Romalis and Schott, 2002) contain the export value and quantity of each product. The quantity information can be used as q_{cj} directly, and the unit price of each product can be inferred by dividing the export value by the quantity (i.e., $p_{cj} = \frac{p_{cj}q_{cj}}{q_{cj}}$). Because the dataset does not have perfect quantity information of each product, some observations will have missing values in the price and quantity, and the sample size used in this section is smaller than the original one. More details of the construction of the price and quantity indices are discussed in appendix C.

The intensive margin in equation 8 can be decomposed into the price index and quantity index as in equations 17 and 18:

$$intensive_{cit} = P_{cit} \times Q_{cit} \tag{19}$$

5.2 Estimation and Results

Because the sample used in this section is different from that used in section 4.1, the two-way-fixed-effects model in equation 11 is estimated again using the new sample, and the results are recorded in columns (1)-(3) of table 1.14. Compared with the estimates in table 1.3, the coefficient on $\ln(patent)$ in the extensive margin regression increases and that in the intensive margin regression falls. The influence of innova-

[26] Because a single country's export quantity index can not exceed world export quantity, the quantity index is smaller than 1. But a country's export price can be higher or lower than the world average price, so the price index can be greater or smaller than 1.

tion on both margins remains positive and significantly different from zero, and the intensive margin accounts for a larger proportion. Using the new sample does not induce any material change in the main conclusions.

To estimate the relative contribution of the price and quantity components to the intensive margin, I regress the natural logs of the price and quantity indices on $\ln(patent)$ and other explanatory variables as in equation 11 ($\ln(pop)$, $\ln(\frac{GDP}{pop})$, $\ln(dist)$, $\ln(lang)$, and $\ln(bord)$). Industry and year dummies are controlled, and standard errors are robust to heteroskedasticity and clustered by country. Since $\ln(intensive_{cit}) = \ln(P_{cit}) + \ln(Q_{cit})$, the effect on the intensive margin can be decomposed additively: $\widehat{\beta}_i^{im} = \widehat{\beta}_i^{p} + \widehat{\beta}_i^{q}$ $i = 1......6$, where $\widehat{\beta}_i^{im}$, $\widehat{\beta}_i^{p}$, and $\widehat{\beta}_i^{q}$ are the coefficients in the intensive margin, price margin, and quantity margin regressions, respectively. According to the two assumed polar cases, we have two competing hypotheses. If innovation increases the intensive margin by reducing production costs, more innovative countries will export higher quantities at lower prices, and we expect to see $\widehat{\beta}_1^{p} < 0$ and $\widehat{\beta}_1^{q} > 0$. If innovation increases the intensive margin by raising product quality, we expect to see $\widehat{\beta}_1^{p} \geq 0$; and the sign of $\widehat{\beta}_1^{q}$ is determined by quality-adjusted price.[27]

The estimated coefficients of the price and quantity regressions are presented in columns 4 and 5 of table 1.14. A 10% increase in patents will increase export prices by 0.5% and export quantities by 2.5%. The higher intensive margin led by innovation is mainly driven by higher export quantities (84%), and the higher export price ac-

[27] If the coefficient in the quantity regression is negative, the absolute value should be smaller than the coefficient in the price regression to have a positive correlation between innovation and intensive margin.

counts for a relatively small contribution (16%). Although innovation does not have economically strong effect on export prices, the effect is statistically significant. The results show evidence that innovation raises product quality. Countries which have more innovations can export higher quantities at higher prices, because their products have higher quality. The rise in the export quantity implies that the quality-adjusted price falls. Although the result indicates that innovation increases product quality, it does not necessarily contradict other empirical studies which find that innovation can increase productivity. It is possible that the two effects coexist, and an increase in productivity can decrease the quality-adjusted price further and contribute to the increased quantities of exports. The bottom line is that the estimates do not show direct evidence that innovations worsen the terms of trade, and thus the increase in exports caused by innovation is more likely to be welfare-improving.

6 Conclusion

In this paper I divide export flows into the extensive and intensive margins to investigate the extent to which innovation increases the number of products and the export value of each product. I use export data of 12 manufacturing industries from 105 countries to the U.S. market for the period 1975-2001 to construct the extensive and intensive margins, and use the number of patents granted by the U.S. as the proxy for innovation, to investigate the relative importance of the extensive and intensive margins of exports regarding innovation's impact. The estimates show that innovation has significantly positive effects on both the extensive margin and the intensive margin of exports. In the benchmark estimation, a country with 10% more patent counts will export 1.6% more products and 3.8% higher value of each product, which leads to a 5.4% increase in overall exports. The intensive margin accounts for a larger proportion of innovation's effect (70%) than the extensive margin (30%). The results are robust to alternative model specifications which consider the persistency of exporting, the endogeneity of innovation, the inclusion of tariffs and freight costs, alternative innovation measurements, and the level of exports aggregation. Further decomposing the intensive margin into the price and quantity indices shows that more innovative countries export greater quantities at higher prices, suggesting that innovation raises product quality of exports. This result implies that innovation improves the innovating countries' welfare not only by increasing the number of varieties but also by improving their terms of trade.

I also investigate how the effect of innovation on exports varies by country, by industry, and by year. First, innovation has stronger impacts on countries which have lower GDP per capita, and the relative importance of the extensive margin is also greater in lower-income countries than in higher-income countries. This result points out that innovation may be an important factor which determines developing countries' technology catch-up. This is different from most existing literature which simply assumes that developing countries do not innovate. Second, innovation has a greater impact on exports in industries which have relatively more differentiated goods than homogeneous goods. This indicates that innovation's impact on exports differs by industry. Except the share of differentiated goods, other industrial characteristics such as technology intensity and the producer-user relation of innovation may also lead to different impact of innovation on exports. Finally, the year-by-year estimation displays that the effect of innovation on exports and the relative contribution of the extensive margin decline over time.

Table 1.1: List of Countries

Algeria	Dominican	Indonesia	Morocco	Sierra Leone
Argentina	Ecuador	Iran	Nepal	Singapore
Australia	Egypt	Iraq	Netherlands	Spain
Austria	El Salvador	Ireland	New Zealand	Sri Lanka
Bahamas	Ethiopia	Israel	Nicaragua	Sudan
Bahrain	Germany	Italy	Niger	Suriname
Belgium	Fiji	Jamaica	Nigeria	Sweden
Belize	Finland	Japan	Norway	Switzerland
Bolivia	France	Jordan	Oman	Tanzania
Brazil	Gabon	Kenya	Pakistan	Taiwan
Bulgaria	Ghana	Korea	Panama	Thailand
Cameroon	Greece	Kuwait	Paraguay	Trinidad and Tobago
Canada	Guatemala	Laos	Peru	Tunisia
Chad	Guinea	Liberia	Philippines	Turkey
Chile	Guyana	Madagascar	Poland	Uganda
China	Haiti	Malawi	Portugal	United Arab Emirates
Colombia	Honduras	Malaysia	Qatar	United Kingdom
Congo	Hong Kong	Mali	South Africa	Uruguay
Costa Rica	Hungary	Mauritania	Romania	Venezuela
Cyprus	Iceland	Mauritius	Saudi Arabia	Zambia
Denmark	India	Mexico	Senegal	Zimbabwe

Table 1.2: List of Industries in 2-digit SIC 87

SIC	Description	Example Sub-Category	Differentiated-product share
20	Food and kindred products	Fluid Milk, Canned Fruits	0.31
22	Textile mill products	Finishers of Broadwoven Fabrics	0.64
28	Chemicals and allied products	Medicinal Chemicals	0.35
29	Petroleum and coal products	Petroleum Refining	0.26
30	Rubber and miscellaneous plastics products	Plastics Bottles	0.65
32	Stone, clay, glass, and concrete products	Glass Containers, Concrete Products	0.89
33	Primary metal industries	Primary Smelting and Refining	0.27
34	Fabricated metal products	Fabricated Structural Metal	0.92
35	Industrial machinery and equipment	Electronic Computers	1.00
36	Electrical and electronic equipment	Telephone Apparatus	1.00
37	Transportation equipment	Motor Vehicle Parts	1.00
38	Instruments and related products	Instruments for Measuring	1.00

Table 1.3: Estimated Results: Two-way Fixed Effects Model

Dependent Variables → Regressors ↓	ln export (1)	ln extensive (2)		ln intensive (3)	
ln patent	0.537***	0.160***	30%	0.378***	70%
	(0.075)	(0.040)		(0.043)	
ln population	1.046***	0.546***	52%	0.501***	48%
	(0.089)	(0.041)		(0.054)	
$\ln \frac{GDP}{pop}$	1.505***	0.891***	59%	0.614***	41%
	(0.17)	(0.080)		(0.10)	
ln distance	-0.616**	-0.383***	62%	-0.233	38%
	(0.29)	(0.13)		(0.17)	
language	0.339	0.199	59%	0.140	41%
	(0.29)	(0.14)		(0.17)	
border	0.829	-0.310	-37%	1.139**	137%
	(1.03)	(0.57)		(0.48)	
constant	-31.27***	-15.49***		-15.77***	
	(3.36)	(1.49)		(2.05)	
Industry dummy	Yes	Yes		Yes	
Year dummy	Yes	Yes		Yes	
Country dummy	No	No		No	
Observations	25268	25268		25268	
R^2	0.61	0.51		0.53	

Notes: This table reports the estimated results of equation 11 using OLS. Robust standard errors clustered by country are in parentheses. Percentages describe the contribution of each margin to overall exports. Coefficients of industry and year dummy variables are skipped. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 1.4: Estimated Results: Three-way Fixed Effects Model

Dependent Variables → Regressors ↓	ln export (1)	ln extensive (2)		ln intensive (3)	
ln patent	0.584***	0.196***	34%	0.388***	66%
	(0.063)	(0.025)		(0.046)	
ln population	1.144*	0.561*	49%	0.584	51%
	(0.64)	(0.30)		(0.42)	
$\ln \frac{GDP}{pop}$	0.614*	0.381***	62%	0.233	38%
	(0.32)	(0.14)		(0.23)	
constant	-33.98***	-16.86***		-17.12**	
	(11.6)	(5.41)		(7.82)	
Industry dummy	Yes	Yes		Yes	
Year dummy	Yes	Yes		Yes	
Country dummy	Yes	Yes		Yes	
Observations	25268	25268		25268	
R^2	0.72	0.61		0.60	

Notes: This table reports the estimated results of equation 12 using OLS. Robust standard errors clustered by country are in parentheses. Percentages describe the contribution of each margin to overall exports. Coefficients of industry, year, and country dummy variables are skipped. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 1.5: Estimated Results: Interaction between GDP per capita and Patent

Dependent Variables →	ln export	ln extensive	ln intensive
Regressors ↓	(1)	(2)	(3)
ln patent	0.663***	0.238***	0.426***
	(0.11)	(0.044)	(0.072)
ln patent × ln $\frac{\widetilde{GDP}}{pop}$	-0.178*	-0.110***	-0.0680
	(0.091)	(0.035)	(0.063)
ln population	1.011***	0.524***	0.487***
	(0.092)	(0.043)	(0.055)
ln $\frac{GDP}{population}$	1.524***	0.902***	0.621***
	(0.17)	(0.080)	(0.100)
ln distance	-0.629**	-0.391***	-0.238
	(0.29)	(0.13)	(0.17)
language	0.309	0.181	0.128
	(0.28)	(0.13)	(0.17)
border	0.794	-0.332	1.126***
	(0.89)	(0.48)	(0.43)
constant	-30.78***	-15.19***	-15.59***
	(3.35)	(1.49)	(2.05)
Observations	25268	25268	25268
prob>F	0.00	0.00	0.00
R^2	0.62	0.51	0.53

Notes: This table reports the estimated results of equation 13 using OLS. Robust standard errors clustered by country are in parentheses. Coefficients of industry and year dummy variables are skipped. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1. The prob>F shows the p-value of testing $\beta1 = \beta2 = 0$ in equation 13.

Table 1.6: Elasticities of Exports with respect to Patents in Countries with Different GDP per capita

Country	$\frac{GDP}{pop}$ ratio	Elasticities with respective to innovation (1) export	(2) extensive		(3) intensive	
Low-income	0.5	0.786	0.314	40%	0.473	60%
Middle-income	1	0.663	0.238	36%	0.426	64%
High-income	2	0.540	0.162	30%	0.379	70%

Notes: $\frac{GDP}{pop}$ ratio is each country's GDP per capita divided by the mean of all countries' GDP per capita. Numbers in columns (1)-(3) are estimated elasticities of each margin of exports with respect to patent, which equals $\beta 1 + \beta 2 \ln((\widetilde{\frac{GDP}{pop}}))$ in equation 13. Percentages describe the contribution of the extensive and intensive margin to overall exports.

Table 1.7: Estimation by Industry Group: Differentiated Products versus Homogeneous Products

Dependent Variables →	ln export	ln extensive	ln intensive
Regressors ↓	(1)	(2)	(3)
ln patent	0.264***	0.116***	0.149***
	(0.069)	(0.036)	(0.038)
ln patent × differentiated	0.381***	0.0321**	0.349***
	(0.036)	(0.015)	(0.028)
ln population	1.107***	0.568***	0.540***
	(0.084)	(0.040)	(0.051)
$\ln \frac{GDP}{pop}$	1.614***	0.938***	0.676***
	(0.16)	(0.077)	(0.096)
ln distance	-0.649**	-0.394***	-0.254
	(0.29)	(0.13)	(0.17)
language	0.403	0.222*	0.181
	(0.27)	(0.13)	(0.17)
border	0.872	-0.310	1.182***
	(0.96)	(0.56)	(0.43)
differentiated	-2.309***	-0.0196	-2.290***
	(0.15)	(0.061)	(0.11)
constant	-33.67***	-16.38***	-17.29***
	(3.25)	(1.45)	(2.00)
Observations	25268	25268	25268
prob>F	0.00	0.00	0.00
R^2	0.58	0.45	0.45

Notes: This table reports the estimated results of equation 14. Robust standard errors clustered by country are in parentheses. Coefficients of year dummy variables are skipped. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1. The prob>F shows the p-value of testing $\beta 1 = \beta 2 = 0$ in equation 14.

Table 1.8: Elasticities of Exports with respect to Patents by Industry Group

	Elasticities with respective to innovation				
	(1)	(2)		(3)	
Industry Group	export	extensive		intensive	
Differentiated	0.645	0.148	23%	0.498	77%
Homogeneous	0.264	0.116	44%	0.149	56%

Notes: Numbers are estimated elasticities of each margin with respect to patents. The elasticity of exports in differentiated-product industries equals $\beta 1 + \beta 2$ in equation 14, and the elasticity of exports in homogeneous-product industries equals $\beta 1$. Percentages describe the contribution of each margin to overall exports.

Table 1.9: Estimation by Year: Patents Classified according to the Application Year

Export → Year	ln export	ln extensive	ln intensive
1975	0.698***	0.223***	0.475***
1976	0.650***	0.224***	0.426***
1977	0.635***	0.303***	0.331***
1978	0.644***	0.208***	0.437***
1979	0.608***	0.209***	0.399***
1980	0.614***	0.204***	0.410***
1981	0.632***	0.207***	0.425***
1982	0.569***	0.184***	0.385***
1983	0.520***	0.149***	0.371***
1984	0.525***	0.149***	0.376***
1985	0.516***	0.166***	0.350***
1986	0.491***	0.113***	0.378***
1987	0.450***	0.117***	0.333***
1988	0.481***	0.117***	0.365***
1989	0.490***	0.134***	0.355***
1990	0.528***	0.159***	0.369***
1991	0.543***	0.161***	0.382***
1992	0.507***	0.118**	0.389***
1993	0.512***	0.143***	0.369***
1994	0.544***	0.183***	0.361***
1995	0.552***	0.151***	0.401***
1996	0.512***	0.135***	0.377***
1997	0.515***	0.132**	0.383***
1998	0.502***	0.108**	0.394***
1999	0.522***	0.0835	0.439***
2000	0.596***	0.108**	0.487***
2001	0.617***	0.0913	0.525***

	ln export	ln extensive		ln intensive	
1975-79 (avg)	0.647***	0.231***	36%	0.417***	64%
1980-89 (avg)	0.526***	0.155***	29%	0.371***	71%
1990-99 (avg)	0.517***	0.140***	27%	0.377***	73%

Notes: The first panel of his table reports the estimated results of the year-by-year estimation of equation 11. The estimated coefficients are elasticities of exports with respect to patents. Estimates of other regressors are skipped. Industry dummy variables are included. The second panel shows the average elasticities in the 70s, 80s, and 90s. Percentages describe the contribution of each margin to overall exports. * indicates significance level: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 1.10: Estimation by Year: Patents Classified according to the Grant Year

Export →	ln export	ln extensive	ln intensive
Year			
1975	0.651***	0.205***	0.445***
1976	0.634***	0.196***	0.438***
1977	0.672***	0.323***	0.350***
1978	0.600***	0.198***	0.402***
1979	0.584***	0.198***	0.386***
1980	0.565***	0.176***	0.389***
1981	0.656***	0.215***	0.441***
1982	0.549***	0.167***	0.382***
1983	0.490***	0.135***	0.355***
1984	0.513***	0.141***	0.372***
1985	0.482***	0.150***	0.332***
1986	0.434***	0.0876**	0.346***
1987	0.467***	0.127***	0.341***
1988	0.487***	0.107***	0.380***
1989	0.435***	0.128***	0.307***
1990	0.498***	0.131***	0.367***
1991	0.523***	0.146***	0.377***
1992	0.491***	0.123***	0.368***
1993	0.507***	0.134***	0.373***
1994	0.522***	0.175***	0.347***
1995	0.520***	0.144***	0.376***
1996	0.458***	0.117**	0.341***
1997	0.502***	0.128**	0.374***
1998	0.416***	0.0960**	0.320***
1999	0.457***	0.0677	0.389***
2000	0.517***	0.103**	0.414***
2001	0.528***	0.104*	0.424***

	ln export	ln extensive		ln intensive	
1975-79 (avg)	0.627***	0.221***	35%	0.406***	65%
1980-89 (avg)	0.506***	0.145***	29%	0.361***	71%
1990-99 (avg)	0.487***	0.128***	26%	0.359***	74%

Notes: The first panel of this table reports the estimated results of the year-by-year estimation of equation 11, with patents counts based on the grant years. The estimated coefficients are elasticities of exports with respect to patents. Estimates of other regressors are skipped. Industry dummy variables are included. The second panel shows the average elasticities in the 70s, 80s, and 90s. Percentages describe the contribution of each margin to overall exports. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 1.11: GMM Estimator: Persistency in Exporting and Endogeneity of Innovation

	(1)	(2)	(3)
	ln export	ln extensive	ln intensive
(A) Persistency in Exporting			
ln patent	0.163***	0.0913***	0.118***
	(0.019)	(0.012)	(0.017)
lag export variable	0.377***	0.123***	0.252***
	(0.026)	(0.023)	(0.021)
(B) Endogenous Innovation			
ln patent	0.532***	0.153***	0.379***
	(0.11)	(0.050)	(0.087)

Notes: This table reports the estimated coefficients on patents in models which take the persistency of exporting and the endogeneity of innovation into account using GMM estimator. Robust standard errors are in parentheses. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 1.12: Robustness Checks: Two-Way Fixed Effects

	Two-Way Fixed Effects		
	ln export	ln extensive	ln intensive
	(1)	(2)	(3)
(A) Factor Endowment			
ln patent	0.336***	0.0892**	0.247***
(B) Tariffs and Freights			
ln patent	0.517***	0.153***	0.363***
(C) Lag Patents			
ln patent t-1	0.508***	0.146***	0.362***
ln patent t-2	0.486***	0.134***	0.352***
(D) CitationWeights			
0%	0.686***	0.183***	0.503***
10%	0.651***	0.179***	0.472***
30%	0.607***	0.172***	0.434***
50%	0.579***	0.167***	0.411***
100%	0.537***	0.160***	0.378***
(E) LinearModel			
patent	0.470***	1.651***	0.504***
(F) Levels of Aggregation			
7/10 digit	0.537***	0.160***	0.378***
6 digit	0.537***	0.138***	0.399***
5 digit	0.537***	0.111***	0.427***
4 digit	0.537***	0.0822**	0.455***
3digit	0.537***	0.0134	0.524***

Notes: This table reports the coefficients on patents.

