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Patent Rights Protection and High-Tech Exports: New Evidence from Taiwan*

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ABSTRACT

An array of literature empirically examines the impact of patent rights (PRs) protection on international trade, but most studies employ the traditional gravity model to estimate and ignore firm-level behavior. Helpman, Melitz and Rubinstein (2008) propose a two-stage, non-linear least squares estimation procedure (the HMR model) to correct potential biases embodied in the gravity estimation of trade flows, which decomposes the impact on trade volumes of all trade resistance measures into their extensive and intensive margin components. Yet, Santos Silva and Tenreyro (2015) suggest that the HMR model is incorrectly specified and propose the Poisson pseudo maximum likelihood (PPML) methodology to solve heteroscedasticity. Utilizing the HMR model and the PPML method, this paper empirically investigates how differences in PRs protection may influence Taiwan's semiconductor exports to 119 destination countries from 1995 to 2010. Our results support the effectiveness of an importing country's patent harmonization in stimulating importation of high-tech goods from Taiwan.

Key Words: patent rights, high-tech, semiconductor, export, HMR, PPML

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I. Introduction

The emergence of global intellectual property rights (IPRs) protection regimes based on the agreement on Trade-Related Intellectual Property Rights (TRIPS) is a subject of considerable debate. Arguments center on the effects of IPRs on international technology generation and transfers, trade performance, FDI flows, and growth. In 1995, the TRIPS agreement, which seeks global harmonization of IPR laws, came into effect. All countries that are members of the World Trade Organization (WTO) are required to follow the TRIPS guidelines to adopt common global laws for protection of intellectual properties as embodied in patents, copyrights, trademarks, and trade secrets. Patent rights (PRs) protection has acquired an important role in the new knowledge-based global economy. Traditionally, developing countries have established weaker regimes that favor technological diffusion through imitation and acquisition from abroad. By contrast, developed countries have long promoted the idea of stronger intellectual property protection throughout the world to improve incentives for private agents to create and advance technology for their own inventors to extract greater returns from their discoveries. Pressure from developed countries and often in conjunction with concessions on opening their domestic product markets to more imports have led many developing countries to begin strengthening their intellectual property systems, particularly on patents.

An ongoing debate over the role of IPRs and international technology diffusion can be observed through a variety of formal and informal channels, including trade in goods, foreign direct investment (FDI), international patenting, technology licensing, etc., at the country level. PRs can affect these channels in different ways. Proponents of less stringent protection suggest that further controls on PRs would harm imitation-cum-innovation development strategies and constitute a barrier to legitimate trade in imitative products. By contrast, proponents of more stringent protection suggest that lax protection distorts natural trading patterns. PRs protection can prevent the product of a manufacturing firm from being imitated by its competitors and protect its economic well-being. However, in the presence of national differences in the IPRs system, the decision made by an exporting firm on a country which its products are shipped to will be distorted. Several empirical studies have considered the relationship between PRs and a particular channel of diffusion (Briggs, 2013; Co, 2004; Deardorff, 1992; Eaton and Kortum, 1996; Helpman et al., 2008; Hsu and Tiao, 2015; Ivus, 2010; Liu and Lin, 2005; Maskus and Eby-Konan, 1994; Maskus and Penubarti, 1995; Rafiquzzaman, 2002; Smith, 1999; Yang and Maskus, 2001; Yang and Woo, 2006). The outcomes of these studies are mixed, although stronger evidence can be found for the importance of PRs protection for trade and patenting than for FDI.

Although previous literature has investigated the effects of PRs protection on overall and industry-level bilateral trade flows across countries, most studies employ traditional gravity models to estimate and ignore firm-level behavior (extensive and/or intensive margin changes). In fact, the effect of PRs can be displayed through the variety (i.e., extensive margin) and volume (i.e., intensive margin) of trade. Helpman, Melitz, and Rubinstein (2008), henceforth HMR, propose a two-stage, non-linear least squares (NLS) estimation procedure to correct the two types of potential bias of the standard gravity model, which are sample selection bias and bias from potential asymmetries in the trade flow between pairs of countries. The model enables insight into a firm's binary decision to export to a given market based on the continuous decision on the amount of exports, and allows empiricists to determine firm-level decision making behavior while using aggregate country data. The ability to obtain such decomposition is important because in practice, a substantial proportion of trade adjustment occurs at the extensive margin, and obtaining consistent firm-level data with export destinations is nearly impossible for many countries. HMR argues that controlling for extensive margin and sample selection would eliminate bias in the estimation.

However, Santos Silva and Tenreyro (2015) argue that the HMR model is valid only under the dependence on homoscedasticity. They suggest the HMR model is specified incorrectly and casts doubts on any inference drawn from the empirical implementation of the HMR model.[1] They propose an econometric solution to the "zero problem," which is the Poisson pseudo-maximum likelihood (PPML) estimator. The Poisson model commonly used for count data can be applied more generally to non-integer variables and is equivalent to (weighted) non-linear least squares. The estimator is consistent under weak assumptions, and data need not be distributed as Poisson. Their point is a very general one, whereby the econometric estimates of log-linearized models can be misleading because of a particular and noxious type of heteroscedasticity.

The influence of stronger PRs protection on the exports of developed countries has not received much attention in the literature. Due to the estimation biases of traditional gravity model, this paper adopts the HMR model and the PPML method accompanied by traditional gravity estimation to examine empirically how differences in PR protection between countries influence the export of a developed coun-

1 They show that HMR two-stage estimator is very sensitive to departures from the assumption of homoscedasticity. However, heteroscedasticity is commonly found in most trade data.

try, such as Taiwan, in a knowledge-based industry, namely the high-tech industry. The study covers 1995 to 2010 and considers 119 trade partners of Taiwan. The semiconductor industry was chosen mainly because it has been thriving on a soft patent regime followed by Taiwan since 1986 and has become one of the most crucial export-oriented sectors of today. Besides, under the development of a global value chain, the semiconductor trade is usually regarded as a trade of intermediate goods, and thus avoids the double-counting problem often found in the final goods trade. Moreover, unlike most previous studies using data from the U.S. or European Union, the advantage of using data from Taiwan is that it is a small country with almost no influence on the patent protection policies in other counties. Thus, there is no worry of the potential reverse causality (i.e. the destination country's protection level might be affected by the trade volume). To the best of our knowledge, this study is the first empirical study on the possible linkage between PRs protection difference and semiconductor exports of Taiwan by using the recently developed HMR model and PPML method. Therefore, this paper can shed light on the related literature by providing a noteworthy exploration of a developed country.

The remainder of the paper is organized in the following way. The next section reviews briefly the main findings of related literature. In the third section, we present the general empirical methodology and introduce the dataset. The fourth section presents and discusses the empirical findings. The last section concludes.

II. Literature Review

An increasing amount of literature is addressing the factors that contribute to international technology diffusion, such as international trade. International technology diffusion is the process by which technology moves from country to country and is considered to have a significant effect on country-income levels. Obtaining technology from another country increases productivity growth, especially for poorer countries that invest less in R&D than more developed nations (Keller, 2004). Technology transfers between countries are at the heart of this issue, and consideration of how PRs influence international trade and technology diffusion is worthwhile. The cost savings from forgoing the R&D process can lead to lower prices for the foreign producer, making it difficult for the original intellectual property creator to compete. In this way, the lack of consistent PRs across countries could hamper international technology diffusion by reducing trade in goods. Therefore, increased understanding of how PRs influence tradeflows is essential to the development of a constructive trade policy that benefits all countries involved.

Empirical studies on the PRs-exports relationship began in the mid–1990s.

This area of research has foundations in the work by Maskus and Penubarti (1995). They use an augmented version of the Helpman-Krugman model of monopolistic competition to estimate the effects of patent protection on international trade flows. They offer two counteracting explanations for how PRs influence trade flows. The market-power effect results from monopolistic characteristics granted by the PR. By granting monopoly rights for patentable products in the domestic market, foreign firms export less because of reduced elasticity of demand. The study addresses the market-expansion effect, which results from a "fairer" market. By strengthening a PR, foreign firms can have more confidence in exporting, given that the legal system is protecting their goods. They state that the theoretical effects are indeterminate, and empirical analysis can provide better insight. They estimate a two-stage econometric model and conclude that increasing PRs strength has positive impact on imports for foreign countries.

Ferrantino (1993) previously found evidence contrary in part to Maskus and Penubarti (1995) that PRs do not influence exports in general, but rather influence exports to foreign affiliates. Smith (1999) groups importing countries into four different categories according to their strengths of PRs and imitative abilities. She uses a measure of PR strength estimated by Ginarte and Park (1997). The study empirically finds that U.S. exports increase with the improvement of PRs when facing a strong threat of imitation, i.e., the importing country has weak PRs and strong imitative ability. However, U.S. exports decrease with the improvement of PRs when facing a weak threat of imitation, i.e., the importing country has strong PRs and weak imitative ability.

Co (2004) estimates a two-way random effects model and concludes that an increase in PRs matters with respect to the ability of the importing countries to imitate imports. In this manner, PRs increase U.S. exports of R&D-intense goods and decrease non-R&D-intense goods. Plasmans and Tan (2004) estimate and compare data on China's bilateral trade with data from the U.S. and Japan. The study uses a three-country multiple-good trade model measuring trade distortions related to patenting activity at the industry level. Here, strong patent rights enhance foreign exports to China in high-technology and patent-sensitive industries, while more stringent IPRs protection has a negative effect on low-technology and trademark-sensitive industries under a strong ability of imitation in China's case.

Liu and Lin (2005) conduct a consecutive pooled data analysis from 1989 to 2000 to investigate the relationship between foreign PRs (FPRs) and the exports of three high-tech industries in Taiwan. The empirical results indicate that market expansion and power effects exist in Taiwan's case. In addition, a new hypothesis (Hypothesis 3) is proposed in the paper that the importing country may exhibit stronger R&D ability than the exporting country. If an importing country has stronger R&D ability than Taiwan, the improvement of FPRs increases Taiwan's exports. If an importing country has lower R&D ability than Taiwan, when the importing country exhibits strong threat of imitation, improvement of FPRs in that country increases Taiwan's exports through the market expansion effect, whereas when the importing country exhibits weak threat of imitation, the improvement of FPRs in that country decreases Taiwan exports through the market power effect.

Doanh and Heo (2007) focus on PRs and trade flows in ASEAN countries. Using a gravity model, they find a strengthened PR in non-ASEAN countries is associated positively with ASEAN exports, and a strengthened PR in ASEAN countries is associated negatively with non-ASEAN exports. Rafiquzzaman (2002) finds that PR strength is an important factor for Canadian exports, and also concludes that where imitative ability is high, stronger IPR induces more Canadian exports, while where imitative ability is low, stronger PRs reduce Canadian exports. The results of these two papers provide evidence for the market expansion and power effects discussed by Maskus and Penubarti (1995).

Falvey et al. (2009) estimate a gravity equation by the threshold model. They find statistical evidence for the importance of the importer's ability to imitate imports and the market size of the importing country, as well as a non-linear relationship between trade flows and PRs. Ivus (2010) performs a difference-in-difference analysis to examine the link between PRs and exports in the developing world. The results support the view that PRs are trade relevant and changes in PRs have real, measurable, and economically significant effects on trade flows.

Although previous literature has investigated the effect of PRs protection on overall bilateral trade flows as well as on different industries across countries, most studies employ traditional gravity models to estimate and ignore firm-level behavior. The impact of PRs can be displayed through the extensive and intensive margins of trade. Helpman et al. (2008) develop a two-stage, NLS estimation procedure to correct a sample selection bias and a bias from potential asymmetries in the trade flow between pairs of countries in the standard gravity model. The HMR model enables us to investigate a firm's binary decision to export to a given market from its continuous decision of how much to export, and allows empiricists to determine firm-level decision-making behavior while using aggregate country data. Most articles employing the HMR method apply it to a cross-section dataset (Baller, 2007; Bao and Qiu, 2010; Bao, 2014; Xiong and Beghin, 2012). Briggs (2013) further provides a conceptual understanding of how patent protection enters into the HMR model, thereby influencing the decision to export and volume of exports. Her empirical results show that patent harmonization across countries is useful in increasing high-technology trade, and differs depending on the income level of the patent reforming country.

In an influential paper, Santos Silva and Tenreyro (2006) recommend a robust alternative approach, the PPML estimation technique, to cope with econometric problems resulting from heteroscedastic residuals and the prevalence of zero bilateral trade flows. The PPML method has been adopted widely for the estimation of gravity equations (Lee and Park, 2016; Liu, 2009; Westerlund and Wilhelmsson, 2011). While Santos Silva and Tenreyro (2015) acknowledge that the HMR model makes a significant contribution to understanding the determinants of bilateral trade flows, they identify two potential limitations to the two-stage estimation procedure. First, the HMR approach does not correct for selection bias completely, and the proposed estimator is not generally consistent. Second, the HMR model relies heavily on distributional assumptions, which makes their results rely on the untested assumption that all random components of the models are homoscedastic. The presence of heteroscedasticity in trade data precludes the use of models that separately identify covariate effects in intensive and extensive margins. For these reasons, this study uses the HMR model and PPML method accompanied by the traditional gravity estimation to investigate the PRs-Trade nexus.