Table 1.13: Robustness Checks: Three-Way Fixed Effects

	Three-Way Fixed Effects		
	ln export	ln extensive	ln intensive
	(1)	(2)	(3)
(A) Factor Endowment			
ln patent	0.442***	0.161***	0.280***
(B) Tariffs and Freights			
ln patent	0.562***	0.188***	0.374***
(C) Lag Patents			
ln patent t-1	0.589***	0.192***	0.397***
ln patent t-2	0.575***	0.185***	0.390***
(D) CitationWeights			
0%	0.869***	0.278***	0.591***
10%	0.814***	0.264***	0.550***
30%	0.725***	0.238***	0.487***
50%	0.668***	0.221***	0.447***
100%	0.584***	0.196***	0.388***
(E) LinearModel			
patent	0.538***	0.906***	0.577***
(F) Levels of Aggregation			
7/10 digit	0.584***	0.196***	0.388***
6 digit	0.584***	0.163***	0.421***
5 digit	0.584***	0.129***	0.455***
4 digit	0.584***	0.0941***	0.490***
3digit	0.584***	0.0111	0.573***

Notes: This table reports the coefficients on patents.

Table 1.14: Decomposing the Intensive Margin into Price and Quantity

Dependent Variables → Regressors ↓	ln export (1)	ln extensive (2)	ln intensive (3)	ln price (4)	ln quantity (5)
ln patent	0.519***	0.219***	0.300***	0.0482***	0.252***
	(0.070)	(0.039)	(0.041)	(0.016)	(0.051)
ln population	0.988***	0.515***	0.473***	-0.0334**	0.506***
	(0.085)	(0.042)	(0.050)	(0.013)	(0.056)
$\ln \frac{GDP}{population}$	1.384***	0.811***	0.572***	0.121***	0.451***
	(0.16)	(0.083)	(0.098)	(0.024)	(0.11)
ln distance	-0.315	-0.171	-0.144	0.0235	-0.168
	(0.27)	(0.13)	(0.16)	(0.033)	(0.17)
language	0.235	0.143	0.0919	0.0415	0.0504
	(0.27)	(0.14)	(0.16)	(0.051)	(0.18)
border	1.363*	0.229	1.134***	-0.232***	1.366***
	(0.78)	(0.48)	(0.34)	(0.073)	(0.32)
constant	-31.87***	-16.26***	-15.61***	-0.731**	-14.88***
	(3.11)	(1.53)	(1.82)	(0.33)	(1.97)
Industry dummy	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes
Country Dummy	No	No	No	No	No
Observations	22804	22804	22804	22804	22804
R^2	0.58	0.49	0.44	0.18	0.39

Notes: This table reports the estimated results of equation 11, with a further decomposition of the intensive margin into the price and quantity indices. Robust standard errors clustered by country are in parentheses. Coefficients of industry and year dummy variables are skipped. * indicates significance level: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

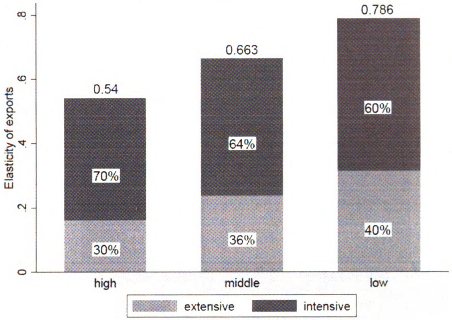

Figure 1.1: The Elasticities of Export with Respect to Innovation by Country Income Level

Note: The height of each bar shows the elasticity of overall export with respect to innovation in countries with different income levels. "High" represents a high-income country which has GDP per capita equals twice as the sample mean, "middle" represents a middle-income country which has GDP per capita equals the sample mean, and "low" is the low-income country which has GDP per capita equals half as the sample mean. The numbers in the bars are elasticities of the extensive and intensive margins, and percentages are the relative contributions of the two margins.

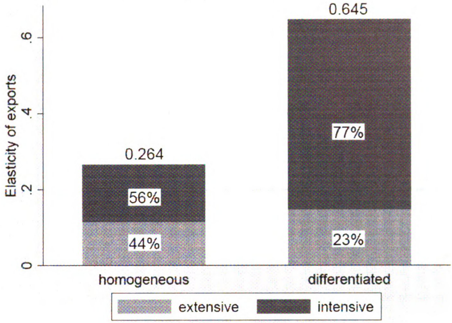

Figure 1.2: The Elasticities of Export with Respect to Innovation: Differentiated vs Homogeneous Products

Note: The height of each bar shows the elasticity of overall export with respect to innovation in different industry groups. "Homogeneous" industries include the six industries which have differentiated-products shares larger than the median of all industries; "differentiated" industries represent the other six industries which have differentiated-products shares smaller than the median of all industries. The numbers in the bars are elasticities of the extensive and intensive margins, and percentages are the relative contributions of the two margins.

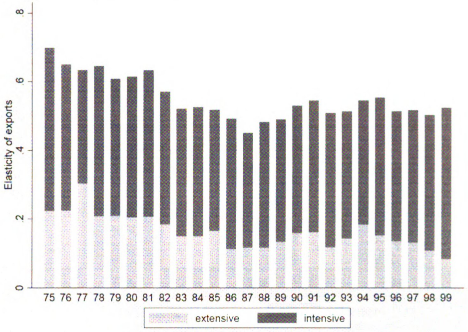

Figure 1.3: The Elasticities of Export with Respect to Innovation by Year

Note: The height of each bar shows the elasticity of overall export with respect to innovation in different years. The numbers in the bars are elasticities of the extensive and intensive margins, and percentages are the relative contributions of the two margins.

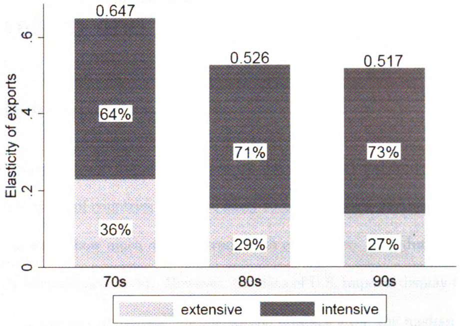

Figure 1.4: The Elasticities of Export with Respect to Innovation by Period

Note: The height of each bar shows the elasticity of overall export with respect to innovation in different time periods. "70s" represents the elasticity of 1975-1979, "80s" represents that of 1980-1989, and "90s" represents 1990-1999. The numbers in the bars are elasticities of the extensive and intensive margins, and percentages are the relative contributions of the two margins.

Chapter 2
Innovation and Export Duration

1 Introduction

Most international trade literature focuses on the cross-sectional trade performance, such as what types of countries are more likely to become trade partners, what products are traded, or how much do they trade with each other. The duration of trade relationship is rarely addressed. However, the data of U.S. imports display that trade pattern is surprisingly dynamic.[28] First, at the product level, the median length of an export relationship is only two to three years. The short trade duration prevails in a wide range of countries and industries. Second, the variation in export duration is large. Even though many trade relationships end in a few years, there is still a considerable proportion (about 25%-35%) survives at least 12 years. Third, about 30% of trade relationships occur more than once. This means a country enters a foreign market, exits it, and then re-enters the market again (and the process can repeat multiple times). In spite of these unexpected facts, it is still not clear what the main determinants of the length of trade relationships are, and how to explain the large variation in export durations. The main object of this chapter is to use survival analysis to investigate the extent to which innovation accounts for export durations. Using the number of patents as the proxy for innovation and data of exports from 105 countries to the U.S. in 1975-2001, I find that innovation has a significantly pos-

[28] Besedeš and Prusa (2006a) first point out that the duration of U.S. import is short.

itive effect on the duration of exports. More innovative countries can sustain their export relationships for a longer period of time, and this result is consistent with the implications of the product cycle model.

The lengh of trade relationships has not been studied extensively. However, Besedeš and Prusa (2007) show that for export growth, the survival of existing trade relationships plays a more important role than building new trade relationships. The empirical estimation of this chapter is inspired by Besedeš and Prusa's (2006a) pioneering work. They first estimate the survivor function of trade durations, and show that trade relationships are exceptionally short. They then report survival rates of trade relationships broken out by regions and industries to examine whether trade durations differ with these factors. This chapter extends their work in the following ways. First, other than region and industry, I include innovation as well as a variety of variables (country size, trade barriers and costs, exchange rate, factor endowment, number of exporters, etc.) in the estimation to analyze the extent to which these factors can explain the duration of exports. Second, instead of breaking out observations into groups, I apply a two-stage estimation strategy which can control multiple explanatory variables at the same time and test the statistically significance level of each variable. The detailed estimation strategy will be discussed in section 4.

Only a limited number of other empirical studies have examined the durations of trade. Besedeš and Prusa (2006b) analyze the extent to which product differentiation affects the duration of U.S. imports. Nitch (2007) examines the duration of German trade and extends previous studies by including more variables, such as contract intensity, market share, and two-way trade. Besedeš (2008) applies a search model of international trade to explore whether initial trade volume, reliability, and search cost play important roles in trade durations. My paper contributes to this strand of literature by offering a new explanation, innovation, to the dynamic trade patterns, which is based on the product cycle model. This paper also makes contribution to empirical studies on the dynamics of trade patterns, especially those which are based on product cycle models (e.g. Feenstra and Rose, 2000). My paper is also related to literature which stresses *zero trade flows* (e.g. Helpman et. al., 2007). While zero trade flows indicate potential trade relationships which are not built, the duration of trade records the length of time until a trade relationship moves from positive trade to zero trade.

The remainder of the chapter is organized as follows. Section 2 shows the theoretical background of the empirical model. Section 3 describes the data source and how I compile the export duration and innovation variables. Section 4 displays the two-stage model of estimation. Section 4.1 presents the model of export duration, and the estimates of survival function and the length of export relationships. Sections 4.2-4.4 show the model of regression and the estimated results of the extent to which innovation affects export durations. Section 5 concludes the paper.

2 Motivation

The trade data demonstrate that export durations are short but have high variation. The duration of trade relationship, however, has rarely been explicitly included in theoretical models. Standard trade theories appear to imply that trade patterns should be stable over time. For instance, the Heckscher-Ohlin (H-O) model predicts that the direction and volume of trade depend on the factor endowment. The short duration of trade and multiple-spell service then indicate that countries' relative factor endowment change very quickly and switch back and forth. The change of factor endowment is not a convincing explanation for dynamic trade pattern. Moreover, theories which consider the dynamic of trade more explicitly also suggest that trade pattern should be static and persistent. Models which emphasize the importance of sunk and entry costs (Baldwin and Krugman, 1989) or search cost (Rauch, 2001) infer that firms tend to export to a market over long periods of time.

Different from these trade theories, the product cycle models can possibly provide an answer to the highly dynamic trade patterns. These models stress the role of innovation and technological progress on international trade. Grossman and Helpman (1991b) construct a model in which innovation takes the form of quality improvement. Each product line has numerous potential varieties (producers), but consumers only buy the variety which has the highest quality.[29] The firm (*leader*) which has the ability to produce the state-of-art product in each product line can make profit, but they face the competition from other firms (*followers*) which produce the second-to-top products. By investing resources in innovative (or imitative) activities, firms can increase the probability of success in research, which will improve the quality of product. Innovation has direct impact on the quality of products, which determines the pattern of international trade.

[29] Grossman and Helpman (1991b) show that in equilibrium, this is also the producer which has the lowest quality-adjusted price.

The quality ladder model is capable to explain the short duration and multiple-spell of trade relationships. First, a follower can capture the market and become the leader by conducting a successful innovation. Since innovations take place frequently, it is not shocking that the leading position can be switched among firms in a short time, which will result in short durations of exports. Second, the leaders can also conduct continuous innovations to remain on the top of the quality ladder. This answers why there is still a certain proportion of trade relationships which can last for a long time. Finally, previous leaders can also restore their advantageous positions and take back the markets with successful innovations. This can explain the multiple spells of service in trade. The model also suggests that countries which have more innovations are more likely to move toward (or remain on) the top of the quality ladder, and are more likely to sustain their exports for a longer period of time. Motivated by the quality ladder model, the empirical estimation of this chapter focuses on the effect of countries' innovations on their export durations.

3 Data

3.1 Export Duration

The duration analysis is based on trade data compiled by Feenstra (1996) and updated by Feenstra, Romalis and Schott (2002), which contain the export and import of the U.S. at the product level. Products are classified according to the 7-digit Tariff Schedule of the United States Annotated (TS7) before 1988, and are classified according to the 10-digit Harmonized System (HS10) in 1989-2001. The dataset covers exports from more than 160 countries to the U.S. market. Because I am interested in the relation between export duration and innovation, the analysis of this chapter will only focus on products of 12 manufacture industries from 105 countries whose export and innovation data are both available.[30] The sample used in this paper is thus different from that of Besedeš and Prusa (2006a, 2006b) and Besedeš (2008).

The export duration indicates the length of time that an export relationship has been existed without breaks. Since export data are reported annually, the duration is measured in years. Table 2.1 lists the export pattern of an example product, gas meters (HS10 code 9028100000), from 10 countries to the U.S. market between 1989 and 2001. A mark "x" represents that a country exports gas meters to the U.S. in the given year. For example, Australia exports gas meters to the U.S. in five years: 1997, 1998, 1999, 2000, and 2001. This export relationship lasts for five consecutive years without a gap, which means the length of this *spell of service* is five. Argentina exports this product in twelve years (1989-1999 and 2001). Because of the gap in 2000, Argentina's export is interpreted as two separate spells whose length are eleven years (1989-1999) and one year (2001), respectively.

To measure the duration of exports, we need to identify the starting and ending years of each spell of service. Nevertheless, the data only record exports of each TS7 product between 1975 and 1988, and each HS10 product between 1989 and 2001.

[30] Lists of these industries and countries are in tables 2.2 and 2.3.

We are not able to observe the exact starting/ending year of an export relationship if it starts/ends before or after the record the sample. In table 2.1, the first spell of Italy's export starts in 1989 and ends in 1991. The starting year is also the first year that export data of HS10 products are available. We cannot be certain whether Italy starts exporting the good in 1989 or before it, because we do not have the data before 1989. Similarly, a country which exports in the last year of the sample (like Australia's export in 2001 in table 2.1) does not have an exact ending year of the trade relationship. Observations like these are inferred to as being *censored*, and must be taken into account when we estimate the durations of exports.

Next, a country may re-export a product after it stops exporting it. These cases are referred to as *multiple spells of service.* For instance, in table 2.1, Argentina has two spells; Belgium, China, and Ireland have three spells; and Italy has four spells. We can treat multiple spells as independent and include all spells in the survival analysis, but this method implicitly assigns greater weights to products which have multiple spells. An alternative method is to include only the first spell of each country-product when estimating the durations of exports (see Besedeš and Prusa, 2006a). Estimated results of both cases will be presented in this paper.

The level of product aggregation will change the estimation of survival time. Export durations are supposed to be longer if we classify products at a more aggregate level. This paper uses the most disaggregate export data available (TS7 and HS10), which is important for distinguishing the difference between countries' export performance in terms of duration. Since there is no appropriate concordance between TS7 and HS10 codes, the trade durations of the two classification systems must be calculated separately. In the first period (1975-1988), products are classified by TS7; and in the second period (1989-2001) products are classified by HS10. The longest observable duration of a TS7 product is 14 years (1975-1988), and that of a HS10 product is 13 years (1989-2001). As a comparison, I also calculate the duration of exports at a more aggregate industry level (5-digit SITC code), which has export information covering both periods of 27 years (1975-2001).

3.2 Innovation

The regressor of interest of paper is the number of patents granted by the U.S. Patent Office, which is the proxy for countries' innovations. The patent data come from Hall, Jaffe and Trajtenberg (2001) and updated by Hall. Because patents vary enormously in their technological and economic significance, I weight each patent by the number of citations that it receives, and the *weighted patent counts* (WPC) are used to assess the innovations or innovative capabilities of countries. The linear weighting scheme which follows Trajtenberg (1990) is applied to construct the weighted patent count index:

$$WPC_j = (1 + g_j) \tag{1}$$

Subscription j is patent, and g_j is the number of citations received by patent j, i.e. a patent receives no citation has $WPC = 1$, and a patent cited for five times has $WPC = 6$, etc. Patents which are cited for more times are supposed to be more important and valuable, and receive higher weights when calculating the weighted patent counts.

The advantages of using patent as the indicator of innovation over R&D is described in the first chapter and will not be repeated here. I need to construct an innovation indicator which affects countries' export durations. I use the number of weighted patent counts of the first year in each period to measure countries' innovations; i.e. for TS7 products, I use the number of weighted patent counts of 1975 as the innovation indicator of the period, and for HS10 products I use that of the year 1989. The weighted patent count is the regressor of interest when I estimate the effect of innovation on the duration of exports.

3.3 Other control Variables

In selecting variables which may affect durations of trade, it seems intuitive to start from gravity variables (country size, trade cost, and trade barrier) which successfully explain trade volume. I include population and GDP per capita to control for country size. The data are from Penn World Table 6.2. I use the *average* population and GDP per capita of each country in the corresponding period. The model of estimation also contains distance, common language, and common border, which are proxies for trade costs. These variables do not change over time, and the data are obtained from Jon Haveman's International Trade Data. Duty and freight costs come from Feenstra et. al. (1996) and Feenstra (2001).