In summary, the effect of stronger PRs protection on the exports of developed countries is worth exploring in the literature. Due to the estimation biases of the traditional gravity model, we consider the HMR model and PPML method accompanied by the traditional gravity framework to examine empirically how differences in PRs protection between countries influence the semiconductor exports of a developed country like Taiwan.

III. Research Methodology

We conduct a gravity model based on traditional ordinary least squares (OLS) estimation, which is the baseline model in our study, as follows:

$$\ln Y_{it} = \alpha_0 + \alpha_1 PRD_{it} + \alpha_2 \ln GDP_{it} + \alpha_3 \ln POP_{it} + \alpha_4 \ln DIST_i + \alpha_5 FTA_{it} + \varepsilon_{it}, \qquad (1)$$

where Y_{it} is the export value of the high-tech industry's goods from Taiwan to country i at year t, PRD_{it} captures the difference in PRs protection standards between Taiwan and country i at year t where the level of PRs protection in each country is measured by the Ginarte-Park Index, GDP_{it} measures GDP in country i at year t in constant 2010 U.S. dollars (PPP), POP_{it} measures population in country i at year t, $DIST_i$ measures the number of kilometers between major cities in Taiwan and in country i, and FTA_{it} is the dummy variable equal to one if Taiwan and country i belong to the same free trade agreement at year t, and zero otherwise. Finally, ε_{it} is a well-behaved error term.

The key variable of interest in this paper is the difference in PRs protection between Taiwan and an importing country, PRD_{it}, on trade. We consider the difference in PRs protection, as defined in Eq. (2):

$$PRD_{it}=PRDP_{it}+PRDN_{it}=\max(0, PR_{Tt}-PR_{it})+\max(0, PR_{it}-PR_{Tt}), \qquad (2)$$

where PR_{Tt} captures Taiwan's PRs protection level in year t and PR_{it} captures an importing country i's PRs protection level in year t. From Eq. (2), a decrease in PRD_{it} indicates patent regimes in two countries are similar. Thus, PRD_{it} is expected to have a negative relationship with trade (Eq. (1)), thereby indicating that synchronization of international patent regimes encourages Taiwan's high-tech trade. Particularly, in Equation (2), PRDP captures the difference between Taiwan and a destination country with weaker PRs protection (e.g. China), and PRDN measures the dissimilarity between Taiwan and an importing country with stronger PRs protection (e.g. the U.S.). When China strengthens its PRs protection and catches up with the PRs level of Taiwan, we expect that Taiwanese firms are more willing to export more semiconductors to it. Therefore, a negative relationship between PRDP and semiconductor exports is expected. On the other hand, the logic behind a positive PRDN is like the case considered in Hypothesis 3 of Liu and Lin (2005). When the U.S. raises its PRs level further and widens the gap with Taiwan, the U.S. firms will concentrate more on R&D innovation (such as IC design) and outsource their semiconductor production to foreigners, so Taiwan's semiconductor exports to the U.S. may increase. By comparing these results, we know that differences in patent regimes across Taiwan and trade partners influence export decisions when firms are exporting to countries with weaker patent regimes and when they are exporting to countries with dissimilar, yet stronger patent regimes. This asymmetric relationship provides insight into how differences in patent regimes of trade partners and patent coordination influence export behavior.

By replacing PRD_{it} in Eq. (1) with the defined format in Eq. (2), Eq. (1) is rewritten and our OLS estimation becomes as follows:

$$\ln Y_{it}=\alpha_0+\alpha_1^{+}PRDP_{it}+\alpha_1^{-}PRDN_{it}+\alpha_2\ln GDP_{it}+\alpha_3\ln POP_{it}+\alpha_4\ln DIST_i+\alpha_5 FTA_{it}+\varepsilon_{it}, \quad (3)$$

Different from the traditional gravity model, we further apply the HMR model to construct a two-stage estimation procedure to discern a firm's binary decision to export into a given foreign market from their continuous decision of how much to export. As Briggs (2013) suggests, the probability that a firm would export is estimated by using a probit model in stage one for extensive margin of trade. The number of exporters is controlled when estimating the volume of trade by using NLS in stage two for an intensive margin of trade.

In the first stage, the probability that the high-tech industry in Taiwan exports to country i can be characterized as follows:

$$EX_{it}=\beta_0+\beta_1^{+}PRDP_{it}+\beta_1^{-}PRDN_{it}+\beta_2\ln GDP_{it}+\beta_3\ln POP_{it}+\beta_4\ln DIST_i$$
$$+\beta_5FTA_{it}+\beta_6REL_{it}+v_{it}$$
$$EX_{it}=\begin{cases}1 & if\,EX_{it}^{*}>0\\ 0 & if\,EX_{it}^{*}=0\end{cases}, \tag{4}$$

where EX_{it}^{*} is the export value of semiconductors from Taiwan to country i at year t, and REL_i measures the similarity of religion in Taiwan and country i. We take the natural log of GDP_{it}, POP_{it}, $DIST_{it}$, and REL_i. All other variables in Eq. (4) are as explained for Eq. (3). Finally, v_{it} is the normally distributed error term.

Studies dealing with selection models suggest that for the complete model to be identified, we should identify at least one factor that affects the decision variable but not the intensity variable (Lee and Park, 2016; Estrin et al., 2008; Maddala, 1983). As suggested by Helpman et al. (2008), Briggs (2013) and Lee and Park (2016), common religion is utilized as the instrument variable in the two-stage estimation procedure.[2] Helpman et al. (2008) point out that common religion has a great influence on a firm's choice of export, but not on its export volume once the exporting decision has been made.[3] Helpman et al. (2008) and Briggs (2013) use data provided by La Porta et al. (1999), which capture the extent to which inhabitants in the two countries share a common religion on the religious composition of each country in our sample. In their study, common religion is computed as the following linear combination: *REL*=(% Protestants in country A * % Protestants in country B)+(% Catholics in country A * % Catholics in country B)+(% Muslims in country A * % Muslims in country B). Since Buddhism, Taoism and Christianity are the three major religions in Taiwan, we change the formula of common religion to: *REL*=(% Buddhists in Taiwan * % Buddhists in country *i*)+(% Taoists in Taiwan * % Taoists in country *i*)+(% Christians in Taiwan * % Christians in country *i*) by using data provided by the CIA World Factbook.