Since this paper highlights the dynamics of trade patterns, the fluctuation of real exchange rate should be added in the model. The nominal exchange rate and consumer price index (CPI) data are obtained from World Development Indicator (WDI) and are used to calculate the change in real exchange rate. Factor endowment proportion of each country is based on the skilled-unskilled labor data of Barro and Lee (2001), and capital and land data are from World Development Indicator (WDI). I get the factor intensity of each industry from NBER-CES Manufacturing Industry Database. The interactions between the factor endowment proportion of each country and the factor intensity of each industry are added in the regression in the robustness check, which account for their effect on exports as predicted in Heckscher-Ohlin model (H-O model). Finally, I calculate the number of countries from which U.S. imports a product. The fact that some products have more exporting countries to the US market can be connected to higher level of product differentiation, higher U.S. demand to the product, or higher degree of competition. For each exporting country, I calculate the average number of exporters of those products that this country exports to the U.S.

4 Models of Estimation and Estimated Results

Several estimation strategies can be applied to study the effect of innovation on the duration of exports. First, I can drop censored observations and regress uncensored export durations on innovation. The estimation does not make use of the complete sample, and it also causes sample selection bias.[31] Second, I can estimate the survival rate of different groups (e.g. highly innovative countries versus less innova-

[31] The durations of censored observations are not randomly distributed.

tive countries) using the Kaplan-Meier estimator, which accounts for data censoring. This model uses the information of all observations. However, it can control only one dependent variable at a time, and the threshold of group classification is rather arbitrary. As a result, I implement a two-stage process to estimate how innovation affects the duration of exports. In the first stage, I use the Kaplan-Meier estimator to estimate the survival function of exports at the product level, and to calculate the mean and median of export duration of each *country-industry*. In the second stage, I regress export durations on innovation, to examine whether more innovative countries have longer export relationships as predicted in trade theories.

4.1 First Stage: Model of Duration

The export duration indicates the length of time until a country stops exporting the product. Let T be a discrete random variable which takes on values t_k, $k = 1, 2, ...n$. In this paper, T represents the number of years that an export relationship survives. The probability density function of T is $f(t_i) = Prob(T = t_i)$. The survivor function of T is expressed as

$$S(t) = prob(T \geq t) = \Sigma_{t_k \geq t}\ f(t_k) \tag{2}$$

The survivor function of an export relationship describes the probability that an export relationship survives over t years.

As explained in section 3, we cannot observe the exact starting or ending year of some trade relationships (e.g. we cannot observe the ending year of a TS7 product if it is after 1988 because TS7 product information after 1988 is not available). For these censored observations, the observed duration length is equal or shorter than the real duration, and this must be considered in the estimation. I use the *Kaplan-Meier estimator* which accounts for data censoring to estimate the survivor function:

$$\hat{S}(t) = \Pi_{t_k \leq t} \frac{(n_k - d_k)}{n_k} \tag{3}$$

n_k is the number of subjects which are *at risk* of being failure right prior to period t_k. It is the number of survivors prior to t_k subtracts the number of subjects which exit the sample (censored observations). In the context of this paper, a failure event indicates that a country stops exporting a product. So n_k is the number of export relationships which have lasted for t_{k-1} years, subtract the number of those which are censored in t_k. d_k is the number of observed failure events which occur at t_k. In this paper, it is the number of export relationships which are active in year t_{k-1} but become inactive (fail) in year t_k. The Kaplan-Meier estimator is nonparametric and robust to data censoring. More details and examples of the Kaplan-Meier estimator are discussed in appendix D.

Tables 2.4 and 2.5 show the estimated survivor function of export in 1975-1988 and 1989-2001 using the Kaplan-Meier estimator. In table 2.5, 370,616 product counts (HS10) are exported to the U.S. from the 105 countries in the sample. Some country-products have multiple spells, so the total number of spells is 550,991. In the left part of table 2.5, I treat each spells as independent to estimate the survivor function; and in the right part, I only use the first spells of each country-product in the estimation. The survival curve of the two periods are depicted in figures 2.1 and 2.2, respectively. The properties of export durations can be summarized by the following points. First, the durations of exports are short in general: only 58%-65% of export relationships survive one year, and 44%-54% of them survive two years. This indicates about half of trade relationships end within two years, even after considering censored data. These facts seem to contradict with empirical findings which show that trade is stable over time at the country level, or even at the firm or plant level (Roberts and Tybout, 1997; Clerides, Lach, and Tybout, 1998). The short durations of exports at the product level indicate that although countries or firms export to the same destination in different years, the products that they export actually change over time. There exists considerable export turnover at the product level which is hidden behind the persistent trade pattern at more aggregate levels. Second, an export relationship can last quite long once it survives the first few years. The survivor rate in the sixth year is 29%-42%, and it only drops slightly to 25%-40% in the thirteenth year. This is also demonstrated in figures 2.1 and 2.2 that the survival curves become flatter in latter years. Third, the survivor rate estimated using all spells is lower than that using only the first spells, which implies that the first spells are generally longer. These properties are similar to the finding of Besedeš and Prusa (2006a). As mentioned in the introduction, the main contribution of this paper to Besedeš and Prusa (2006a) is to adopt the two-stage estimation method and to introduce the influence of innovation on export durations, which will be displayed in section 4.2.

Using the estimated survivor rates, I derive the median (in which year the survivor rate reaches 50%) and the restricted mean[32] (the area under the survival curve) of export durations. The summary of statistics is shown in table 2.6. The first panel shows the summary of TS7 products in 1975-1988, and the second panel includes the summary of HS10 in 1989-2001. As a comparison, I also present the means and medians of *observed spells length*, which do not account for data censoring. In each period, the mean and median of duration based on the Kaplan-Meier estimator is longer than that based on observed spell length, which confirms that durations are underestimated when calculated with observed spell length. The statistics of SITC products are listed in the last panel of table 2.6. I also report the percentile of spell length in table 2.7 to display the variation and dispersion of export durations.

The results in tables 2.4, 2.5, 2.6 and 2.7 summarize the properties of export durations at the product level. To study whether more innovative country-industry have longer export durations, I need the export durations of each country-industry. I estimate the survivor function and get the mean and median[33] of export duration of each *country-industry* following the same procedures. The estimated mean and median of export durations of each country-industry are the dependent variables in the second-stage regression.

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[32]The mean of export durations should be the area under the survival curve. Due to data censoring, the survival curve does not reach zero at the longest observed duration (thirteenth year in the first period and fourteenth year in the second period). The restricted mean is the area under the survival curve up to the largest observed duration. It will underestimate the real mean of the duration.

[33]Some subjects (country-product) have many censored spells and thus their survival rates never reach 50% until the longest observed duration. This means the median of export duration is longer than the maximum observed duration, but we cannot estimate how long it is exactly. In these cases, I use the longest observed length of spells as the median of export durations.

4.2 Second Stage: Model of Regression

The second stage of the estimation is to run a regression to find the correlation between innovation and export duration. The benchmark model is:

$$\begin{aligned} duration_{ci} &= \beta_0 + \beta_1 WPC_{ci} + \beta_2 population_c + \beta_3 (\frac{GDP}{pop})_c \\ &+ \beta_4 distance_c + \beta_5 language_c + \beta_6 border_c \\ &+ \beta_7 dury\_freight_{ci} + \beta_8 exchange_c + \beta_9 \mu_i + + \varepsilon_{ci} \end{aligned} \tag{4}$$

The dependent variable, $duration_{ci}$, is country c's median or mean of export duration in industry i. The median or mean of export durations are estimated in the first stage as explained in section 4.1. In the benchmark case, I assume that multiple spells from the same country-product are independent. Results using durations based on only the first spells will be shown in the section of robustness analysis.

The regressor of interest, the proxy of innovation, is the weighted patent count (WPC_{ci}) of the first year in each period. $population_c$ and $(\frac{GDP}{pop})_c$ represent the average population and GDP per capita in each period, respectively. These two variables are country-specific and do not vary by industry but will change over time. $distance_c$ is the distance between country c and the U.S. $language_c$, and $border_c$ are binary variables which show whether country c uses the same main language and share a common border with the U.S., respectively. These three variables are country-specific and do not change with industry or time. $dury\_freight_{ci}$ is the sum of duty paid and freight cost relative to the total export value in that period. $exchange_c$ is the percentage change of country c's real exchange rate between the first and last years of each period. Finally, I include an industry dummy variable (μ_i) to account for industry-specific duration pattern.[34] Basically this model looks at the *cross-country* variation in innovation to investigate its influence on the duration of exports. The summary of statistics of the regressors is listed in table 2.8.

The model in equation 4 is estimated by OLS. For each period, I use both the median and mean of export durations as the dependent variables. The expectation is that innovation increases countries' competitiveness, which enables them to maintain export relationships for longer. The estimated coefficients and standard deviations are reported in table 2.9. For the convenience of interpreting the results, I also report the beta coefficients in table 2.10. Table 2.9 shows that in both periods (75-88 and 89-01), innovation has a positive and significant impact on export durations. During the period of 1975-1988, an increase in initial weighted patent counts by 1,000 will raise the median and mean of export duration of a country-industry by 1.27 and 0.83 year, respectively. Considering that the median of duration is only two years, the influence of innovation is not negligible. In 1989-2001, a 1,000 increase in initial patent counts will increase the median and mean by 0.27 and 0.12 year, respectively. These coefficients are significant at 1% level. From the beta coefficients in table 2.10, an one standard deviation increase in patents will increase the mean and median of export duration by 0.15-0.47 standard deviation. The estimates confirm the implications of trade theories that countries which have more innovations are

[34] It is possible that U.S. imports products of an industry for a longer time than that of another.

more likely to sustain export relationships for a longer period of time.

Except common language, coefficients on other regressors have expected signs, although some of them are not statistically significant. Larger countries have longer export durations, and the effect is statistically significant. This is consistent with the result in Besedeš and Prusa (2006a), in which they find that OECD countries have longer export durations than non-OECD countries. Higher trade costs and trade barriers reduce the durations of export relationships. Countries whose currencies experience higher rates of depreciation (against U.S. Dollar) have longer export durations, though the effect is not significant. These findings hold in both periods, either when the median or mean of export duration is used as the dependent variable.

4.3 Robustness Analysis

I conduct several robustness checks. First, I re-estimate equation 4, but this time the durations of exports are estimated using only the first spell of each country-product in the first-stage estimation. The estimates are stored in table 2.11. Second, I estimate the survivor function of each country-industry using the more aggregate industry level data (5-digit SITC). Different from exports data at the product level which are recorded by TS7 and HS10 in two periods, export data of SITC industries are available throughout 1975-2001. The estimated results are presented in table 2.12. Using only the first spells or measuring durations at more aggregate do not alter the finding that innovation has a significantly positive effect on export durations. Third, I estimate the benchmark model with all variables taken natural logs (except binary variables). Estimated coefficients now represent the elasticity of export duration. In table 2.13, the estimates indicate that a 10% increase in weighted patent counts will raise the export duration by 0.4%-1%, and the effect is still statistically very significant.

Finally, I include the interaction between countries' factor endowment proportions and industries' factor intensities:

$$\begin{aligned} duration_{ci} &= \beta_0 + \beta_1 WPC_{ci} + \beta_2 pop_c + \beta_3 (\frac{GDP}{pop})_c + \beta_4 dist_c \\ &+ \beta_5 lang_c + \beta_6 bord_c + \beta_7 dury\_freight_{ci} + \beta_8 exchange_c \\ &+ \beta_9 endow_c \times intensity_i + \beta_{10} \mu_i + + \varepsilon_{ci} \end{aligned} \quad (5)$$

For each country c, I develop the endowment ratio of skilled labor, unskilled labor, and capital stock, all made relative to land. I also calculate the factor intensity of skilled labor, unskilled labor, and capital stock of each industry i. The interaction ($endow_c \times intensity_i$) is intended to account for possible endogeneity problem caused by omitted variables. The Heckscher-Ohlin (H-O) model predicts that cross-sectional trade pattern is determined by the factor endowment, and this influence may exist in the durations of exports. The interaction is not included in the benchmark model because 21 out 105 countries in the sample do not have complete factor endowment information. The estimated results are in table 2.14. Among the estimates of three factors, only that of the skilled labor has a correct sign and is statistically significant. But the inclusion of factor endowment does not change how innovation affects export durations: more innovative countries still have longer export durations in both periods.

In summary, the main finding of this paper is robust to alternative estimation of duration and model specifications.

4.4 The Number of Exporters

The number of providers of each product differs greatly in U.S. imports. This difference can be related with several factors. First, the number of providers of a product can represent the degree of product differentiation or sophistication. According to Besedeš and Prusa (2006b), the export duration of differentiated products is longer than that of the homogeneous products. Second, the fact that U.S. imports a product from more countries than other products can imply that U.S. has special demand to that product (e.g. specific design for each buyer or contract relation). Third, a higher number of exporters may reflect more intense market competition, which may reduce the durations of exports.

In this section, I construct an *exporter index* to examine how the number of exporters affects trade durations. For each product, I identify the number of exporters in the year that this product firstly enters the U.S. market. For each country, I calculate the exporter index which equals the average number of providers of those products that this country exports to the U.S.[35] A higher exporter index of a country means that the products that this country exports have more exporters.

I estimate the following model using OLS:

[35] Suppose that a country exports three products to the US during 1975-1988. The number of exporters of these three product in the first year that they are exported to the U.S. are 10, 20, and 30. So the average number of exporters faced by this country is $(10 + 20 + 30)/3 = 20$.

$$duration_{ci} = \beta_0 + \beta_1 WPC_{ci} + \beta_2 population_c + \beta_3(\frac{GDP}{pop})_c + \beta_4 distance_c \quad (6)$$
$$+\beta_5 language_c + \beta_6 border_c + \beta_7 dury\_freight_{ci}$$
$$+\beta_8 exchange_c + \beta_9 exporter_c + \beta_{10}\mu_i + +\varepsilon_{ci}$$

The regressor $exporter_c$ is the exporter index of country c. All other variables have the same definition as in equation 4. Tables 2.15 and 2.16 show the estimates. The coefficients on the exporter index are positive, meaning that a country which exports products with more exporters will have longer durations of trade relationships. The result supports the hypothesis that more exporters implies higher degree of product differentiation. The effect of innovation on export durations remains positive and significant.

5 Conclusion

Trade pattern is more dynamic than generally thought. Approximately half of export relationships last for only two to three years, but another one third survives 12 years or more. In addition, many countries enter and exit a foreign market repeatedly. In spite of the evidence, literature does not offer a clear answer to what the main determinants of the length of trade relationships are, and how to explain the large variation in export durations. Using the number of patents as the proxy for innovation and data of exports to the U.S. market, I find that more innovative countries have longer durations of exports. The finding provides a new explanation to the volatility of trade pattern, and is consistent with the implications of the product cycle model. The length of export relationships also increases with country size, and decreases with trade barriers and costs.

Table 2.1: Example of Export Spells

Product: Gas Meters HS10 code: 2028100000						Year							number	service
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	of spells	years
Country															
Argentina	x	x	x	x	x	x	x	x	x	x	x		x	2	12
Australia									x	x	x	x	x	1	5
Belgium				x	x	x		x				x	x	3	6
Canada	x	x	x	x	x	x	x	x	x	x	x	x	x	1	13
China					x	x	x		x	x		x	x	3	7
Ireland		x	x		x	x		x						3	5
Italy	x	x	x		x	x		x			x	x	x	4	11
Japan	x	x	x	x	x	x	x	x	x	x	x	x	x	1	13
Sweden						x	x	x	x	x	x	x		1	7
Thailand							x							1	1

Notes: This table demonstrates the export patter of an example product, gas meter, from 10 countries to the U.S. between 1989 and 2001. Mark "x" indicates that a country exports the product in the year.

Table 2.2: List of Countries

Algeria	Dominican	Indonesia	Morocco	Sierra Leone
Argentina	Ecuador	Iran	Nepal	Singapore
Australia	Egypt	Iraq	Netherlands	Spain
Austria	El Salvador	Ireland	New Zealand	Sri Lanka
Bahamas	Ethiopia	Israel	Nicaragua	Sudan
Bahrain	Germany	Italy	Niger	Suriname
Belgium	Fiji	Jamaica	Nigeria	Sweden
Belize	Finland	Japan	Norway	Switzerland
Bolivia	France	Jordan	Oman	Tanzania
Brazil	Gabon	Kenya	Pakistan	Taiwan
Bulgaria	Ghana	Korea	Panama	Thailand
Cameroon	Greece	Kuwait	Paraguay	Trinidad and Tobago
Canada	Guatemala	Laos	Peru	Tunisia
Chad	Guinea	Liberia	Philippines	Turkey
Chile	Guyana	Madagascar	Poland	Uganda
China	Haiti	Malawi	Portugal	United Arab Emirates
Colombia	Honduras	Malaysia	Qatar	United Kingdom
Congo	Hong Kong	Mali	South Africa	Uruguay
Costa Rica	Hungary	Mauritania	Romania	Venezuela
Cyprus	Iceland	Mauritius	Saudi Arabia	Zambia
Denmark	India	Mexico	Senegal	Zimbabwe

Table 2.3: List of Industries in 2-digit SIC 87

SIC	Description	Example Sub-Category	Differentiated-product share
20	Food and kindred products	Fluid Milk, Canned Fruits	0.31
22	Textile mill products	Finishers of Broadwoven Fabrics	0.64
28	Chemicals and allied products	Medicinal Chemicals	0.35
29	Petroleum and coal products	Petroleum Refining	0.26
30	Rubber and miscellaneous plastics products	Plastics Bottles	0.65
32	Stone, clay, glass, and concrete products	Glass Containers, Concrete Products	0.89
33	Primary metal industries	Primary Smelting and Refining	0.27
34	Fabricated metal products	Fabricated Structural Metal	0.92
35	Industrial machinery and equipment	Electronic Computers	1.00
36	Electrical and electronic equipment	Telephone Apparatus	1.00
37	Transportation equipment	Motor Vehicle Parts	1.00
38	Instruments and related products	Instruments for Measuring	1.00

Table 2.4: Survivor Function (1975-1988)

TS7 (1975-1988)									
All spells					First spells				
Time	Begin total	Fail	Lost	Survivor fun.	Time	Begin total	Fail	Lost	Survivor fun.
1	337795	140429	34111	0.5843	1	243858	101121	21849	0.5853
2	163255	38317	19225	0.4471	2	120888	25953	13635	0.4597
3	105713	14478	15731	0.3859	3	81300	9435	12440	0.4063
4	75504	9236	9020	0.3387	4	59425	6436	7339	0.3623
5	57248	5149	6648	0.3082	5	45650	3603	4843	0.3337
6	45451	2772	4134	0.2894	6	37204	1993	2607	0.3158
7	38545	1914	4056	0.2751	7	32604	1357	2777	0.3027
8	32575	1409	2970	0.2632	8	28470	1063	1973	0.2914
9	28196	950	6438	0.2543	9	25434	779	5750	0.2825
10	20808	472	2437	0.2485	10	18905	388	1989	0.2767
11	17899	104	6423	0.2471	11	16528	77	5294	0.2754
12	11372	33	1182	0.2464	12	11157	33	967	0.2746
13	10157	0	1095	0.2464	13	10157	0	1095	0.2746
14	9062	0	9062	0.2464	14	9062	0	9062	0.2746

Notes: This table reports the the survivor function of products estimated by the Kaplan-Meier estimator.

Table 2.5: Survivor Function (1989-2001)

HS10 (1989-2001)									
All spells					First spells				
Time	Begin total	Fail	Lost	Survivor fun.	Time	Begin total	Fail	Lost	Survivor fun.
1	550991	205251	65815	0.6275	1	370616	131290	43335	0.6458
2	279925	55893	29873	0.5022	2	195991	33186	17529	0.5364
3	194159	23568	18155	0.4412	3	145276	13829	10306	0.4853
4	152436	12869	13328	0.4040	4	121141	8193	8293	0.4525
5	126239	6945	17586	0.3818	5	104655	4407	13591	0.4335
6	101708	3635	18488	0.3681	6	86657	2360	15289	0.4217
7	79585	1816	13176	0.3597	7	69008	1102	10659	0.4149
8	64593	1123	9715	0.3535	8	57247	727	7426	0.4097
9	53755	619	5959	0.3494	9	49094	443	4008	0.4060
10	47177	350	3957	0.3468	10	44643	291	2413	0.4033
11	42870	241	3964	0.3449	11	41939	241	3033	0.4010
12	38665	0	4429	0.3449	12	38665	0	4429	0.4010
13	34236	0	34236	0.3449	13	34236	0	34236	0.4010

Notes: This table reports the the survivor function of products estimated by the Kaplan-Meier estimator.

Table 2.6: Summary of Statistics: Estimated Duration

	Observed spell length		K-M estimator		No. of spells
	mean	median	mean	median	
TS7 (1975-1988)					
All spells	2.8230	1	5.1346	2	337,795
First spells only	3.0372	1	5.4409	2	243,858
HS10 (1989-2001)					
All spells	3.2057	2	5.8239	3	550,991
First spells only	3.6673	2	6.4110	3	370,616
SITC5 (1975-2001)					
All spells	4.5638	2	7.9855	2	170,948
First spells only	5.7108	1	9.5389	2	82,966

Notes: This table reports the descriptive statistics of the mean and median of export durations in each period.

Table 2.7: Percentile of Durations

	Observed spell length					K-M estimator				
	10%	25%	50%	75%	90%	10%	25%	50%	75%	90%
TS7 (1975-1988)										
All spells	1	1	1	3	7	1	1	2	10	14
First spells only	1	1	1	3	9	1	1	2	14	14
HS10 (1989-2001)										
All spells	1	1	2	4	8	1	1	3	13	13
First spells only	1	1	2	5	12	1	1	3	13	13
SITC5 (1975-2001)										
All spells	1	1	2	4	13	1	1	2	11	27
First spells only	1	1	1	6	22	1	1	2	27	27

Table 2.8: Summary of Statistics: Regressors

Variable	Mean	S.D.	Min	Max	No. of obs
WPC (75-88)	131.1157	777.5972	0	11378.92	1272
WPC (89-01)	272.0184	2567.644	0	67037.63	1272
pop (75-88)	34608753	119436728	154389.4	1007752832	1272
pop (89-01)	43575997	147700053	220977.7	1208505600	1272
GDP per capita (75-88)	8363.553	8119.112	479.7626	46719	1248
GDP per capita (89-01)	9823.622	8667.726	408.2531	28922	1272
distance	8390.758	3745.914	733.894	16370	1272
language	0.2453	0.4304	0	1	1272
border	0.0189	0.1361121	0	1	1272
duty-frieght (75-88)	0.2027183	0.309168	-0.0016379	2.628709	1272
duty-frieght (89-01)	0.1452907	0.2620224	0	2.126527	1272
real exchange rate (75-88)	2.759917	12.65822	.0001267	93.76871	984
real exchange rate (89-01)	1.179807	4.298482	.0001447	40.3639	1128

Notes: This table reports the descriptive statistics of regressors. The negative number in the minimum of duty-frieght (75-88) is supposed to be a recording error.

Table 2.9: Estimated Results of the Benchmark Model

	1975-1988 (TS7)		1989-2001 (HS10)	
	Median	Mean	Median	Mean
	(1)	(2)	(3)	(4)
patent	1.27***	0.834***	0.271***	0.123***
	(0.000196)	(0.000219)	(5.06e-05)	(2.83e-05)
population	0.0136	0.0418***	0.0437***	0.0472***
	(1.19e-09)	(1.53e-09)	(1.11e-09)	(6.14e-10)
GDP per capita	0.0501***	0.0948***	0.0850***	0.113***
	(1.59e-05)	(2.58e-05)	(2.10e-05)	(1.88e-05)
dury_freight	-0.795***	-1.370***	-0.767***	-1.383***
	(0.111)	(0.237)	(0.175)	(0.176)
distance	-0.0467	-0.0128	-0.0169	-0.0174
	(1.79e-05)	(2.66e-05)	(3.04e-05)	(3.40e-05)
language	0.183	-0.198	-0.0833	-0.306
	(0.253)	(0.242)	(0.380)	(0.283)
border	3.014**	2.872***	5.169***	3.380***
	(1.424)	(0.415)	(1.100)	(0.317)
real exchange rate	0.000471	0.00435	0.00583	0.00514
	(0.00231)	(0.00490)	(0.00780)	(0.0132)
Constant	1.146***	3.351***	0.995***	3.164***
	(0.182)	(0.297)	(0.276)	(0.324)
Observations	984	984	1128	1128
R^2	0.422	0.477	0.373	0.485

Notes: The estimated specification is equation 4. Coefficients on patent, GDP per capita, and distance are multiplied by 1,000; coefficients on population is multiplied by 10^7. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 2.10: Estimated Results: Beta Coefficients

	1975-1988 (TS7)		1989-2001 (HS10)	
	Median	Mean	Median	Mean
	(1)	(2)	(3)	(4)
patent	0.477	0.325	0.281	0.153
population	0.0554	0.177	0.266	0.343
GDP per capita	0.175	0.345	0.286	0.456
duty-freight	-0.110	-0.197	-0.0803	-0.173
distance	-0.00916	-0.0261	-0.0251	-0.0310
language	0.0399	-0.0447	-0.0141	-0.0621
border	0.236	0.233	0.290	0.227
real exchange rate	0.00302	0.0289	0.00975	0.0103

Notes: Estimated beta coefficients of the regression model in equation 4.

Table 2.11: Robustness Checks: First-spell only

	First spell			
	TS7 median	TS7 mean	HS10 median	HS10 mean
	(1)	(2)	(3)	(4)
patent	1.44***	0.917***	0.266***	0.141***
	(0.000322)	(0.000260)	(6.89e-05)	(3.51e-05)
population	0.0195	0.0484***	0.0517***	0.0507***
	(1.55e-09)	(1.79e-09)	(1.13e-09)	(7.16e-10)
GDP per capita	0.0677***	0.110***	0.134***	0.140***
	(2.14e-05)	(2.97e-05)	(3.07e-05)	(2.28e-05)
dury_freight	-0.869***	-1.379***	-0.620***	-1.292***
	(0.138)	(0.266)	(0.224)	(0.200)
distance	-0.0239	-0.0216	-0.0331	-0.0204
	(2.26e-05)	(2.90e-05)	(4.43e-05)	(3.90e-05)
language	0.201	-0.240	-0.114	-0.321
	(0.324)	(0.270)	(0.496)	(0.335)
border	4.178**	3.294***	6.478***	3.952***
	(1.932)	(0.509)	(1.238)	(0.386)
real exchange	0.00167	0.00505	0.00943	0.00719
	(0.00267)	(0.00530)	(0.0119)	(0.0156)
Constant	1.134***	3.429***	0.930**	3.168***
	(0.247)	(0.330)	(0.401)	(0.364)
Observations	984	984	1128	1128
R^2	0.445	0.477	0.381	0.493

Notes: The estimated specification is equation 4. Coefficients on patent, GDP per capita, and distance are multiplied by 1,000; coefficients on population is multiplied by 10^7. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. This table reports estimated results in which durations are calculated based on only the first spell of each country-product. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 2.12: Robustness Checks: SITC Industry

	SITC	
	SITC median	SITC mean
	(1)	(2)
patent	2.45***	1.46***
	(0.000772)	(0.000480)
population	0.0455	0.108***
	(3.15e-09)	(3.28e-09)
GDP per capita	0.187***	0.253***
	(5.29e-05)	(4.82e-05)
dury_freight	-0.349	-2.600**
	(0.518)	(1.092)
distance	-0.0699	-0.0137
	(6.33e-05)	(6.65e-05)
language	0.556	-0.364
	(0.982)	(0.714)
border	10.43**	8.464***
	(5.100)	(1.403)
real exchange	0.000705	0.00101
	(0.00479)	(0.00439)
Constant	0.0204	3.361***
	(0.577)	(0.654)
Observations	948	948
R^2	0.445	0.537

Notes: The estimated specification is equation 4. Coefficients on patent, GDP per capita, and distance are multiplied by 1,000; coefficients on population is multiplied by 10^7. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. This table reports estimated results in which products are classified by 5-digit SITC code. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 2.13: Robustness Check: Variables in Natural Logs

	1975-1988 (TS7)		1989-2001 (HS10)	
	Median	Mean	Median	Mean
	(1)	(2)	(3)	(4)
patent	0.0989***	0.0648***	0.100***	0.0386***
	(0.0142)	(0.0101)	(0.0139)	(0.0108)
population	0.0389***	0.122***	0.0869***	0.165***
	(0.0101)	(0.0125)	(0.0151)	(0.0147)
GDP per capita	0.0391**	0.168***	0.0817***	0.247***
	(0.0163)	(0.0280)	(0.0147)	(0.0279)
dury_freight	-0.115***	-0.182***	-0.0781***	-0.102***
	(0.0200)	(0.0297)	(0.0149)	(0.0265)
distance	-0.0201	-0.0744**	-0.0462	-0.132***
	(0.0247)	(0.0284)	(0.0283)	(0.0378)
language	0.0121	0.0163	-0.00131	0.0512
	(0.0396)	(0.0300)	(0.0416)	(0.0360)
border	0.243	-0.0936	0.384***	-0.137
	(0.156)	(0.0783)	(0.0885)	(0.130)
real exchange rate	-0.000588	0.00611	-0.00593	-0.00117
	(0.00577)	(0.00715)	(0.00596)	(0.00732)
Constant	-0.172	-1.566***	-0.934***	-2.309***
	(0.324)	(0.488)	(0.352)	(0.499)
Observations	983	983	1125	1125
R^2	0.550	0.665	0.562	0.664

Notes: The estimated specification is an alternative version of equation 4 in which all (except binary) variables are in natural log form. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 2.14: Robustness Check: Including Factor Endowment

	1975-1988 (TS7)		1989-2001 (HS10)	
	Median	Mean	Median	Mean
	(1)	(2)	(3)	(4)
patent	1.36***	0.762***	0.256***	0.128***
	(0.000318)	(0.000243)	(6.70e-05)	(3.20e-05)
population	0.0215	0.0474***	0.0525***	0.0485***
	(1.61e-09)	(1.71e-09)	(1.10e-09)	(6.50e-10)
GDP per capita	0.0780***	0.119***	0.147***	0.151***
	(2.63e-05)	(3.51e-05)	(3.67e-05)	(2.38e-05)
dury_freight	-0.858***	-1.455***	-0.691**	-1.417***
	(0.205)	(0.408)	(0.295)	(0.263)
distance	-0.0450	-0.0341	-0.0538	-0.0124
	(2.88e-05)	(3.45e-05)	(5.34e-05)	(4.46e-05)
language	0.316	-0.195	-0.170	-0.443
	(0.398)	(0.318)	(0.604)	(0.374)
border	4.036**	3.198***	6.243***	3.786***
	(1.873)	(0.515)	(1.252)	(0.416)
real exchange rate	0.00230	0.00453	0.0148	0.00773
	(0.00228)	(0.00446)	(0.0127)	(0.0151)
unskill_labor	-0.00154	-0.00252*	-0.00148	-0.000817
	(0.00102)	(0.00138)	(0.00137)	(0.00106)
skill_labor	0.0580	0.110**	0.0238***	0.0129***
	(0.0392)	(0.0488)	(0.00415)	(0.00312)
capital	-1.74e-07	-3.85e-07	-1.08e-07**	-7.14e-08
	(2.28e-07)	(3.02e-07)	(5.22e-08)	(5.10e-08)
Constant	1.084***	3.509***	1.008**	3.193***
	(0.295)	(0.399)	(0.435)	(0.379)
Observations	840	840	960	960
R^2	0.473	0.541	0.423	0.545

Notes: The estimated specification is equation 5. Coefficients on patent, GDP per capita, and distance are multiplied by 1,000; coefficients on population is multiplied by 10^7. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 2.15: Estimated Results: Number of Exporters 1975-1988

	1975-1988 (TS7)			
	Median	Mean	Median	Mean
	(1)	(2)	(3)	(4)
patent	1.26***	0.829***	1.07***	0.769***
	(0.000194)	(0.000218)	(0.000135)	(0.000209)
population	0.0144	0.0421***	0.0146	0.0422***
	(1.21e-09)	(1.54e-09)	(1.23e-09)	(1.54e-09)
GDP per capita	0.0508***	0.0952***	0.0520***	0.0955***
	(1.60e-05)	(2.59e-05)	(1.62e-05)	(2.61e-05)
dury_freight	-0.804***	-1.374***	-0.797***	-1.372***
	(0.110)	(0.236)	(0.110)	(0.237)
distance	-0.00608	-0.0134	-0.00595	-0.0134
	(1.79e-05)	(2.66e-05)	(1.80e-05)	(2.67e-05)
language	0.190	-0.195	0.187	-0.196
	(0.253)	(0.242)	(0.253)	(0.243)
border	2.995**	2.863***	2.984**	2.860***
	(1.415)	(0.412)	(1.408)	(0.411)
real exchange rate	-0.0000961	0.00409	-0.0000940	0.00409
	(0.00272)	(0.00510)	(0.00268)	(0.00509)
exporter	0.0331*	0.0152	0.0433***	0.0185
	(0.0171)	(0.0185)	(0.0162)	(0.0182)
exporter*patent			9.35×10^{-5}***	2.98×10^{-5}***
			(3.17e-05)	(7.29e-06)
Constant	0.802***	3.194***	0.674**	3.153***
	(0.292)	(0.373)	(0.276)	(0.372)
Observations	984	984	984	984
R^2	0.425	0.477	0.443	0.479

Notes: The estimated specification is equation 6. Coefficients on patent, GDP per capita, and distance are multiplied by 1,000; coefficients on population is multiplied by 10^7. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

Table 2.16: Estimated Results: Number of Exporters 1989-2001

	1989-2001 (HS10)			
	Median	Mean	Median	Mean
	(1)	(2)	(3)	(4)
patent	0.253***	0.109***	0.581***	0.255***
	(4.68e-05)	(2.60e-05)	(6.31e-05)	(7.56e-05)
population	0.0406***	0.0449***	0.0400***	0.0447***
	(1.07e-09)	(6.01e-10)	(1.07e-09)	(5.87e-10)
GDP per capita	0.0804***	0.110***	0.0760***	0.108***
	(1.96e-05)	(1.86e-05)	(1.85e-05)	(1.85e-05)
dury_freight	-0.747***	-1.368***	-0.755***	-1.372***
	(0.180)	(0.168)	(0.178)	(0.167)
distance	-0.0180	-0.0182	-0.0185	-0.0184
	(2.88e-05)	(3.27e-05)	(2.76e-05)	(3.25e-05)
language	-0.0442	-0.277	-0.0381	-0.274
	(0.363)	(0.270)	(0.353)	(0.267)
border	4.842***	3.139***	4.828***	3.133***
	(1.059)	(0.309)	(1.038)	(0.304)
real exchange rate	0.00844	0.00706	0.00853	0.00710
	(0.00721)	(0.0131)	(0.00711)	(0.0130)
exporter	0.140***	0.103***	0.127***	0.0972***
	(0.0448)	(0.0356)	(0.0450)	(0.0357)
exporter*patent			-4.55×10^{-5}***	-2.02×10^{-5}***
			(3.70e-06)	(7.16e-06)
Constant	-0.294	2.215***	-0.111	2.296***
	(0.559)	(0.451)	(0.550)	(0.455)
Observations	1128	1128	1128	1128
R^2	0.415	0.518	0.430	0.522

Notes: The estimated specification is equation 6. Coefficients on patent, GDP per capita, and distance are multiplied by 1,000; coefficients on population is multiplied by 10^7. Robust standard errors clustered by country are in parentheses. Industry dummies are included but not reported. * indicates significance level: *** p<0.01, ** p<0.05, * p<0.1.

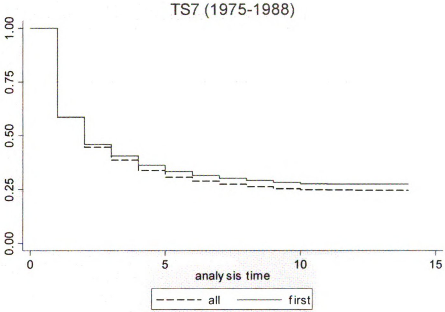

Figure 2.1: The survivor function of TS7 products in 1975-1988 using the Kaplan-Meier estimator

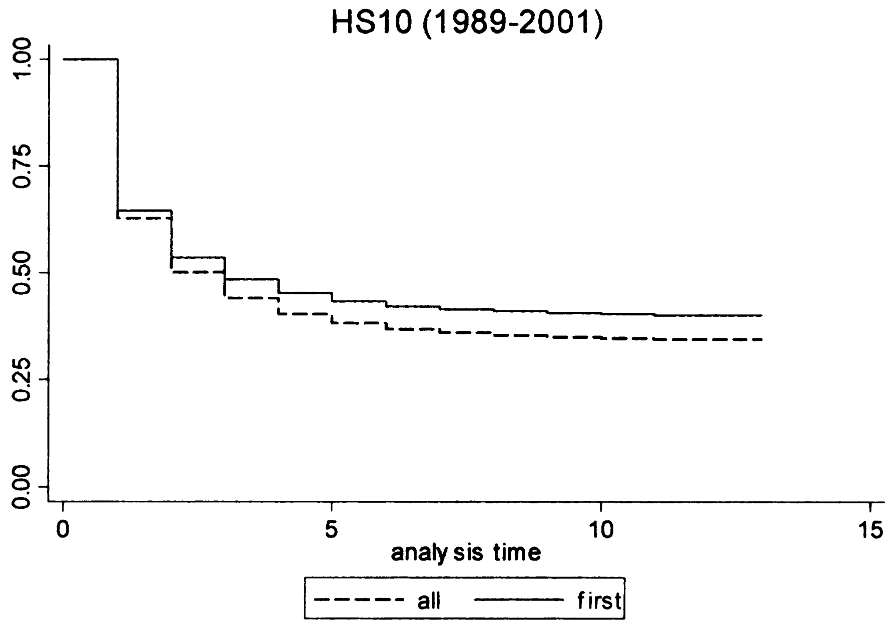

Figure 2.2: The survivor function of HS10 products in 1989-2001 using the Kaplan-Meier estimator

Chapter 3
Network Externality, Compatibility, and Foreign Entry Mode

1 Introduction

Foreign direct investment (FDI) stock grew dramatically in the last 15 years of the twentieth century. This trend slows down in recent years, but the growth of FDI still outpaces the growth of world income. Firms undertake FDI for many reasons: saving trade cost, reducing production cost, or gaining strategic competition advantage. On the other hand, FDI also induces costs such as loss of economies of scale, and the costs of disintegration.[36] These arguments can be summarized by the proximity-concentration trade-off[37] and the factor-proportions hypothesis. These theories are also used to explain different patterns of FDI across firms, industries and countries. A deficiency of these theories is that they only focus on explanations from the supply side. The impact of the difference from the demand side has not been broadly studied. This paper develops a differentiated-product duopoly model that includes the economies of scale on the demand side (network externality) to analyze the difference of FDI patterns across industries and firms.