In the second stage, the export volume in the semiconductor industry can be estimated as follows:

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2 Briggs (2013) conducts an empirical study on high-tech exports as well, and thus we decided to use the common religion as the instrumental variable for the reason of comparison with Briggs (2013).

3 Helpman et al. (2008) also use the common language as the instrument variable, and obtain results almost identical to those using common religion.

$$\ln Y_{it} = \gamma_0 + \gamma_1^{+} PRDP_{it} + \gamma_1^{-} PRDN_{it} + \gamma_2 \ln GDP_{it} + \gamma_3 \ln POP_{it} + \gamma_4 \ln DIST_i + \gamma_5 FTA_{it} + \ln\{\exp[\delta(\hat{p}_i^{*} + \hat{imr}_{it}^{*})] - 1\} + B_{imr}\hat{imr}_{it}^{*} + \xi_{it}, \quad (5)$$

where Y_{it} is the non-zero export value of the semiconductor industry's goods from Taiwan to country i at year t, $\hat{imr}_{it}^{*}$ is the inverse Mills ratio estimated from the first stage probit equation used to correct for sample selection bias, and $\hat{p}_i^{*}$ is the predicted latent variable from the first stage estimation equation that captures the dichotomous export decision of firms. All other variables in Eq. (5) are explained for Eq. (3). Finally, ξ_{it} is the normally distributed error term. The sample selection of firms into certain exporting markets and the endogenous number of exporters of the stage one equation are isolated and controlled for stage two.

Under the specification of the difference in PRs protection, the stage one Probit estimation approximates the bilateral binary export decision. From this stage one equation, estimates of $\hat{p}_i^{*}$ and $\hat{imr}_{it}^{*}$ are derived and input non-linearly into the second stage equation of the volume of bilateral exports from the high-tech industry in Taiwan to country i to correct for endogeneity and sample selection biases. The use of $\hat{imr}_{it}^{*}$ is the standard Heckman (1979) correction for sample selection. However, this does not correct for the biases generated by the underlying unobserved firm-level heterogeneity. The latter biases are corrected by the additional control $\hat{p}_i^{*}$. The term, $\ln\{\exp[\delta(\hat{p}_i^{*} + \hat{imr}_{it}^{*})] - 1\}$, controls for unobserved firm heterogeneity, that is, the effect of trade frictions and country characteristics on the proportion of exporters. The standard Heckman correction is a valid estimation only in conditions where there is no firm-level heterogeneity, that is, where all firms are identically affected by trade costs. When firm-level heterogeneity is present and when there are fixed as well as variable trade costs, the consistent estimation method is a variant of the Heckman procedure that also corrects for the effect of exporting firms. The two-stage procedure of the HMR model is designed to correct for two potential problems in gravity equation estimations: selection bias resulting from dropping observations with zero trade volume, and bias due to unobserved firm-level heterogeneity resulting from a failure to measure the impact of exporting firms. In the second stage Eq. (5), two aspects of the first stage Eq. (4) are isolated and controlled for: (1) the sample selection of firms into certain exporting markets and (2) the endogenous number of exporters. The interdependence of (1) and (2) results in the nonlinearity of the coefficient δ in Eq. (5), thus necessitating that Eq. (5) be estimated using non-linear least squares (NLS). The results then provide an unbiased estimate of the impact of the explanatory variables on the export volume of exporting firms.

According to Helpman et al. (2008), the two-stage estimation of the HMR model simultaneously corrects for the sample selection bias and the bias due to unobserved firm heterogeneity embodied in the traditional gravity estimation of trade flows. The latter bias is due to an omitted variable that measures the influence of the number (fraction) of exporting firms (extensive margin). In a world without firm heterogeneity, or where such heterogeneity is not correlated with the export decision, all firms are indistinguishably affected by trade barriers and country characteristics and make the same export decision, or make export decisions that are uncorrelated with trade barriers and country characteristics. Then the potentially important effect of trade barriers and country characteristics on the share of exporting firms will be ignored. In a world with firm heterogeneity, firms are not equally affected by trade barriers and country characteristics, and make different export decisions. The estimation of the traditional gravity model confounds the effects of trade barriers and country characteristics on firm-level trade with their effects on the proportion of exporting firms. In Helpman et al. (2008), the empirical approach of the HMR model is driven from the theory they develop, and can be estimated with standard data sets. They argue that even without any firm-level data, it becomes possible to separately control for the number of exporting firms as well for the volume of trade per exporting firm corrected for the non-random export selection through the characteristics of the marginal exporters to different destinations. As a result, there exist sufficient statistics, which can be computed from aggregate data, to predict the selection of heterogeneous firms into export markets and their associated aggregate trade volumes. This is an important advantage of the HMR approach, which extracts from country-level data information that would normally require firm-level data.[4]

Santos Silva and Tenreyro (2015) suggest that the HMR probit model is incorrectly specified and casts doubts on any inference drawn from the empirical implementation of the HMR model. Instead, Santos Silva and Tenreyro (2006; 2010; 2011) propose an econometric solution to the “zero problem,” the PPML estimator. The Poisson model, used commonly for count data, can be applied more generally to non-integer variables and is equivalent to (weighted) non-linear least squares. The estimator is consistent under weak assumptions and the data need to be distributed as Poisson. Their point is in fact a very general one, whereby the econometric estimates of log-linearized models can be misleading because of the particular and noxious type of heteroscedasticity. The Poisson model enables the estimation of a gravity model, which includes the zeros. The dependent variable is trade, not log (trade). The independent variables still enter in logs and the coeffi-

4 For a more detailed description on the theoretical derivation, refer to Helpman et al. (2008), pages 449–457. Briggs (2013) further provides a theoretical discussion on how the HMR model is affected by the level of patent protection (Appendix A, pages 49–50).

cients can be interpreted as elasticities. For abstract reasons of statistical theory, Poisson is actually a very good workhorse estimator for gravity even if zeros are not a problem in the data. The type of heteroscedasticity that "the log of gravity" deals with seems very common. Poisson implicitly assumes nothing "special" about zeros, in which the problem is merely to consolidate the data into the estimation sample.