Network externality indicates the utility that a consumer derives from using a good

[36] These theories are summarized in Navaretti and Venables (2004).

[37] Firms choose to enter the foreign market through FDI when the gains from saving trade costs outweigh the cost of building a subsidiary in a foreign country. See Horstmann and Markusen(1987,1992), and Markusen and Venables(1998, 2000). For empirical evidence see Brainard(1997).

depends on the number of people using the same brand or compatible goods. Katz and Shapiro (1994) summarize different types of network externality and the sources of them. Direct network externality is defined as the value of a product directly increases with the number of people using the same or compatible products. The most obvious examples are communication products, such as telephone, fax machine, and E-mail. A telephone that can not call out or receive from other users is not valuable. The indirect network externality comes from *market mediated effects*. The system which has a larger network usually has more varieties of complements and easily accessible services. A prominent computer operating system attracts more companies to design software that can be used on it, which increases the utility that users derive from it. For both types of network externality, consumers benefit from making the same choice as most other people do.

A central concept related to network externality is compatibility. In this paper, the level of compatibility measures the degree of interdependency between the network size of two rivalry systems. Two systems are (partially) compatible if the utility that an user derives from a system depends not only on the number of agents using the same system, but also on the number of agents using the other system. A Hotmail E-mail account is compatible with a Yahoo E-mail account because users having different accounts can still send e-mails to each other. By this definition, Yahoo messenger and MSN messenger are not (perfectly) compatible since agents using different messenger systems cannot contact each other directly.

This paper highlights the role of network externality and compatibility in explaining the following facts of international investment. First, firms producing compatible products are more likely to undertake FDI in same locations than firms producing incompatible products. I use two examples to demonstrate that firms' FDI decisions differ with the degree of products' compatibility. The first example is the personal computer market. Dell, Hewlett-Packard(HP), and Apple are multinational companies selling personal computers and laptops worldwide. Dell and HP sell computers using Microsoft Windows system, while Apple sells computers using Mac OS. The FDI destinations of these three firms match the compatibility of their products. Dell mainly invests in India, China, and Canada. HP mainly invests in India, China, and Singapore. Apple mainly invests in UK, Japan, and Denmark. These FDI destinations show that Dell and HP, which produce more compatible products, choose same main FDI locations; while Apple, which produces less compatible product, chooses different FDI locations. The second example is the digital camera market. A digital camera needs memory cards to store the data. The standards of memory card include Secure Digital Card(SD), Memory Stick(MS) and, xD-picture Card(xD). Among these standards, xD is used only on cameras produced by Olympus and Fujifilm. The fact is Olympus and Fujifilm also have the same FDI destinations: their largest FDI destination is China, followed by the U.S. The main FDI locations of other Japanese companies which have camera as their main products are: Nikon's main FDI locations are China and South Korea; Canon's main FDI locations are Vietnam and China. These examples reveal the positive correlation between firms' product compatibility and their main FDI locations. The factors affecting firms' FDI decision can be complicated, but these examples inspire me that network externality and compatibility may play a role. Second, FDI is more important in industries with strong network externality. Since high-technology industries usually present stronger network effect, this result provides a new explanation to a stylized fact in international trade that FDI is more prevalent in technology-intensive and skill-intensive industries (Markusen 2002; Navaretti and Venables 2004). Third, firms which have more existing users (which I refer to a greater installed base) are more likely to undertake FDI. Since larger and older firms are more likely to have a greater installed base, the last finding corresponds to another stylized fact in trade literature that firms which undertake FDI are on average larger and older than firms which do not undertake FDI.

The impact of network externality effect on international market has not drawn much attention. The only paper, to the best of my knowledge, which relates network externality and international entry mode is completed by Klimenko and Saggi (2007). They examine the preferences of a foreign firm and the government of the host country under the effects of network externality and compatibility over two entry modes: the de novo entry by the foreign firm and the acquisition of the domestic incumbent. There are at least three main differences between their paper and mine. First, in their model, firms choose either to enter through greenfield FDI or acquisition and merger (M&A). In my paper, firms choose between entering through FDI and exporting. Second, the market structure of their paper is the competition between one firm in the host country and one firm in the FDI source country. In my paper, the host country does not produce, and competition is between two firms from foreign countries. The model is especially suitable to analyze high-technology industries in which companies from developed countries compete in developing countries which cannot produce the products by themselves. Third, the main object of Klimenko and Saggi (2007) is to explore how the host country's government should set optimal policies to increase welfare under network externality. My paper focuses on how network externality affects firms' strategic incentives to undertake FDI.

The remainder of the paper is organized as the follows. In section 2, I outline the benchmark model to analyze the impacts of network externality and compatibility on equilibrium prices, market shares, and foreign entry decisions. In section 3, I study the case that one firm has more existing customers (a larger installed base) in the foreign country before it directly competes with the other firm. The main result of this section is to find how an installed base imposes different effects on the incumbent and the entrant. Section 4 is the conclusion and I discuss possible extensions of this model.

2 Benchmark Model: No Installed-Base

There are three countries in the model, denoted as A, B, and Foreign. Two firms, A and B, are located in country A and B, respectively. The number of firms is fixed due to the high corporate-level fixed cost. The two firms produce differentiated systems and sell the products in the foreign country. The foreign country itself does not produce. The structure of the model is similar to the strategic trade policy literature (e.g. Brander and Spencer, 1985) that two countries export to a third country. I refer the model of this section to the *symmetric case* because the two firms are identical in all aspects except they produce differentiated systems. This is contrary to the model in section 3, which is defined as the *asymmetric case*, in which one firm has existing users (an installed base) in the foreign market before it directly competes with the rival. The producers play a two-stage game. At the first stage, they determine how to serve the foreign market. There are two entry modes available to each firm: export (X) or foreign direct investment (F). At the second stage, the firms compete in the foreign market by setting prices. The equilibrium is found by backwards induction beginning with the second stage.

2.1 Preferences of Consumers

In this section, I derive the demand function of a duopoly model in the presence of network externalities. There is a unit mass of consumers in the foreign country, and each consumer has an inelastic demand of one unit of the good (one system). The total value of a system is constituted by its stand-alone utility and network utility. The stand-alone utility a consumer derives from a system depends on his taste, x. The tastes of consumers are uniformly distributed along the interval [0,1]. A consumer who has taste x derives the stand-alone utility which equals

$$v - ax \quad \text{if he or she buys from firm A} \tag{1a}$$

$$v - a(1-x) \quad \text{if he or she buys from firm B} \tag{1b}$$

v is the base value of the systems. A consumer who has a high x prefers system B to system A. The parameter a measures the degree of products' differentiation.

Equation 1 shows that the disutility consumers derive from choosing the less preferred system increases with a. This setting is the same as the Hotelling model. We can think x as consumer's location on the unit interval and a as the transportation cost. The locations of firm A and firm B are fixed at the two end points, 0 and 1, respectively. Consumers who live close to point 0 prefer A to B because buying from A induces less transport cost.

The network utility of a system depends on its network size; i.e. the number of agents joining the compatible network. I assume consumers have perfect foresight, so they can correctly anticipate the network size at the moment they make their purchase decisions. The network size of firm i is:

$$y_i = S_i + \gamma S_j; \quad i, j = A, B, \quad i \neq j \tag{2}$$

y_i denotes the size of network of system i; S_i denotes the equilibrium output level (which is also the market share) of firm i. I assume that the base value v is high enough that in equilibrium the whole market is fully covered by the two producers: $S_A + S_B = 1$. The network size of a system depends not only on its own output level but also on its rival's output level, and the degree of interdependency is determined by γ. I express $\gamma \in [0, 1]$ as the degree of compatibility between the two systems. For instance, if $\gamma = 0$, the two systems are incompatible and the network size of each system is solely determined by its own market share. If $\gamma = 1$, the two systems are perfectly compatible and always have an identical network size: $y_A = y_B = S_A + S_B = 1$. I allow *partially compatible* in the range $0 < \gamma < 1$. If $\gamma = 0.5$,

$y_A = S_A + 0.5S_B$. The network size of A depends on A's and B's market shares jointly, but A's market share has a greater weight than B's market share. I assume that the degree of compatibility is predetermined before the firms enter the foreign market.

Combine the stand-alone utility and network utility, a consumer of type x has a total utility net of price which equals

$$u = v - ax + ny_A - p_A \qquad \text{if he or she buys from firm A} \tag{3a}$$

$$u = v - a(1-x) + ny_B - p_B \quad \text{if he or she buys from firm B} \tag{3b}$$

p_A and p_B are the prices of good A and B, respectively. n is the strength of network effect. A large n means consumers get higher utility from network effect.[38] From equation 3, we can see that the utility consumers derive from product i increases with the size of network y_i.

Each agent purchases the system that maximizes his or her utility. To get the demand function faced by firm A and B, I find the consumer with type x^* who is indifferent from buying good A to good B. Type x^* must equate 3a and 3b: $v - ax^* + ny_A - p_A = v - a(1-x^*) + ny_B - p_B$. In equilibrium, consumers who have type $x < x^*$ buy from firm A and those who have type $x \geq x^*$ buy from firm B.

[38] The setting of the utility is similar to Katz and Shapiro (1985) and Klimenko and Saggi (2007).

Solving this equation, I get the demand functions faced by the two firms

$$S_A = x^* = \frac{a - n(1-\gamma) - p_A + p_B}{2a - 2n(1-\gamma)} \tag{4a}$$

$$S_B = 1 - x^* = \frac{a - n(1-\gamma) + p_A - p_B}{2a - 2n(1-\gamma)} \tag{4b}$$

2.2 The Second Stage: Price Competition Game

At the second stage, each firm has to set a price simultaneously under the entry modes that they chose at the first stage. There are four possible combinations of entry modes at the beginning of the price competition game:

(1) XX: Both firms export.

(2) FF: Both firms undertake FDI.

(3) XF: Firm A exports and firm B undertakes FDI.

(4) FX: Firm A undertakes FDI and firm B exports.

The direct trade-off between FDI and export can be explained by the proximity-concentration hypothesis. The benefit of investing in the foreign market is to achieve proximity to consumers. It saves the trade cost, such as transportation cost and tariff. The benefit of exporting is to achieve concentrating production. It saves the fixed cost of building a plant in the foreign country. Firms' profit functions under these two entry modes are:

$$\pi_i = (p_i - \tau)S_i \quad \text{if firm i enters through exporting} \tag{5a}$$

$$\pi_i = p_i S_i - f \quad \text{if firm i enters through investing} \tag{5b}$$

Notation τ is the unit export cost, and f is the fixed cost of FDI. S_i is market share of firm i in equation 4. Without loss of generality, I assume the unit production cost equals zero in all countries.[39] A firm enters the foreign country by exporting has a marginal cost equals τ and has no additional fixed cost. A firm enters through FDI has zero marginal cost but has a fixed cost equals f. This cost structure shows FDI is more likely to be beneficial to the firm capturing a large market share, while exporting is more likely to be beneficial to the firm has low level of output.

Suppose at the first stage both firms enter through export (mode XX). The profit functions of A and B are as equation 5a. The firms then choose their prices simultaneously to maximize the profit of each. By setting the first order derivatives equal zero, I can get firms' best-response functions

$$\begin{aligned} \frac{1}{2(a-n+n\gamma)}(a-n-2p_A+p_B+n\gamma) &= 0 \\ \frac{1}{2(a-n+n\gamma)}(a-n+p_A-2p_B+n\gamma) &= 0 \end{aligned} \tag{6}$$

[39] In reality, an important advantage of making FDI in developing countries is to save production cost. In my model, assuming a positive production cost will not change the trade-off between export and FDI. Carrying out FDI still leads to a lower unit cost but higher fixed cost. It is just now the unit cost FDI saves includes both the producton cost and trade cost.

Solving the best response functions simultaneously gives us the equilibrium price of mode XX:

$$p_A^{XX} = p_B^{XX} = a - n(1-\gamma) + \tau \tag{7}$$

The superscript denotes the entry mode: "XX" means that both firms enter through exporting. Plug these prices into the demand functions in equation 4 and profit functions in equation 5a. The equilibrium market shares and profits are

$$S_A^{XX} = S_B^{XX} = \frac{1}{2} \tag{8}$$

$$\pi_A^{XX} = \pi_B^{XX} = \frac{1}{2}(a - n(1-\gamma)) \tag{9}$$

Similarly, we can find the equilibrium outcomes of the other three modes. In mode *FF*, the profit function of both firms is equation 5b. In mode *XF* and *FX*, the exporter's profit function is equation 5a and the investor's profit function is equation 5b. In each mode, firms maximize their profits by choosing prices. I derive the equilibrium prices, market shares, and profits from solving the first order conditions.[40] The results are listed in table 3.1.

To ensure that both firms have positive prices, market shares, and profits in all four possible equilibrium entry modes, I assume $a > \frac{1}{3}\tau + n(1-\gamma)$ and $a > 2f + n(1-\gamma)$. The products differentiation a must be relatively large than the network effect $n(1-\gamma)$, otherwise the strong network externality effect will dominate and drive consumers to

[40] See Appendix E for detailed steps of finding these results.

end up buying from only one firm.

Lemma 1, 2, and proposition 1 summarize the findings from Table 3.1.

Lemma 1 *The equilibrium prices of both firms in each entry mode will increase with (1) an increase in the level of products difference(a), (2) an increase in the level of compatibility(γ), and (3) a decrease in the strength of network externality(n).*

Proof. From Table 3.1: $\frac{\partial p_i^{kl}}{\partial a} = 1 > 0$, $\frac{\partial p_i^{kl}}{\partial \gamma} = n > 0$, $\frac{\partial p_i^{kl}}{\partial n} = -1 < 0$, for $\forall k, l = X, F$ and $i = A, B$. ■

(1) of lemma 1 verifies the principle of differentiation in industrial organization.[41] Under a standard price competition, firms have greater market power when their products are more different and thus they can set higher prices and make more profits. (2) seems to contradict with (1) if we think *greater products differentiation* is the same as *lower degree of compatibility*. In fact, greater compatibility increases the dependency of a firm's profit on the size of its rival's network, and thus decreases the intensity of competition between the two firms.[42] Contrary to compatibility, (3) shows that strong network externality effect induces firms to compete more aggressively to get a large market share.

Lemma 2 *Firms will set a lower price when they enter through FDI, and will set a higher price when they enter through exporting.*

Proof. Suppose firm B exports. Firm A will set a higher price when it enters through exporting than when it enters through FDI: table 3.1 shows $p_A^{XX} > p_A^{FX}$. Similarly,

[41] See Tirole (1988) chapter 7.
[42] See Klimenko and Saggi (2007).

when B enters with FDI, firm A will charge a higher price when it exports than invests: $p_A^{XF} > p_A^{FF}$. When the two firms take different actions at the entry game (mode XF or FX), the price of the investor is lower than the exporter: $p_B^{XF} < p_A^{XF}$ and $p_A^{FX} < p_B^{FX}$. ■

Lemma 2 shows the *strategic effect* of FDI in this model. In a standard price competition model, the equilibrium prices and sales depend on firms' marginal costs. A firm sets a lower price when its marginal cost is lower. From equation 5a and 5b, we see that firms have lower marginal cost when they enter through FDI. Thus a firm competes more aggressively in the price competition game if it enters through FDI in the entry game. Lemma 2 compares the equilibrium prices across different entry mode and when firms take different entry actions, but lemma 1 describes the comparative statics for each given entry mode.

Proposition 1 *When export and FDI coexist in the market, the ratio of the FDI firm's market share to the exporter's market share increases with the strength of network externality (n).*

Proof. Let R denotes the ratio of the output of the FDI firm to the output of the exporting in mode XF and FX. From table 3.1, $R = (\frac{1}{2} + \frac{\tau}{6(a-n(1-\gamma))})/(\frac{1}{2} - \frac{\tau}{6(a-n(1-\gamma))})$. We can verify that $\frac{dR}{dn} = \frac{6\tau(1-\gamma)}{(3n-3a+\tau-3n\gamma)^2} > 0$. ■

Proposition 1 presents one of the three main finding of this paper. From lemma 2, we know that the investor sets a lower price than the exporter. The lower price directly attracts more consumers to buy from the investor. But a strong network externality strengthens this effect and increases the market share of the investor even further. Network externality effect (direct or indirect) is especially prominent in high-technology industries, such as information and telecommunication. From proposition 1, we expect that FDI is more important in high-technology industries, which verifies a stylized fact in FDI literature.

2.3 The First Stage: Entry Game

In section 2.2, I determined the equilibrium prices and profits for each of the four possible entry modes. At the first stage, each firm chooses to enter either through export or through FDI. To find the equilibrium, we need to determine each firm's optimal entry decision given its rival's action.

1. The rival enters through export

Consider the case that the rival enters through exporting. To simplify the analysis, I introduce the notation $\Delta\pi^k$ to denote the attractiveness of FDI relative to exporting, i.e. the profit of choosing FDI subtract the profit of exporting, where $k = X, F$ indicates the entry action that the rival undertakes. Consider the case that firm B enters through export. If firm A chooses to export, the outcome is mode XX in Table 3.1 and A's profit equals π_A^{XX}. If firm A decides to enter through FDI, the outcome is mode FX and A's profit equals π_A^{FX}. Firm A will choose FDI if and only if $\Delta\pi^X(\tau, f, \gamma, n) = \pi_A^{FX} - \pi_A^{XX} > 0$. Similarly, given A exports, B will choose FDI if $\Delta\pi^X(\tau, f, \gamma, n) = \pi_B^{XF} - \pi_B^{XX} > 0$. In summary, when the rival exports, a firm will choose FDI if and only if $\Delta\pi^X > 0$. I analyze the impact of each of the four parameters on the entry decision by calculating the comparative static effects. The signs of the derivatives are:[43]

$$\frac{d\Delta\pi^X}{d\tau} > 0, \frac{d\Delta\pi^X}{df} < 0, \frac{d\Delta\pi^X}{d\gamma} < 0, \frac{d\Delta\pi^X}{dn} > 0 \tag{10}$$

The first two derivatives demonstrate that $\Delta\pi^X$ increases with export cost and decreases with FDI cost. This matches the proximity-concentration argument that a high export cost and a low FDI fixed cost encourage firms to invest in foreign markets. The other two derivatives show that the attractiveness of FDI decreases with compatibility and increases with the strength of network externality, given the rival enters through export. In lemma 2, we know that the investor in mode XF or FX competes more aggressively in the price game and captures a larger market share. How much additional market share it can capture depends on the strength of network externality effect and the degree of compatibility. Under stronger network externality, the investor can capture a larger market share. High compatibility, however, tends to equate the network size and weakens the advantage of the only investor. So the strategic incentive for a firm to enter through FDI given its rival exports increases with n and decreases with γ, because FDI is more likely to be optimal to the firm with a high level of output.

2. The rival enters through FDI

Consider a case that the rival directly invests in the foreign market. A firm will choose FDI if and only if $\Delta\pi^F(\tau, f, \gamma, n) = \pi_A^{FF} - \pi_A^{XF} = \pi_B^{FF} - \pi_B^{FX} > 0$. The

[43]The proofs are in appendix F.

comparative static effects are:[44]

$$\frac{d\Delta\pi^F}{d\tau} > 0, \frac{d\Delta\pi^F}{df} < 0, \frac{d\Delta\pi^F}{d\gamma} > 0, \frac{d\Delta\pi^F}{dn} < 0 \tag{11}$$

The proximity-concentration trade-off still hold: a high export cost and a low FDI fixed cost make a firm more willing to enter through FDI. The signs of derivatives with respect to compatibility (γ) and network externality effect (n) are different from the previous case: now FDI is more attractive when compatibility is higher and when network externality effect is weaker.[45] The intuition is as follows. If my rival makes FDI, I can either enter with FDI and share the market equally with him, or I can enter by exporting. The incentive of exporting is to save the FDI fixed cost. So exporting is optimal when the saving of FDI fixed cost outweights the sum of the variable export cost, and this will sustain only when my market share is small enough. From table 3.1, the market share after switching to export is increasing with n and decreasing with γ, which means export is optimal when network effect is strong or when compatibility is low. Or equivalently, FDI is optimal when network effect is weak or when compatibility is high.

These comparative static effects can be summarized in proposition 2:

[44] The proofs are in appendix F.

[45] At first glance this result is counterintuitive, because in the previous case I show that a strong network externality effect and low compatibility make FDI more attractive. The point is: a firm can never become the only investor when its rival enters through FDI. In fact, in this case we are looking for the strategic incentives to be the only exporter. Lemma 2 demonstrates that firms set a higher price when they export. The only exporter in equilibrium earns a higher marginal revenue but loses some market share. The smaller output level the only exporter has, the more trade cost it saves by entering through export. Thus the attractiveness of entering through exporting increases with network externality effect and decreases with compatibility. This implies the attractiveness of entering through FDI decreases with network externality and increases with compatibility.

Proposition 2 *(1) The attractiveness of entering through FDI always increases with export cost (τ) and decreases with FDI fixed cost (f). (2) Given the rival exports, the attractiveness of entering through FDI decreases with compatibility (γ) and increases with the strength of network effect (n). (3) Given the rival enters through FDI, the attractiveness of FDI increases with compatibility and decreases with the strength of network effect.*

To find the Nash equilibrium of the entry game, I need to consider both firms' optimal entry decisions simultaneously. As indicated in proposition 2, the attractiveness of FDI depends on τ, f, γ, and n. In fact, these four parameters can be classified into two categories: proximity-concentration factors (τ and f) and network externality factors (γ and n). As we can see in both cases, the two factors in each category always have opposite impacts on the attractiveness of FDI, i.e. $\frac{d\Delta\pi^k}{d\tau}$ and $\frac{d\Delta\pi^k}{df}$ have different signs and $\frac{d\Delta\pi^k}{d\gamma}$ and $\frac{d\Delta\pi^k}{dn}$ have different signs for $k = X, F$. To reduce the number of cases to analyze, I will pick one parameter from each category to show how these two forces determine equilibrium entry mode.

Figure 3.1 shows the market outcome of the no-installed-base case. The two letters in each region show the equilibrium entry mode. Curve (i) in figure 3.1 indicates the parameter values of export cost(τ) and compatibility(γ) that a firm is indifferent between exporting and FDI when its rival enters through export ($\Delta\pi^X = 0$). From equation 10, we know that $\frac{d\Delta\pi^X}{d\tau} > 0$ and $\frac{d\Delta\pi^X}{d\gamma} < 0$, and thus the locus of $\Delta\pi^X = 0$ is positive sloping. FDI is optimal in the area above the curve ($\Delta\pi^X > 0$) and export is optimal in the region below the curve ($\Delta\pi^X < 0$). Curve (ii) indicates the parameter values that a firm is indifferent between exporting and FDI when its rival enters through FDI ($\Delta\pi^F = 0$). Equation 11 shows that $\frac{d\Delta\pi^X}{d\tau} > 0$ and $\frac{d\Delta\pi^X}{d\gamma} > 0$, and so the locus of $\Delta\pi^F = 0$ is downward sloping. FDI is optimal in the area above the curve ($\Delta\pi^F > 0$) and export is optimal in the region below this curve ($\Delta\pi^F < 0$). In region (I), the market equilibrium is that both firms undertake FDI (FF). Any point in this area is above curve (i) ($\Delta\pi^X > 0$) and (ii) ($\Delta\pi^F > 0$), which means FDI is a dominant strategy because the export cost τ is relatively high. In region (III), the equilibrium is that both firms enter through exporting (XX) because the export cost is relatively low. Any point located in this area is below curve (i)($\Delta\pi^X < 0$) and curve (ii)($\Delta\pi^F < 0$), which means export is optimal regardless of the rival's action. In region (II), the Nash equilibrium is that the two firms make different entry decisions (FX or XF). This is because FDI is the best action when the rival exports ($\Delta\pi^X > 0$), but exporting is the best action given the rival invests ($\Delta\pi^F < 0$). From figure 3.1, we can see the height of region (II) decreases with compatibility, while the height of area (I) and (III) increases with compatibility. This brings us the following proposition.

Proposition 3 *The two firms are more likely to take same action to enter a foreign market when compatibility is high, and they are more likely to choose different entry action when compatibility is low.*

This proposition shows an important finding of this paper that the FDI decisions of firms producing products with network externality are related to the compatibility of their products. It reproduces the FDI pattern in personal computer market and digital camera market. Firms producing compatible products tend to choose same FDI locations, and firms producing less compatible products choose different locations.

3 Model with an Installed-Base

In this section I address a model in which one of the two firms has an installed base in the foreign market. An installed base of the incumbent indicates that there are some existing consumers using the incumbent's system before the two firms compete directly in the market. This installed-base or lock-in effect appears in many high-technology industries. In the personal computer operation system(OS) market, Microsoft Windows has more than 95% market share.[46] In the personal computer CPU market, Intel has about 77% of the market.[47] In the domestic market, an installed base can affect consumers' choices of technology and can change firms' motivation of innovation. (Farrell and Saloner 1985, 1986). I name the model in this section the *asymmetric* case because only one firm (the incumbent) has an installed base while the other firm (the entrant) does not. In this section, I analyze how an installed base imposes different effects on the incumbent's and the entrant's entry decisions in a foreign market.

I assume that the installed base is formed before the two firms compete directly, and existing consumers who adopted the incumbent's system do not switch after the

[46] According to ITFacts: in 2007, there are 665 million copies of XP installed worldwide, giving it 74.3% share of the PC installed base. Other versions of Windows account for another 190 million units, or 21.6% share.

[47] In 2006, Intel has 77.7% of the x86 CPU market. AMD's x86 market share is 22.3%.

entrant enters the market. Since the installed base is part of the network, new consumers take it into consideration when they make their purchase decisions.

3.1 Preferences of Consumers

Let firm A be the *incumbent* and have an installed base in the foreign country before it competes with firm B, the *entrant*. The installed base does not affect the stand-alone utility. It enters the total utility function through the network size:

$$y_A = m + S_A + \gamma S_B \quad (12a)$$

$$y_B = S_A + \gamma S_B \quad (12b)$$

Notation m measures the size of the installed base, and it is predetermined. We can think the symmetric case in section 2 (equation 2) as a special case of equation 12 by setting $m = 0$. All other assumptions and settings are identical to section 2.1. With the installed base, the demand functions of the incumbent and the entrant are

$$S_A = x^* = \frac{a - n(1-\gamma) - p_A + p_B + mn(1-\gamma)}{2a - 2n(1-\gamma))} \quad (13a)$$

$$S_B = 1 - x^* = \frac{a - n(1-\gamma) + p_A - p_B - mn(1-\gamma)}{2a - 2n(1-\gamma))} \quad (13b)$$

3.2 The Second Stage: Price Competition Game

To find the market outcome of the price competition game, I derive the best-response functions of the incumbent and the entrant in each of the four entry modes. Following the same procedures as in section 2.2, I can solve for the equilibrium prices, market shares, and profits under different entry modes.[48] These results are reported in table 3.2.[49]

With an installed base, the two firms set different prices and have different profits even when they choose the same entry action (XX and FF). In addition to lemma 1 and 2, the asymmetric case result also shows the following property:

Lemma 3 *The incumbent's price, market share, and profit increase with the size of installed base m under all entry modes. The entrant's price, market share, and profit decrease with m.*

Proof. From table 3.2: $\frac{\partial p_A^{kl}}{\partial m} = \frac{1}{3}n(1-\gamma) > 0$, $\frac{\partial p_B^{kl}}{\partial m} = -\frac{1}{3}n(1-\gamma) < 0$; $\frac{\partial S_A^{kl}}{\partial m} = \frac{n(1-\gamma)}{6(a-n(1-\gamma))} > 0$, $\frac{\partial S_B^{kl}}{\partial m} = -\frac{n(1-\gamma)}{6(a-n(1-\gamma))} < 0$; $k, l = X, F$ ■

A greater installed base m makes the incumbent's product more attractive relatively to the entrant's, and leads to higher price and market share to the incumbent.

[48] I assume $a - n(1-\gamma) > (1/3)\tau + (1/3)mn(1-\gamma)$ and $(a - (1 + (1/3)m)n(1-\gamma)) \times (a - (1 + (1/3)m)n(1-\gamma)) > 2f(a - n(1-\gamma))$ to ensure both firms have positive prices, market shares and profits in all four possible equilibrium entry modes.

[49] See Appendix E for detailed calculations.

3.3 The First Stage: Entry Game

To find the equilibrium of the entry game, I firstly determine each firm's optimal entry decision given its rival's action. I discuss all four cases, since with the installed base the two firms are no longer symmetric. To simplify the expression, let $\Delta\pi_i^k$ denotes the attractiveness of FDI to firm i given its rival takes action k, where $i = A, B$ and $k = X, F$. For instance, if firm B exports, firm A will undertake FDI if and only if $\Delta\pi_A^X = \pi_A^{FX} - \pi_A^{XX} > 0$. If B enters through FDI, A will undertake FDI if and only if $\Delta\pi_A^F = \pi_A^{FF} - \pi_A^{XF} > 0$. For firm B, FDI is the best action if $\Delta\pi_B^X = \pi_B^{XF} - \pi_B^{XX} > 0$ when A exports; FDI is the best action if $\Delta\pi_B^F = \pi_B^{FF} - \pi_B^{FX} > 0$ when A invests. In summary, given the rival's action is k, firm i will undertake FDI if and only if $\Delta\pi_i^k > 0$.

I summarize the signs of comparative static effects in table 3.3.[50]

The signs of derivatives with respect to export cost (τ) and FDI fixed cost (f) for both the incumbent and the entrant are consistent with the no-installed-base case. A higher export cost and a lower FDI cost make FDI more attractive. The signs with respect to the size of installed base (m) demonstrate that the chance that the incumbent enters through FDI increases with m, and the chance that the entrant enters through FDI decreases with m.

The signs of derivatives with respective to γ and n are different for the incumbent and the entrant. As shown in Table 3, these signs are also affected by the size of installed base m. To clarify the impact of network externality and compatibility

[50]See Appendix F for proofs.

on equilibrium entry mode, I discuss it with two cases: the small-installed-base case ($0 < m < \frac{\tau}{2a}$) and the large-installed-base case ($m \geq \frac{\tau}{2a}$).

1. Small installed base: $0 < m < \frac{\tau}{2a}$

With a small installed base ($m < \frac{\tau}{2a}$), the possibility to enter through FDI decreases with compatibility (increases with the strength of network effect) when the rival enters through export; the possibility of FDI increases with compatibility (decreases with the strength of network effect) when the rival enters through FDI. This conclusion is the same as proposition 2, in which neither firm has an installed base. Although the installed base makes the equilibrium prices and profits different, the impact is not strong enough to reverse the direction of marginal effects of γ and n on firms' best response.

Figure 3.2 shows the equilibrium entry mode with a small installed base. Curve (i) indicates the parameter values of export cost(τ) and compatibility(γ) that makes the incumbent indifferent between exporting and FDI, given the entrant enters through export ($\Delta\pi_A^X = 0$). Curve (iii) shows the τ and γ that makes the entrant indifferent between exporting and FDI, given the incumbent exports($\Delta\pi_B^X = 0$). These two curves are upward sloping as curve (i) in Figure 3.1. We can see that curve (i) locates below curve (iii) for $\forall\ \gamma < 1$: a lower export cost is needed to induce the incumbent to enter through exporting. When the two products are perfectly compatible, i.e. $\gamma = 1$, the entrant can take fully advantage of the incumbent's installed base and thus curve (i) and (iii) merges at $\gamma = 1$.

Curve (ii) indicates the parameter values of τ and f that makes the incumbent indifferent between exporting and FDI, given the entrant enters through FDI ($\Delta\pi_A^F = 0$). Curve (iv) demonstrates the τ and f that makes the entrant indifferent between exporting and FDI, given the incumbent enters through FDI ($\Delta\pi_B^F = 0$). These two curves are downward sloping, as curve (ii) in Figure 3.1. Again the incumbent requires a lower export cost than the entrant to find exporting to be optimal. Compare the equilibrium entry mode in figure 3.1 and figure 3.2, the different point is that in figure 3.2 there are two regions, (II) and (IV), that only the incumbent undertakes FDI. The small installed base enables the incumbent to capture a larger market share, and this makes FDI more likely to be beneficial to the incumbent than to the entrant. When $m \to 0$, curve (i) and (iii) will converges and curve (ii) and (vi) will converge, and figure 3.2 eventual becomes identical to figure 3.1.

2. Large installed base: $m > \frac{\tau}{2a}$

Figure 3.3 shows the parameter space of equilibrium entry mode when the incumbent has a large installed base. Curve (i)-(iv) have same definitions as in figure 3.2 which indicate the parameter values of export τ and γ that satisfy $\Delta\pi_A^X = 0$, $\Delta\pi_A^F = 0$, $\Delta\pi_B^X = 0$, and $\Delta\pi_B^F = 0$, respectively. We can see curve (iii) is downward sloping and curve (ii) is upward sloping, which are different from those in figure 3.2. With a large installed base, the incumbent always finds FDI more attractive when compatibility is low (or when network effect is strong). This effect is independent of the entrant's action, because both curve (i) and (ii) are upward sloping. On the contrary, the entrant always finds FDI more attractive when compatibility is high (or when network effect is weak), and this condition holds regardless of incumbent's action because both curve (iii) and (iv) are downward sloping.

I summarize the result of figure 3.2 and 3.3 in the following proposition.

Proposition 4 *(1) The incumbent is more likely to enter through FDI than the entrant. (2)The attractiveness of FDI to the incumbent increases with the installed base (m), and the attractiveness of FDI to the entrant decreases with the installed base.*

In figure 3.2 and 3.3, the regions that the entrant undertakes FDI is smaller than the set of the incumbent.[51] The second part of proposition 4 comes from the third column "m" of Table 3.3. The intuition for proposition 4 is: the installed base makes the incumbent's product more attractive and lets the incumbent to capture a larger market share. Since FDI benefits firms with high levels of output, it is more possible for incumbent to find FDI to be beneficial when it has an installed base, and the benefit increases with the size of the installed base.

Proposition 4 provides an explanation to the fact in international trade: large and old companies are more likely to undertake FDI than small and new companies. Systems of large firms usually have a relatively larger installed base or lock-in effect than those of small firms. FDI is more attractive to these large firms because the network externality effect helps them to capture a larger market share.

4 Conclusion

In this paper I examine firms' different entry modes in an industry with network externality. A firm's optimal entry mode depends on several factors. First, it depends

[51] In figue 2, the regions that incumbant possibly undertakes FDI are I, II, III, IV, and those of the entrant are I and III. In figure 3, the regions that the incumbant possibly undertaks FDI are I, II, III, IV, V; the regions that the entrant possibly chooses FDI are I and V.

on the export cost and FDI fixed cost, as the proximity-concentration hypothesis predicts. Second, it depends on the strength of network effect and the degree of compatibility. Third, it depends on the size of the installed base in the foreign market. The result shows that FDI is more important in industries with strong network externality, and FDI is more attractive to firms with large installed base. The model also shows that firms producing compatible products have stronger incentive to choose same FDI locations than firms producing incompatible products.

There are several ways to extend this paper. The first direction is to build a dynamic model. In this paper, the size of the installed base is predetermined before the two firms compete directly in the foreign market. In a dynamic model, we can let the incumbent enters the market in the first period as a monopolist. The sales in the first period form incumbent's installed base at the beginning of second period. A multiple-period model also enalbes us to study the optimal *timing* to enter through FDI. By intuition, the advantage of an installed base gives the incumbent an incentive to *overproduce* in the first period, and thus the incumbent may enter earlier through FDI in an industry with network externality than in an industry with no network externality.

The second extension is to let the firms choose the degrees of compatibility endogenously. In the long run, firms can choose the degree of compatibility by changing the design or by producing adopters. In section 2.1, I show that if the two firms are symmetric (no installed base), equilibrium prices and profits increase with compatibility. In an asymmetric case, firms' incentives to make products compatible may be different. A change in compatibility has two effects. First, a higher compatibility increases consumers' willingness to pay as in the symmetric case. Second, higher compatibility reduces the advantage that the incumbent gains from the installed base. By intuition, the entrant should always prefer a higher degree of compatibility because both effects benefit it. The incumbent, however, may have an incentive to make the products incompatible because a decrease of the importance of the installed base reduces incumbent's market power over the entrant. In this paper, compatibility further affects firms' entry modes and thus the problem is more complicated and requires further studying.