We finally conduct the PPML estimation on how the difference in PRs protection between Taiwan and the trading countries affects Taiwan's semiconductor exports. The empirical gravity equation of PPML model takes the following exponential function:

$$E(Y_{it}|Z_{it})=\exp(\delta_0+\delta_1^{+}PRDP_{it}+\delta_1^{-}PRDN_{it}+\delta_2\ln GDP_{it}+\delta_3\ln POP_{it}+\delta_4\ln DIST_i \\ +\delta_5 FTA_{it}), \quad (6)$$

where all variables in Eq. (6) are as they are explained for Eq. (3), and ξ_{it} is the normally distributed error term. The vector Z_{it} represents the explanatory variables. The implementation of the PPML estimator is straightforward: there are standard econometric programs with commands that permit the estimation of Poisson regression, even when the dependent variables are not integers. In particular, within Stata, the PPML estimation can be executed using a ready-to-use package directly. For a more detailed introduction of the estimation procedure of PPML, refer to Santos Silva and Tenreyro (2006).

For the robustness check, an importing country's PRs protection level, PR_{it}, is considered to examine the level impact of importing countries' PRs protection rather than the difference in PRs protection. Since semiconductors are often regarded as intermediate goods and production inputs of other high-tech final goods (such as computers and smart phones), we also consider whether the industry structure, represented by the ratio of high-tech exports to manufacturing exports of the importing country, HX_{it}, will influence Taiwan's semiconductor exports. We compare the results of Eqs. (3), (4), (5) and (6) under these specifications.

IV. Data

Table 1 explains the data used in this paper and their sources. Table 2 provides a statistical summary of the variables. Park (2008) updates the Ginarte-Park Index, ranging from 0 (no protection) to 5 (strongest protection), for 122 selected countries for the period of 1960–2005 at five-year intervals.[5] After excluding Taiwan (as the

5 For the period of 2006–2010, we assume the indices are identical to that of 2005. For the period of

Table 1: Variable Explanations

Variable Abbreviation	Explanation	Data Source
EX	Semiconductor trade=1 if exports>0, 0 otherwise.	Identified by authors
Y	The dollar value of semiconductor exports from Taiwan to the destination country	Directorate General of Customs, Taiwan
PR	PRs protection level of the destination country	Park (2008)
PRDP	Difference in PRs protection standards between Taiwan and the destination country with weaker PRs protection level than Taiwan	Park (2008)
PRDN	Difference in PRs protection standards between Taiwan and the destination country with stronger PRs protection level than Taiwan	Park (2008)
REL	Similarity of religion in Taiwan and the destination country	The CIA World Factbook
GDP	Gross domestic product of the destination country (in 2010 constant US dollars)	WDI
POP	Population of the destination country	WDI
DIST	Kilometers between the major cities in Taiwan and the destination country	CEPII
HX	The share of high-tech exports to all manufacturing exports of the destination country	WDI
FTA	Free trade agreement=1, if Taiwan and the destination country belong to the same free trade agreement, 0 otherwise.	Bureau of Foreign Trade, Taiwan

exporting country in this study) and two other nations (Somalia and Syria) for which the World Development Indicator (WDI) database does not provide the data of both GDP and population; the remaining 119 countries are chosen as the importing (destination) countries in this study. Therefore, the full sample size of our study is 1,904

1995–2005, we employ three measures to construct the indices for various years. First, we assume PRs improves gradually over time, so we calculate the average annual growth rate of indices between 1995 and 2000 and then obtain the index for 1996 by multiplying that of 1995 by the average annual growth rate. Second, we assume the indices for 1996 and 1997 are the same as that of 1995 and the indices for 1998 and 1999 are the same as that of 2000. Third, we assume the indices for 1995–1999 are identical to that of 1995. We find that the estimates are similar for different measures, and the results reported in the empirical analyses adopt the third measure.

Table 2: Summary Statistics

Variable	Observation	Mean	Std. Dev.	Min.	Max.
EX	1904	0.774	0.418	0	1
Y	1904	2.29×10^{8}	1.19×10^{8}	0	1.66×10^{10}
PR	1904	3.027	1.041	0	4.88
PRDP	1904	0.646	0.707	0	3.54
PRDN	1904	0.253	0.420	0	1.71
REL	1904	0.036	0.051	0	0.334
GDP	1902	4.4×10^{11}	1.41×10^{12}	2.40×10^{8}	1.51×10^{13}
POP	1904	5.04×10^{7}	1.56×10^{8}	100,255	1.34×10^{9}
DIST	1904	10,343.82	4,225.009	815.092	19,951.16
HX	1636	0.115	0.142	2.6×10^{-6}	0.987
FTA	1904	0.011	0.104	0	1

(119 countries times 16 years). We downloaded export data from the online database of Taiwan's Directorate General of Customs. Among 1,904 observations, around 22.6% of the sample (430 observations) has zero export value (Y), i.e. EX = 0. The average of the Ginarte-Park Index for our sample countries during 1995-2010 is 3.027, and the average of semiconductor exports is US$229 million. As a natural logarithm of 0 is undefined, we usually run the log-linearized gravity model for observations with positive trade value only. However, dropping zeros means we are getting rid of potentially useful information. We might be able to learn why certain countries trade in products, while others do not. By using only a portion of the available data, we might be producing biased estimates of the coefficients we are primarily interested in. Recent literature has paid considerable attention to the "zero trade problem." Three main approaches to overcome the problem are the (1) ad hoc solution, (2) HMR model, and (3) PPML. The ad hoc solution means adding a small, positive number (e.g., 1 in our study here) to all trade flows and seeing if including or excluding zeros appears to make a difference empirically. This approach is commonly used in policy literature, but has no theoretical basis, and is approximate at best (De, 2013). In the following sub-sections, we explain the three approaches in detail accordingly.

The religious population data provided by the CIA World Factbook is used to calculate common religion (REL), which ranges from 0 to 0.334. GDP, population (POP) and high-tech export share (HX) are collected from WDI, and the geographic distances between the major cities in Taiwan and the destination country are obtained from CEPII. The maximum value of HX is 0.987 (Singapore, 2006), while the minimum value is 0.0000026 (Nepal, 1999). After checking the website of Taiwan's Bureau of Foreign Trade, we identify five countries which had signed FTAs with Taiwan during 1995–2010: Panama (June, 2002), Guatemala (July, 2006), Nicaragua (January, 2008), El Salvador (March, 2008) and Honduras (July, 2008). The detailed figures of common religion and the trends of the Ginarte-Park index (PR) and export value (Y) for 119 destination countries are provided in the Appendix.