Table 3.1: Equilibrium price, market share, and profit of each entry mode in the no-installed-base case

Mode	P	S	π
XX	$p_A^{XX} = a - G + \tau$ $p_B^{XX} = a - G + \tau$	$S_A^{XX} = \frac{1}{2}$ $S_B^{XX} = \frac{1}{2}$	$\pi_A^{XX} = \frac{(a-G)}{2}$ $\pi_B^{XX} = \frac{(a-G)}{2}$
FF	$p_A^{FF} = a - G$ $p_B^{FF} = a - G$	$S_A^{FF} = \frac{1}{2}$ $S_B^{FF} = \frac{1}{2}$	$\pi_A^{FF} = \frac{(a-G)}{2} - f$ $\pi_B^{FF} = \frac{(a-G)}{2} - f$
XF	$p_A^{XF} = a - G + \frac{2}{3}\tau$ $p_B^{XF} = a - G + \frac{1}{3}\tau$	$S_A^{XF} = \frac{1}{2} - \frac{\tau}{6(a-G)}$ $S_B^{XF} = \frac{1}{2} + \frac{\tau}{6(a-G)}$	$\pi_A^{XF} = \frac{\left(a-G-\frac{1}{3}\tau\right)^2}{2(a-G)}$ $\pi_B^{XF} = \frac{\left(a-G+\frac{1}{3}\tau\right)^2}{2(a-G)} - f$
FX	$p_A^{FX} = a - G + \frac{1}{3}\tau$ $p_B^{FX} = a - G + \frac{2}{3}\tau$	$S_A^{FX} = \frac{1}{2} + \frac{\tau}{6(a-G)}$ $S_B^{FX} = \frac{1}{2} - \frac{\tau}{6(a-G)}$	$\pi_A^{FX} = \frac{\left(a-G+\frac{1}{3}\tau\right)^2}{2(a-G)} - f$ $\pi_B^{FX} = \frac{\left(a-G-\frac{1}{3}\tau\right)^2}{2(a-G)}$

Notes: To simplify the expressions, I let $G = n(1 - \gamma)$.

Table 3.2: Equilibrium price, market share, and profit of each entry mode when firm A has an installed base

Mode	P	S	π
XX	$p_A^{XX} = a - G + \tau + \frac{1}{3}H$	$S_A^{XX} = \frac{1}{2} + \frac{H}{6(a-G)}$	$\pi_A^{XX} = \frac{\left(a-G+\frac{1}{3}H\right)^2}{2(a-G)}$
	$p_B^{XX} = a - G + \tau - \frac{1}{3}H$	$S_B^{XX} = \frac{1}{2} - \frac{H}{6(a-G)}$	$\pi_B^{XX} = \frac{\left(a-G-\frac{1}{3}H\right)^2}{2(a-G)}$
FF	$p_A^{FF} = a - G + \frac{1}{3}H$	$S_A^{FF} = \frac{1}{2} + \frac{H}{6(a-G)}$	$\pi_A^{FF} = \frac{\left(a-G+\frac{1}{3}H\right)^2}{2(a-G)} - f$
	$p_B^{FF} = a - G - \frac{1}{3}H$	$S_B^{FF} = \frac{1}{2} - \frac{H}{6(a-G)}$	$\pi_B^{FF} = \frac{\left(a-G-\frac{1}{3}H\right)^2}{2(a-G)} - f$
XF	$p_A^{XF} = a - G + \frac{2}{3}\tau + \frac{1}{3}H$	$S_A^{XF} = \frac{1}{2} - \frac{(\tau-H)}{6(a-G)}$	$\pi_A^{XF} = \frac{\left(a-G-\frac{1}{3}\tau+\frac{1}{3}H\right)^2}{2(a-G)}$
	$p_B^{XF} = a - G + \frac{1}{3}\tau - \frac{1}{3}H$	$S_B^{XF} = \frac{1}{2} + \frac{(\tau-H)}{6(a-G)}$	$\pi_B^{XF} = \frac{\left(a-G+\frac{1}{3}\tau-\frac{1}{3}H\right)^2}{2(a-G)} - f$
FX	$p_A^{FX} = a - G + \frac{1}{3}\tau + \frac{1}{3}H$	$S_A^{FX} = \frac{1}{2} + \frac{(\tau+H)}{6(a-G)}$	$\pi_A^{FX} = \frac{\left(a-G+\frac{1}{3}\tau+\frac{1}{3}H\right)^2}{2(a-G)} - f$
	$p_B^{FX} = a - G + \frac{2}{3}\tau - \frac{1}{3}H$	$S_B^{FX} = \frac{1}{2} - \frac{(\tau+H)}{6(a-G)}$	$\pi_B^{FX} = \frac{\left(a-G-\frac{1}{3}\tau-\frac{1}{3}H\right)^2}{2(a-G)}$

Notes: To simplify the expressions, I let $G = n(1-\gamma)$ and $H = mn(1-\gamma)$.

Table 3.3: Comparative statics effects

	τ	f	m	γ		n	
				$m < \frac{\tau}{2a}$	$m > \frac{\tau}{2a}$	$m < \frac{\tau}{2a}$	$m > \frac{\tau}{2a}$
$\Delta\pi_A^X$	(+)	(-)	(+)	(-)	(-)	(+)	(+)
$\Delta\pi_A^F$	(+)	(-)	(+)	(+)	(-)	(-)	(+)
$\Delta\pi_B^X$	(+)	(-)	(-)	(-)	(+)	(+)	(-)
$\Delta\pi_B^F$	(+)	(-)	(-)	(+)	(+)	(-)	(-)

Notes: The (+) and (-) in each cell indicates the sign of derivative of $\Delta\pi$ with respect to each of the parameters on the top of the table. For instance, the (+) corresponds to row $\Delta\pi_A^X$ and column τ indicates $\frac{\partial\Delta\pi_A^X}{\partial\tau} > 0$; the (-) corresponds to row $\Delta\pi_A^F$ and column f indicates $\frac{\partial\Delta\pi_A^F}{\partial f} < 0$.

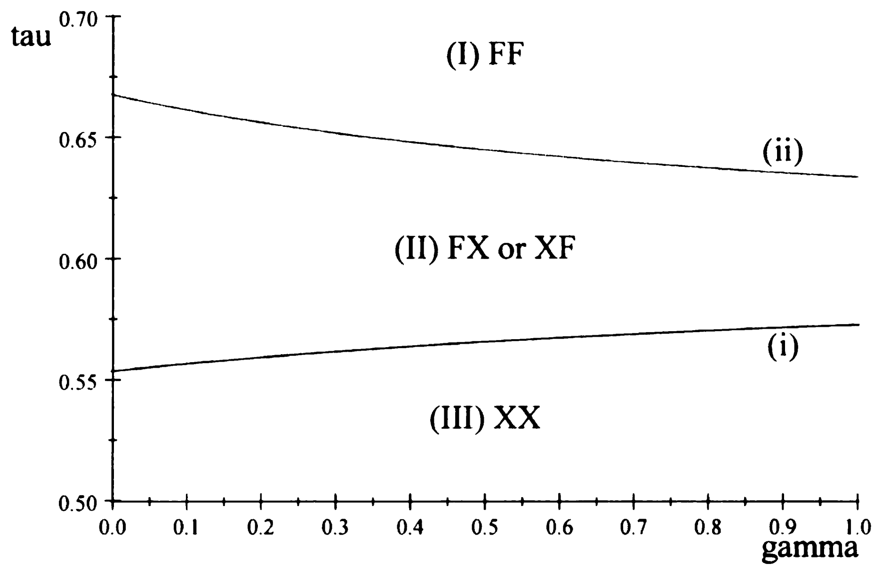

Figure 3.1: Nash equilibrium of the entry game of the no-installed-base case

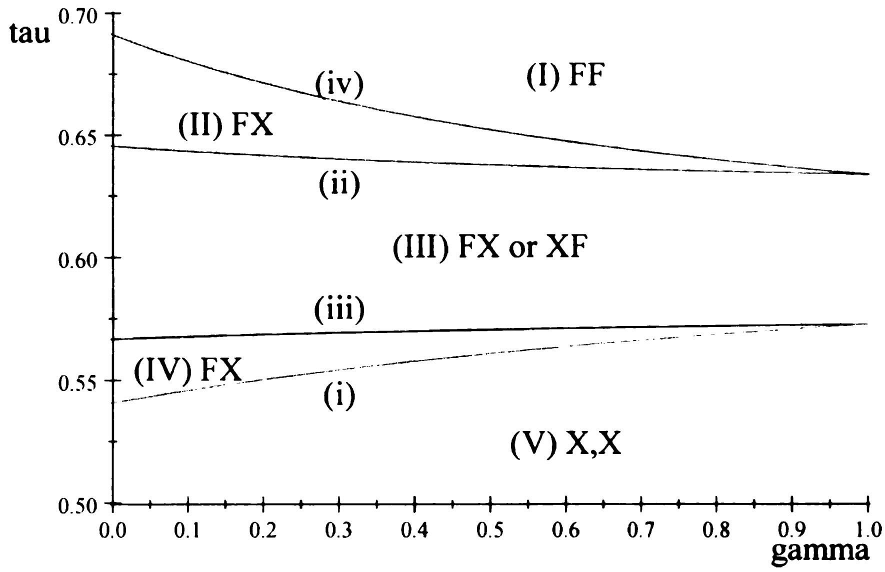

Figure 3.2: Nash equilibrium of entry mode when the installed base is small

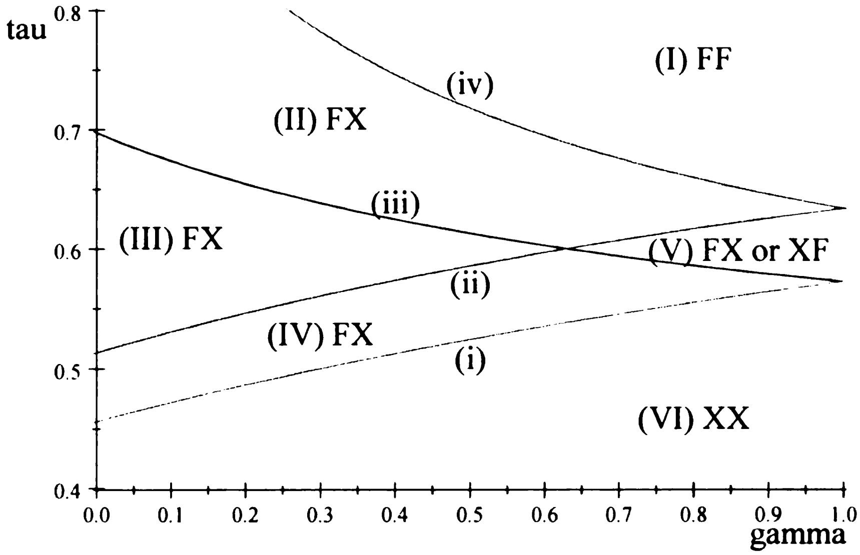

Figure 3.3: Nash equilibrium of entry mode when the installed base is large

Appendix

A Innovation Data

Since the focus of this paper is innovation at the industry level, the first task is to classify each patent into an industry (or industries). In the patent dataset, most patents could not be classified into a single 2-digit SIC industry. USPTO has developed a classification system for the technologies to which the patented inventions belong, consisting of about 400 main patent classes. In Hall et. al. (2001) NBER dataset, each patent class has one or more corresponding SIC-sequence code(s).

Each patent SIC sequence corresponds to a 2-digit SIC industry, but not all 2-digit SIC industries are covered. Also, a 2-digit SIC industry can contain more than one patent SIC sequence. My sample contains the 12 industries which have at least one corresponding SIC-sequence code. For patent classes which have more than one corresponding SIC-sequences, I assume each SIC-sequence has equal share and calculate the number of "patent count" of each industry. For example, suppose a patent class has 3 corresponding SIC-sequence: 1, 3 and 4. SIC-sequence 1 matches with SIC industry 20, and SIC-sequence 3 and 4 match with SIC industry 28. Patents of this SIC-sequence have 1/3 weight going to industry 20 and 2/3 weight going to industry 28.

Some empirical studies use simple patent count as a proxy for innovations. This assumes each patent has equal quality and importance. I take the number of citations received by each patent to measure quality and importance, and use it as weight to calculate the "weighted patent counts" as a proxy for innovation. The average number of citation received by each patent is 5, and I set the weight of each citation received equals 100% of patent counts.[52] This selection of weight seems to be arbitrary, but I will compare the results using different weights in the sensitivity analysis. It turns out the results of using different weights are very similar.

There are two indices of year of each patent in the sample: the application year and the grant year. In general, the application year is earlier than the grant year because it takes time for the Patent Office to examine each patent and to decide whether to grant it or not. The average lag between application and grant year in the sample is 1.97 years, with more than 95% of patents are granted within 3 years after they are applied. In economic sense, we should classify patents according to their application year rather than grant year, because countries' innovation capability or technology level are reflected on the year patents are applied, not the year patents are granted.[53] The patent dataset records patents which are granted until the year 2002. A patent is recorded in the database only after it is granted, not when it is applied. This means if I count the number of patents according to the application year, I have data truncation: I cannot see most patents applied in 2002 in the database, though many of them should be included in the sample because they are going to be granted in following years. In other words, although the data covers patents granted until the year 2002, I cannot accurately measure the number of patents applied in each year

[52] For example, a patent which has been cited for five times will be 1+5=6 patent counts.

[53] For example, a patent applied in 1990 and granted in 1995 should reflect the innovation capability of the country in 1990, not 1995.

especially in the last few years of the sample.[54] To mitigate the possible measurement bias caused by truncation, I drop observations of the last three years (2000-2002) and use observations in 1975-1999 as my benchmark sample. As I mentioned, more than 95% of patents are granted within three years after they are applied. So the effect of truncation to patents applied before 1999 should be relatively small. I will split my sample by year and use them separately to estimate my model, to show the conclusion is not affected by inclusion\exclusion of observations of the last few years. I will also compare results using grant year to classify patents (which does not suffer from the truncation problem) with results using application year, and there is no material difference.

[54] The number of granted patents applied in 1999 is 146,000. This number drops to 107,037 in 2000, to 38,867 in 2001 and to 1,664 in 2002. Obviously, the low numbers of patents in at least the last two years is due to data truncation.

B Data of Factor Endowment and Factor Intensity

I consider four factors of production: skilled labor, unskilled labor, capital, and land. The data of skilled and unskilled labor shares are from Barro and Lee (2001). Skilled labor is defined as those who have completed the secondary school education and above, and unskilled labor is defined as those who have attained secondary school but not completed and below. The Barro and Lee (2001) data contain the percentage of each level of education in every five years, so I use interpolation to calculate the percentages of each education level in years between. I multiply the skilled and unskilled labor shares by population to get the skilled and unskilled labor endowments of each country in each year. The capital stock and land data are obtained from World Development Indicator. Skilled labor, unskilled labor, and capital are divided by land to get the factor endowment proportions of each country-year.

The data of production factor intensity of each industry come from NBER-CES Manufacturing Industry Database. Corresponding to the factor proportions, I calculate the factor intensities of skilled labor, unskilled labor, and capital based on Romalis (2004). The capital intensity k equals one less the total compensation in value added. Skilled labor intensity is measured as $(1-k)s$, where s equals the ratio of non-production workers to total employment in each industry. Unskilled labor intensity equals $(1-k)(1-s)$.

C Data of Price and Quantity in Exports

The trade data of Feenstra (1996) and Feenstra, Romalis and Schott (2002) contain the export value and quantity of each product variety defined by TS7 or HS10. The quantity information can be used as q_{cj} directly, and the unit value of each product can be inferred by dividing the export value by the quantity (i.e., $p_{cj} = \frac{p_{cj}q_{cj}}{q_{cj}}$). The world export quantity of product j is the sum of all countries' export quantities: $q_{wt} = \Sigma_c q_{ct}$, and the world average unit value of product j equals all countries' total export value divided by total quantity: $p_{wt} = \frac{\Sigma_c p_{ct} q_{ct}}{\Sigma_c q_{ct}}$.

The export value and quantity of each product are required to construct the price index and quantity index as in equations 17 and 18. Unfortunately, the trade data does not have perfect quantity information of each variety. From 1975-2001, about 18% of the products exported to the U.S. do not have the quantity information. These products have to be dropped out when calculating the price and quantity indices. In addition to the missing data problem, the quantity is recorded with measurement errors (See General Accounting Office, 1995). To mitigate this problem, I apply a similar criteria as Hallak (2006) which drops observations with very low quantity (below 50 units), which are more likely to be problematic.

As a result, the sample used in this section is different from the one used in previous sections. Some observations will have different values in exports variables. Some other observations, especially those with very few positive export products, will be dropped out from the sample. The sample used in this section contains 22,804 observations, which is fewer than that of the previous one (27,450 observations).

Other variables, including innovation, country size and trade cost are from the same data sources and constructed by the same way as in section 4.1.

D Kaplan Meier Estimator

I use table 2.5 to explain the Kaplan-Meier estimator and its application in this paper. From the left part of table 2.5, the number of spells at risk in the beginning of the first year is 550,991. This means $n_1 = 550,991$ in equation 3. The number of spells fail after the first year (i.e. those country-product which export in the first year but not in the second year) is 205,251, which means $d_1 = 205,251$ in equation 3. The survivor rate of the first year is $\frac{550{,}991-205{,}251}{550{,}991} = 0.6275$. This estimate is intuitive: $205,251$ out of $550,991$ spells fail after the first year, indicating that the rest $345,740$ spells survive the first year. So the probability that a trade relationship survive the first year is $\frac{345{,}740}{550{,}991} = 0.6275$. Without data censoring, the number of spells at risk prior to the second year should be $345,740$, i.e. those spells which survive the first year. However, $65,815$ spells are *lost* after their first year. We know that these spells survive at least one year, but we cannot track their exact fail time since their data of the second year and thereafter are not available. These spells are not at risk at the beginning of the second year, and thus $n_2 = 345,740 - 65,815 = 279,925$. Among these spells, $55,893$ fail in the second year. Using equation 3, the survivor rate of the second year is $(\frac{550{,}991-205{,}251}{550{,}991})(\frac{279{,}925-55{,}893}{279{,}925}) = 0.5022$. The survivor rate of other years can be calculated following the same procedure.