In Table 2, two variables are found to have missing values. GDP has two missing values because there is no GDP data for Haiti and Iceland in 1995. In contrast, HX suffers a more serious missing data problem and has 268 missing values. Therefore, in order to keep more observations in our regressions, HX is used for the robustness check only. The maximum number of observations which can be used in the regressions is 1,902.

V. Empirical Results

1. Specification Tests

Table 3 provides the pairwise correlation matrix of variables used in our study. Two observations are worth noting. First, a correlation value of 1 between lnY and ln(Y+1) (which is the ad hoc solution of the zero trade), as well as between Y and Y+1, implies that the two pairs of variables are almost the same. Second, the pair correlation of PRs protection (PR) and PRDP is about −0.924 and that of PR and PRDN is around 0.759, which exceed the minimum threshold of strong correlation, 0.7.

To check further for a multicollinearity problem among these variables, we conduct variance inflation factor (VIF) tests, which are reported in Part (a) of Table 4. The square root of the VIF value indicates how much larger the standard error is, compared with the value if that variable is uncorrelated with the other predictor variables in the model. Columns (1) to (4) and Columns (5) to (8) of Table 4 are the test results based on different model specifications with PR and PRD and different dependent variables (lnY and Y), respectively. A VIF value of 1 means there is no correlation among the k^{th} predictor and the remaining predictor variables. Hence, the variance of b_k is not inflated. The general rule of thumb is that VIF values exceeding 5 warrant further investigation, whereas VIF values exceeding 10 are signs of serious multicollinearity requiring correction. All model specifications, no matter which the dependent variable is, have VIF values less than 3, which in turn guarantees that there is no multicollinearity problem.

Estimations of OLS and HMR are based on the assumptions of normality and

Table 3: Pairwise Correlation Matrix

	Y	Y+1	lnY	ln(Y+1)	PR	PRDP	PRDN	REL	lnGDP	lnPOP	lnDIST	HX	FTA
Y	1.000												
Y+1	1.000	1.000											
lnY	0.424	0.424	1.000										
ln(Y+1)	0.315	0.315	1.000	1.000									
PR	0.189	0.189	0.600	0.617	1.000								
PRDP	−0.164	−0.164	−0.491	−0.531	−0.924	1.000							
PRDN	0.129	0.129	0.577	0.566	0.759	−0.551	1.000						
REL	0.261	0.261	0.212	0.208	−0.025	0.063	0.044	1.000					
lnGDP	0.242	0.242	0.750	0.788	0.630	−0.523	0.635	0.121	1.000				
lnPOP	0.145	0.145	0.362	0.358	0.089	−0.038	0.134	0.109	0.6441	1.000			
lnDIST	−0.490	−0.490	−0.495	−0.442	−0.043	0.008	−0.094	−0.445	−0.314	−0.356	1.000		
HX	0.255	0.255	0.539	0.441	0.318	−0.276	0.329	0.290	0.271	−0.014	−0.392	1.000	
FTA	0.160	0.160	−0.040	0.017	−0.002	0.011	−0.061	−0.006	0.001	0.034	−0.056	−0.055	1.000

Table 4: VIF and Heteroscedasticity Tests

Model specification	PR				PRD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Depend variable	lnY	lnY	Y	Y	lnY	lnY	Y	Y
(a) VIF test								
PR	2.31	2.35	2.35	2.53				
PRDP					1.73	1.78	1.80	1.93
PRDN					2.25	2.31	2.21	2.25
lnGDP	4.02	4.28	4.04	4.47	4.63	4.87	4.57	4.94
lnPOP	2.65	2.95	2.43	2.73	2.84	3.11	2.55	2.83
lnDIST	1.13	1.39	1.18	1.41	1.13	1.39	1.18	1.41
FTA	1.01	1.02	1.01	1.01	1.01	1.02	1.01	1.01
HX		1.42		1.41		1.43		1.42
Mean VIF	2.22	2.23	2.20	2.26	2.27	2.27	2.22	2.26
(b) Breusch-Pagan/Cook-Weisberg test for heteroscedasticity								
$\chi^2(1)$	60.50	72.87	8999.2	6920.26	55.78	67.83	9148.65	7032.64
P value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(c) White's general test for heteroscedasticity								
$\chi^2(n)$	$\chi^2(19)=$ 105.61	$\chi^2(26)=$ 107.70	$\chi^2(19)=$ 756.37	$\chi^2(26)=$ 722.66	$\chi^2(25)=$ 110.83	$\chi^2(33)=$ 119.66	$\chi^2(25)=$ 814.52	$\chi^2(33)=$ 767.59
P value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(d) White's special test for heteroscedasticity								
$\chi^2(2)$	49.33	54.93	654.84	544.27	49.08	52.31	661.38	558.26
P value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

homoscedasticity. The estimations may be inconsistent if the data exhibits heteroscedasticity, which is usually found in panel data such as that used in this study. Three tests for heteroscedasticity, the Breusch-Pagan/Cook-Weisberg test, White's general test and White's specific test, are conducted and their results are reported in Parts (b) to (d) of Table 4. All tests confirm the existence of heteroscedasticity. Therefore, PPML should be used to obtain consistent estimations. In the next subsection, we will report the estimation results of PPML, followed by those of OLS and HMR for comparisons.

2. Results from PPML

Tables 5 and 6 show the results estimated by PPML. Columns (1) to (5) of Table 5 exhibit different model specifications of time and importer fixed-effects on estimating the impact of PRs differences (PRD) on the semiconductor exports. Column (2) is applied for observations with the positive export value (i.e., Y > 0). In addition, Column (6) is a robustness check, adding an extra variable, high-tech export share (HX). Overall, country size and distance have expected signs in the gravity model, i.e. a positive coefficient for GDP (lnGDP) and a negative one for distance (lnDIST). Population (lnPOP) has a negative impact on the semiconductor exports, which might reflect the fact that only small amounts of semiconductors are shipped to less developed countries with large populations which do not have

Table 5: PPML Estimation of the Impact of the Differences in PRs Protection

Model specification	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Y	Y > 0	Y	Y	Y	Y
PRDP	−2.45***	−2.43***	−1.68***	−1.83***	−0.89***	−0.90***
	(0.41)	(0.41)	(0.29)	(0.38)	(0.31)	(0.31)
PRDN	−1.06***	−1.05***	−0.60***	0.05	1.31***	1.31***
	(0.19)	(0.19)	(0.17)	(0.19)	(0.39)	(0.39)
lnGDP	0.94***	0.94***	0.83***	2.51***	0.88***	0.84***
	(0.06)	(0.06)	(0.05)	(0.33)	(0.24)	(0.25)
lnPOP	−0.38***	−0.38***	−0.35***	−0.71	−2.32***	−2.21***
	(0.06)	(0.06)	(0.05)	(0.78)	(0.76)	(0.80)
lnDIST	−1.70***	−1.69***	−1.75***	−2.00***	−3.32***	0.60
	(0.06)	(0.06)	(0.05)	(0.47)	(0.38)	(0.97)
FTA	0.20	0.20	0.01	−0.07	−0.07	−0.08
	(0.15)	(0.15)	(0.21)	(0.07)	(0.06)	(0.06)
HX						0.16
						(0.30)
Time FE	No	No	Yes	No	Yes	Yes
Importer FE	No	No	No	Yes	Yes	Yes
Observations	1902	1472	1902	1838	1838	1589
R^2	0.788	0.785	0.820	0.953	0.979	0.979

Notes: Robust standard errors are reported in parentheses.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

Table 6: Robustness Check for PPML Estimation

Model specification	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Y	Y > 0	Y	Y	Y	Y
PR	0.68***	0.67***	0.32***	1.11***	1.16***	1.16***
	(0.09)	(0.09)	(0.10)	(0.18)	(0.19)	(0.19)
lnGDP	0.56***	0.55***	0.70***	1.85***	0.88***	0.84***
	(0.07)	(0.07)	(0.06)	(0.25)	(0.25)	(0.25)
lnPOP	−0.19**	−0.19**	−0.31***	−0.92	−2.28***	−2.16***
	(0.09)	(0.09)	(0.07)	(0.80)	(0.74)	(0.77)
lnDIST	−1.90***	−1.89***	−1.90***	−2.65***	−3.26***	0.59
	(0.07)	(0.07)	(0.06)	(0.45)	(0.39)	(0.97)
FTA	0.72***	0.72***	0.21	0.01	−0.09	−0.09
	(0.19)	(0.19)	(0.22)	(0.07)	(0.06)	(0.06)
HX						0.17
						(0.29)
Time FE	No	No	Yes	No	Yes	Yes
Importer FE	No	No	No	Yes	Yes	Yes
Observations	1902	1472	1902	1838	1838	1589
R^2	0.638	0.636	0.735	0.963	0.980	0.979

Notes: Robust standard errors are reported in parentheses.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

the technological capability to turn semiconductors, the intermediate goods, into high-tech final goods, such as computers and smart phones. The impact of free trade agreements (FTA) is insignificant, which is not surprising at all given that few FTAs were signed during the sample period.

The results in Columns (1) (with 1,902 observations) and (2) (with 1,472 observations), in which we do not control for either the time fixed-effect or the importer fixed-effect, are indistinguishable quantitatively, and the value of *R*-squared is around 0.79. Similarity is found between Columns (1) (with 1,902 observations) and (2) (with 1,472 observations) of Table 6 when we explore the impact of PRs (PR). Furthermore, the results in Columns (3) and (4) of Table 5, which control for the time fixed-effect and the importer fixed-effect, respectively, still support a negative and statistically significant coefficient for PRDP, but the coefficient of PRDN becomes positive (0.05) and insignificant in Column (4). Their values of *R*-squared improve to 0.82 and 0.95, respectively. Column (5), in which we control both time and importer fixed effects, has the highest value of *R*-squared (0.979) among Columns (1) to (5) and shows a positive and statistically significant coefficient for PRDN. Along with the finding of a negative and significant coefficient for PRDP, it implies that improvements in international patent regimes do encourage Taiwan's semiconductor exports.

To test whether the results obtained from PPML are consistent, we add HX in Column (6) under the specification similar to Column (5). This modification reduces the number of observations from 1,838 to 1,589 due to the missing values in HX, but the results are quite similar, except that the impact of distance on the semiconductor exports now becomes positive and insignificant. All specifications in Table 6 support a positive impact of PRs protection on the semiconductor exports. Therefore, we may conclude that the impacts of both PRD and PR are robust under different model setups.[6]

3. Results from Traditional Gravity Model

Table 7 provides the results of the impact of PR differences (PRD) on Taiwan's semiconductor exports for OLS, random effect and fixed effect models. Columns (1) to (4) of Table 7 illustrate four model specifications for OLS estimations on the impact of PRD. These specifications are (1) the basic model for the positive export observations only, (2) the basic model with the ad hoc solution, (3) the model including HX for the positive export observations only, and (4) the model including HX with the ad hoc solution. Several findings are worth noting. First, with 430 observations with zero export value, the results in Column (1) are dissimilar to the values in Column (2), i.e., adding a positive and small number, which is 1 here, into export value does alter the results qualitatively. Second, PRDP (PRDN) has significant and negative (positive) impact on Taiwan's semiconductor exports and export elasticity ranging from −0.30 to −0.85 (0.97 to 1.31) based on different specifications in Columns (1) and (3). The impact of PRDN becomes insignificant in Columns (2) and (4) when the ad hoc solution is applied. Third, adding an extra variable (HX) changes the coefficients of PRDP and PRDN substantially when the

6 As also observed later in the estimations of traditional gravity model and HMR, in all regressions with the importer fixed-effect, the coefficient on HX is never significant. Moreover, in the HMR estimations, including HX will cause the first stage coefficients on REL to become insignificant, suggesting that there may be some multicollinearity problems. Therefore, our discussions hereafter will focus on the results from regressions without HX.