E Equilibrium Outcomes of the Price Game

E.1 Symmetric Case (No installed base)

- Both firms export (XX)

For both firms, plug the demand functions in equation 4 into the profit functions 5a.

$$\pi_A = (p_A - \tau)(\frac{(a-n-p_A+p_B+n\gamma)}{2a-2n(1-\gamma)})$$

$$\pi_B = (p_B - \tau)(\frac{(a-n+p_A-p_B+n\gamma)}{2a-2n(1-\gamma)})$$

The first order conditions are:

$$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}(a-n+\tau-2p_A+p_B+n\gamma) = 0$$

$$\frac{d\pi_A}{dp_B} = \frac{1}{2(a-n+n\gamma)}(a-n+\tau+p_A-2p_B+n\gamma) = 0$$

Solve the two first order conditions to get the equilibrium prices:

$$p_A^{XX} = p_B^{XX} = a - n + \tau + n\gamma$$

Plug into equation 4 and 5a to get equilibrium market share and profit.

$$S_A^{XX} = S_B^{XX} = \frac{(a-n-p_A+p_B+n\gamma)}{2a-2n(1-\gamma)} = \frac{1}{2}$$

$$\pi_A^{XX} = \pi_B^{XX} = (a-n+\tau+n\gamma-\tau)(\tfrac{1}{2}) = \tfrac{1}{2}a - \tfrac{1}{2}n + \tfrac{1}{2}n\gamma,$$

Also check the second order condition:

$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$ iff $a > n(1-\gamma)$, which is satisfied by assumption $a > \frac{1}{3}\tau + n(1-\gamma)$.

- Both firms do FDI (FF)

Plug the demand functions in equation 4 into the profit function 5b.

$$\pi_A = p_A(\frac{(a-n-p_A+p_B+n\gamma)}{2a-2n(1-\gamma)}) - f$$

$$\pi_B = p_B(\frac{(a-n+p_A-p_B+n\gamma)}{2a-2n(1-\gamma)}) - f$$

The first order conditions are:

$$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}\,(a - n - 2p_A + p_B + n\gamma) = 0$$

$$\frac{d\pi_B}{dp_B} = \frac{1}{2(a-n+n\gamma)}\,(a - n + p_A - 2p_B + n\gamma) = 0$$

Solve the two first order conditions to get the equilibrium prices:

$$p_A^{FF} = p_B^{FF} = a - n + n\gamma$$

Plug into equation 4 and 5b to get equilibrium market share and profit.

$$S_A^{FF} = S_B^{FF} = \frac{(a-n-p_A+p_B+n\gamma)}{2a-2n(1-\gamma)} = \frac{1}{2}$$

$$\pi_A^{FF} = \pi_B^{FF} = (a - n + n\gamma)\frac{1}{2} - f = \frac{1}{2}a - \frac{1}{2}n + \frac{1}{2}n\gamma - f$$

Also check the second order condition:

$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$ iff $a > n(1-\gamma)$, which is satisfied by assumption $a > \frac{1}{3}\tau + n(1-\gamma)$.

- One firm exports and the other invests (XF and FX)

Assume firm A exports and firm B invests(XF). Plug the demand functions into the profit functions

$$\pi_A = (p_A - \tau)(\frac{(a-n-p_A+p_B+n\gamma)}{2a-2n(1-\gamma)})$$

$$\pi_B = p_B(\frac{(a-n+p_A-p_B+n\gamma)}{2a-2n(1-\gamma)}) - f$$

The first order conditions are:

$$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}\,(a - n + \tau - 2p_A + p_B + n\gamma) = 0$$

$$\frac{d\pi_B}{dp_B} = \frac{1}{2(a-n+n\gamma)}\,(a - n + p_A - 2p_B + n\gamma) = 0$$

Solve the two first order conditions to get the equilibrium prices:

$p_A^{XF} = a - n + \frac{2}{3}\tau + n\gamma$

$p_B^{XF} = a - n + \frac{1}{3}\tau + n\gamma$

Plug into equation 4, 5a and 5b to get equilibrium market share and profit.

$S_A^{XF} = \frac{1}{2} - \frac{\tau}{6a-6n+6n\gamma}$

$S_B^{XF} = \frac{1}{2} + \frac{\tau}{6a-6n+6n\gamma}$

$\pi_A^{XF} = \frac{1}{2(a-n+n\gamma)}\left(a - n - \frac{1}{3}\tau + n\gamma\right)^2$

$\pi_B^{XF} = \frac{1}{2(a-n+n\gamma)}\left(a - n + \frac{1}{3}\tau + n\gamma\right)^2 - f$

Second order condition

$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$ which is satisfied by assumption $a > \frac{1}{3}\tau + n(1-\gamma)$.

E.2 Asymmetric Case (with an Installed Base)

- Both incumbent A and entrant B enter through export (XX)

$\pi_A = (p_A - \tau)(\frac{(a-n-p_A+p_B+n\gamma+mn-mn\gamma)}{2(a-n+n\gamma)})$

$\pi_B = (p_B - \tau)(\frac{(a-n+p_A-p_B+n\gamma-mn+mn\gamma)}{2(a-n+n\gamma)})$

The first order conditions are

$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}(a - n + \tau - 2p_A + p_B + n\gamma + mn - mn\gamma) = 0$

$\frac{d\pi_B}{dp_B} = \frac{1}{2(a-n+n\gamma)}(a - n + \tau + p_A - 2p_B + n\gamma - mn + mn\gamma) = 0$

Solve the first order conditions simultaneously to get equilibrium prices:

$p_A^{XX} = a - n + \tau + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma$

$p_B^{XX} = a - n + \tau + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma$

Plug prices back into market share and profit functions

$$S_A^{XX} = \frac{1}{2} + \frac{mn(1-\gamma)}{6a-6n+6n\gamma}$$
$$S_B^{XX} = \frac{1}{2} - \frac{mn(1-\gamma)}{6a-6n+6n\gamma}$$
$$\pi_A^{XX} = \frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2$$
$$\pi_B^{XX} = \frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2$$

And check the second order condition:

$$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$$

- Both incumbent A and entrant B enters through FDI (FF)

$$\pi_A = p_A\left(\frac{(a-n-p_A+p_B+n\gamma+mn-mn\gamma)}{2(a-n+n\gamma)}\right) - f$$
$$\pi_B = p_B\left(\frac{(a-n+p_A-p_B+n\gamma-mn+mn\gamma)}{2(a-n+n\gamma)}\right) - f$$

The first order conditions are

$$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}(a - n - 2p_A + p_B + n\gamma + mn - mn\gamma) = 0$$
$$\frac{d\pi_B}{dp_B} = \frac{1}{2(a-n+n\gamma)}(a - n + p_A - 2p_B + n\gamma - mn + mn\gamma) = 0$$

Solve the first order conditions to get

$$p_A^{FF} = a - n + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma$$

$$p_B^{FF} = a - n + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma$$

Plug prices back into market share and profit functions

$$S_A^{FF} = \frac{1}{2} + \frac{mn(1-\gamma)}{6a-6n+6n\gamma}$$
$$S_B^{FF} = \frac{1}{2} - \frac{mn(1-\gamma)}{6a-6n+6n\gamma}$$
$$\pi_A^{FF} = \frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2 - f$$
$$\pi_B^{FF} = \frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2 - f$$

The second order condition

$$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$$

- Incumbent A enters through export and entrant B enters through FDI (XF)

$\pi_A = (p_A - \tau)(\frac{(a-n-p_A+p_B+n\gamma+mn-mn\gamma)}{2(a-n+n\gamma)})$

$\pi_B = p_B(\frac{(a-n+p_A-p_B+n\gamma-mn+mn\gamma)}{2(a-n+n\gamma)}) - f$

The first order conditions are

$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}(a - n + \tau - 2p_A + p_B + n\gamma + mn - mn\gamma) = 0$

$\frac{d\pi_B}{dp_B} = \frac{1}{2(a-n+n\gamma)}(a - n + p_A - 2p_B + n\gamma - mn + mn\gamma) = 0$

Solve the first order condition to get:

$p_A^{XF} = a - n + \frac{2}{3}\tau + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma$

$p_B^{XF} = a - n + \frac{1}{3}\tau + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma$

Plug prices back into market share and profit functions

$S_A^{XF} = \frac{1}{2} - \frac{(\tau-mn+mn\gamma)}{6a-6n+6n\gamma}$

$S_B^{XF} = \frac{1}{2} + \frac{(\tau-mn+mn\gamma)}{6a-6n+6n\gamma}$

$\pi_A^{XF} = \frac{1}{(2a-2n+2n\gamma)}\left(a - n - \frac{1}{3}\tau + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2$

$\pi_B^{XF} = \frac{1}{(2a-2n+2n\gamma)}\left(a - n + \frac{1}{3}\tau + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2 - f$

The second order condition

$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$

- Incumbent A enters through FDI and entrant B enters through export (FX)

$\pi_A = p_A(\frac{(a-n-p_A+p_B+n\gamma+mn-mn\gamma)}{2(a-n+n\gamma)}) - f$

$\pi_B = (p_B - \tau)(\frac{(a-n+p_A-p_B+n\gamma-mn+mn\gamma)}{2(a-n+n\gamma)})$

The first order conditions are

$\frac{d\pi_A}{dp_A} = \frac{1}{2(a-n+n\gamma)}(a - n - 2p_A + p_B + n\gamma + mn - mn\gamma) = 0$

$$\frac{d\pi_B}{dp_B} = \frac{1}{2(a-n+n\gamma)}\left(a - n + \tau + p_A - 2p_B + n\gamma - mn + mn\gamma\right) = 0$$

Solve the first order condition to get:

$$p_A^{FX} = a - n + \tfrac{1}{3}\tau + n\gamma + \tfrac{1}{3}mn - \tfrac{1}{3}mn\gamma$$

$$p_B^{FX} = a - n + \tfrac{2}{3}\tau + n\gamma - \tfrac{1}{3}mn + \tfrac{1}{3}mn\gamma$$

Plug prices back into market share and profit functions

$$S_A^{FX} = \tfrac{1}{2} + \tfrac{(\tau+mn-mn\gamma)}{6a-6n+6n\gamma}$$

$$S_B^{FX} = \tfrac{1}{2} - \tfrac{(\tau+mn-mn\gamma)}{6a-6n+6n\gamma}$$

$$\pi_A^{FX} = \frac{1}{2a-2n+2n\gamma}\left(a - n + \tfrac{1}{3}\tau + n\gamma + \tfrac{1}{3}mn - \tfrac{1}{3}mn\gamma\right)^2 - f$$

$$\pi_B^{FX} = \frac{1}{(2a-2n+2n\gamma)}\left(a - n - \tfrac{1}{3}\tau + n\gamma - \tfrac{1}{3}mn + \tfrac{1}{3}mn\gamma\right)^2$$

The second order condition

$$\frac{d^2\pi_A}{d(p_A)^2} = \frac{d^2\pi_B}{d(p_B)^2} = -\frac{1}{a-n+n\gamma} < 0$$

F Proofs of Comparative Static Effects

F.1 Symmetric Case (No installed base)

- Rival exports:

A firm will choose FDI if and only if

$$\Delta\pi^X = \frac{1}{2(a-n(1-\gamma))}\left(a - n(1-\gamma) + \frac{1}{3}\tau\right)^2 - f - \frac{1}{2}(a - n(1-\gamma)) > 0$$

To find how changes in τ, f, γ, n affect one firm's decision in entry mode when its rival exports, I check

$$\frac{d\Delta\pi^X}{d\tau} = \frac{1}{9a-9n+9n\gamma}(3a - 3n + \tau + 3n\gamma) > 0$$

$$\frac{d\Delta\pi^X}{df} = -1 < 0$$

$$\frac{d\Delta\pi^X}{d\gamma} = -\frac{1}{18}n\frac{\tau^2}{(a-n+n\gamma)^2} < 0$$

$$\frac{d\Delta\pi^X}{dn} = -\frac{1}{18}\tau^2\frac{\gamma-1}{(a-n+n\gamma)^2} > 0$$

- Rival invests:

A firm will choose FDI if and only if

$$\Delta\pi^F = \frac{1}{2}(a - n(1-\gamma)) - f - \frac{1}{2(a-n+n\gamma)}\left(a - n(1-\gamma) - \frac{1}{3}\tau\right)^2 > 0$$

The signs of derivatives are

$$\frac{d\Delta\pi^F}{d\tau} = \frac{1}{9a-9n+9n\gamma}(3a - 3n + 3n\gamma - \tau) > 0 \text{ by the assumption } a > \frac{1}{3}\tau + n(1-\gamma)$$

$$\frac{d\Delta\pi^F}{df} = -1 < 0$$

$$\frac{d\Delta\pi^F}{d\gamma} = \frac{1}{18}n\frac{\tau^2}{(a-n+n\gamma)^2} > 0$$

$$\frac{d\Delta\pi^F}{dn} = \frac{1}{18}\tau^2\frac{\gamma-1}{(a-n+n\gamma)^2} < 0$$

F.2 Asymmetric Case (Installed Base)

- Incumbent's optimal entry mode given entrant enters through export

The incumbent, firm A, will choose to enter through FDI if and only if

$$\Delta\pi_A^X = \frac{1}{2a-2n+2n\gamma}\left(a - n + \frac{1}{3}\tau + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2 - f$$
$$-\frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2 > 0$$

The comparative statics are:

$$\frac{d\Delta\pi_A^X}{d\tau} = \frac{1}{3} + \frac{(\tau+mn-mn\gamma)}{9a-9n+9n\gamma} > 0$$
$$\frac{d\Delta\pi_A^X}{df} = -1 < 0$$
$$\frac{d\Delta\pi_A^X}{d\gamma} = -\frac{1}{18}n\tau\frac{\tau+2am}{(a-n+n\gamma)^2} < 0$$
$$\frac{d\Delta\pi_A^X}{dn} = \frac{1}{18}\tau\,(1-\gamma)\,\frac{\tau+2am}{(a-n+n\gamma)^2} > 0$$
$$\frac{d\Delta\pi_A^X}{dm} = -\frac{1}{9}n\tau\frac{\gamma-1}{a-n+n\gamma} > 0$$

- Incumbent's optimal entry mode given entrant enters through FDI

The incumbent will do FDI if and only if

$$\Delta\pi_A^F = \frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2 - f$$
$$-\frac{1}{(2a-2n+2n\gamma)}\left(a - n - \frac{1}{3}\tau + n\gamma + \frac{1}{3}mn - \frac{1}{3}mn\gamma\right)^2 > 0$$

The comparative statics are:

$$\frac{d\Delta\pi_A^F}{d\tau} = \frac{1}{3} - \frac{\tau-mn(1-\gamma)}{9(a-n+n\gamma)} > 0 \text{ by the assumption } a-n(1-\gamma) > \frac{1}{3}\tau + \frac{1}{3}mn(1-\gamma)$$
$$\frac{d\Delta\pi_A^F}{df} = -1 < 0$$
$$\frac{d\Delta\pi_A^F}{d\gamma} = \frac{1}{18}n\tau\frac{\tau-2am}{(a-n+n\gamma)^2} > 0 \text{ if } m < \frac{\tau}{2a}\text{; and}$$
$$\frac{d\Delta\pi_A^F}{d\gamma} = \frac{1}{18}n\tau\frac{\tau-2am}{(a-n+n\gamma)^2} < 0 \text{ if } m > \frac{\tau}{2a}$$
$$\frac{d\Delta\pi_A^F}{dn} = \frac{1}{18}\tau\,(\gamma-1)\,\frac{\tau-2am}{(a-n+n\gamma)^2} < 0 \text{ if } m < \frac{\tau}{2a}\text{; and}$$

$$\frac{d\Delta\pi_A^F}{dn} = \frac{1}{18}\tau(\gamma - 1)\frac{\tau - 2am}{(a-n+n\gamma)^2} > 0 \text{ if } m > \frac{\tau}{2a}$$

$$\frac{d\Delta\pi_A^F}{dm} = -\frac{1}{9}n\tau\frac{\gamma-1}{a-n+n\gamma} > 0$$

- Entrant's optimal entry mode given incumbent enters through export

The entrant will do FDI if and only if

$$\Delta\pi_B^X = \frac{1}{(2a-2n+2n\gamma)}\left(a - n + \frac{1}{3}\tau + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2 - f$$
$$-\frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2$$

The comparative statics are:

$$\frac{d\Delta\pi_B^X}{d\tau} = \frac{1}{3} + \frac{(\tau - mn + mn\gamma)}{9a-9n+9n\gamma} > 0 \text{ by the assumption } a - n(1-\gamma) > \frac{1}{3}\tau + \frac{1}{3}mn(1-\gamma)$$

$$\frac{d\Delta\pi_B^X}{df} = -1 < 0$$

$$\frac{d\Delta\pi_B^X}{d\gamma} = -\frac{1}{18}n\tau\frac{\tau-2am}{(a-n+n\gamma)^2} < 0 \text{ if } m < \frac{\tau}{2a}\text{;and}$$

$$\frac{d\Delta\pi_B^X}{d\gamma} = -\frac{1}{18}n\tau\frac{\tau-2am}{(a-n+n\gamma)^2} > 0 \text{ if } m > \frac{\tau}{2a}$$

$$\frac{d\Delta\pi_B^X}{dn} = \frac{1}{18}\tau(1-\gamma)\frac{\tau-2am}{(a-n+n\gamma)^2} > 0 \text{ if } m < \frac{\tau}{2a}\text{; and}$$

$$\frac{d\Delta\pi_B^X}{dn} = \frac{1}{18}\tau(1-\gamma)\frac{\tau-2am}{(a-n+n\gamma)^2} < 0 \text{ if } m > \frac{\tau}{2a}$$

$$\frac{d\Delta\pi_B^X}{dm} = \frac{1}{9}n\tau\frac{\gamma-1}{a-n+n\gamma} < 0$$

- Entrant's optimal entry mode given incumbent enters through FDI

The follower will do FDI if

$$\Delta\pi_B^F = \frac{1}{2(a-n+n\gamma)}\left(a - n + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2 - f$$
$$-\frac{1}{(2a-2n+2n\gamma)}\left(a - n - \frac{1}{3}\tau + n\gamma - \frac{1}{3}mn + \frac{1}{3}mn\gamma\right)^2 > 0$$

The comparative statics are:

$$\frac{d\Delta\pi_B^F}{d\tau} = \frac{1}{3} - \frac{(\tau + mn(1-\gamma))}{9a-9n+9n\gamma} > 0 \text{ by the assumption } a - n(1-\gamma) > \frac{1}{3}\tau + \frac{1}{3}mn(1-\gamma)$$

$$\frac{d\Delta\pi_B^F}{df} = -1 < 0$$

$$\frac{d\Delta\pi_B^F}{d\gamma} = \frac{1}{18} n\tau \frac{\tau + 2am}{(a - n + n\gamma)^2} > 0$$

$$\frac{d\Delta\pi_B^F}{dn} = \frac{1}{18} \tau \left(\gamma - 1\right) \frac{\tau + 2am}{(a - n + n\gamma)^2} < 0$$

$$\frac{d\Delta\pi_B^F}{dm} = \frac{1}{9} n\tau \frac{\gamma - 1}{a - n + n\gamma} < 0$$

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