Table 7: Traditional Estimation of the Impact of the Differences in PRs Protection

Model specification	OLS				Random Effect				Fixed Effect			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dependent variable	lnY	ln(Y+1)	lnY	ln(Y+1)	lnY	ln(Y+1)	lnY	Ln(Y+1)	lnY	ln(Y+1)	lnY	ln(Y+1)
PRDP	−0.85***	−1.04***	−0.30**	−0.41**	−0.69***	−0.01	−0.55**	−0.01	−0.79***	0.19	−0.72**	0.03
	(0.12)	(0.17)	(0.12)	(0.20)	(0.24)	(0.28)	(0.24)	(0.32)	(0.26)	(0.34)	(0.27)	(0.41)
PRDN	1.31***	0.12	0.97***	−0.36	1.68***	1.55***	1.49***	1.69***	1.75***	2.09***	1.69***	2.38***
	(0.19)	(0.25)	(0.17)	(0.24)	(0.38)	(0.46)	(0.37)	(0.45)	(0.36)	(0.45)	(0.37)	(0.47)
lnGDP	1.38***	2.65***	1.37***	2.68***	1.38***	2.73***	1.37***	2.59***	1.99***	3.40***	2.14***	3.57**
	(0.07)	(0.09)	(0.07)	(0.09)	(0.15)	(0.20)	(0.13)	(0.19)	(0.58)	(1.13)	(0.70)	(1.42)
lnPOP	−0.50***	−1.19***	−0.33***	−1.06***	−0.61***	−1.31***	−0.44***	−1.13***	−6.46***	−3.68*	−5.64***	−4.07
	(0.06)	(0.09)	(0.06)	(0.09)	(0.15)	(0.22)	(0.13)	(0.22)	(1.49)	(2.13)	(1.49)	(2.79)
lnDIST	−2.75***	−3.28***	−2.19***	−2.72***	−2.78***	−3.23***	−2.42***	−3.16***				
	(0.09)	(0.11)	(0.10)	(0.12)	(0.30)	(0.40)	(0.30)	(0.40)				
FTA	−1.23***	0.44	−1.10**	0.34	−0.67	−0.04	−0.66	−0.15	−0.48	−0.03	−0.51	−0.17
	(0.35)	(0.39)	(0.43)	(0.40)	(0.50)	(0.23)	(0.48)	(0.25)	(0.54)	(0.24)	(0.52)	(0.26)
HX			6.25***	4.95***			3.53***	0.69			1.98	−0.84
			(0.43)	(0.69)			(1.11)	(1.69)			(1.34)	(1.91)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer FE	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	1472	1902	1353	1634	1472	1902	1353	1634	1472	1902	1353	1634
R^2	0.765	0.736	0.813	0.758	0.762	0.727	0.804	0.745	0.284	0.144	0.314	0.162

Notes: Robust standard errors are reported in parentheses.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

importer fixed effect is not controlled in the OLS and random effect models. Fourth, the signs of variables in the traditional gravity model meet the common expectation, i.e., a positive sign for country size (lnGDP) and a negative sign for distance (lnDIST) across all specifications. Fifth, HX exhibits positive correlation with exports as indicated in Columns (3) and (4), implying Taiwan exports more semiconductors to countries with a larger high-tech export share. Finally, the impacts of both FTA and population are negative and significant in Columns (1) and (3), while the negative signs of FTA become insignificant in the ad hoc solution setups shown in Columns (2) and (4). The findings repeat in setups of the random effect (Columns (5) to (8)) and fixed effect (Columns (9) to (12)) models, although the time invariant variable (lnDIST) is omitted in the estimations of the fixed effect model, and the effects of HX and FTA become insignificant.

Table 8 reports the results on how the PRs protection level (PR) may influence Taiwan's semiconductor exports to the destination country. OLS, random and fixed effect models show significant and positive relationships between PRs protection level and export value, ranging from 0.52 to 1.03 for the positive export observations. However, the estimations for the ad hoc solution are less supportive, except for the result reported in Column (2). Country size (lnGDP) exhibits positively significant effects on semiconductor exports, while distance has a significantly negative effect on exports. No evidence supports the view that free trade agreements have influence in random and fixed effect models.

4. Results from HMR

Tables 9 and 10 provide estimations of the HMR model based on the two-stage approach suggested by WTO (2012). For each model specification, we run a Probit (trade propensity) model with the random effect to estimate the probability of the exporting behavior and calculate the inverse Mill's ratio (imr),[7] which is later added into a nonlinear least square (NLS) regression for the second-stage outcome estimation. Following Helpman et al. (2008), Briggs (2013) and Lee and Park (2016), we consider the degree of communality of religion (REL) as exclusion restrictions (i.e., cost variable that enters into the first stage, but not in the second-stage regression) to help identification, because regressors are allowed to have different effects on

7 WTO (2012) points out that the use of the Probit model with the fixed effect in the first stage estimation may induce "incidental parameters problem," which leads to inconsistent estimation of all parameters of the model. One possible solution is to use the random effect (see Cameron and Trivedi, 2005).

Table 8: Robustness Check for Traditional Estimation

Model specification	OLS				Random Effect				Fixed Effect			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dependent variable	lnY	ln(Y+1)	lnY	ln(Y+1)	lnY	ln(Y+1)	lnY	ln(Y+1)	lnY	ln(Y+1)	lnY	ln(Y+1)
PR	0.98***	0.81***	0.52***	0.17	0.93***	0.33	0.79***	0.40*	1.03***	0.26	0.97***	0.51
	(0.10)	(0.14)	(0.10)	(0.15)	(0.21)	(0.23)	(0.21)	(0.24)	(0.23)	(0.29)	(0.24)	(0.33)
lnGDP	1.42***	2.59***	1.41***	2.64***	1.46***	2.87***	1.44***	2.73***	2.17***	3.66***	2.28***	3.81***
	(0.07)	(0.09)	(0.06)	(0.09)	(0.15)	(0.20)	(0.13)	(0.19)	(0.61)	(1.12)	(0.73)	(1.39)
lnPOP	−0.52***	−1.15***	−0.35***	−1.04***	−0.65***	−1.39***	−0.48***	−1.21***	−6.65***	−3.69*	−5.86***	−4.19
	(0.06)	(0.09)	(0.06)	(0.09)	(0.15)	(0.22)	(0.13)	(0.22)	(1.54)	(2.20)	(1.55)	(2.85)
lnDIST	−2.76***	−3.27***	−2.18***	−2.74***	−2.78***	−3.23***	−2.40***	−3.13***				
	(0.08)	(0.12)	(0.09)	(0.12)	(0.28)	(0.37)	(0.29)	(0.37)				
FTA	−1.25***	0.52	−1.09***	0.37	−0.72	−0.13	−0.70	−0.23	−0.52	−0.13	−0.54	−0.27
	(0.35)	(0.39)	(0.43)	(0.40)	(0.52)	(0.26)	(0.50)	(0.28)	(0.55)	(0.26)	(0.54)	(0.31)
HX			6.32***	4.84***			3.71***	0.93			2.17	−0.49
			(0.43)	(0.69)			(1.11)	(1.66)			(1.34)	(1.90)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer FE	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	1472	1902	1353	1634	1472	1902	1353	1634	1472	1902	1353	1634
R^2	0.764	0.735	0.812	0.757	0.762	0.733	0.804	0.752	0.279	0.136	0.308	0.151

Notes: Robust standard errors are reported in parentheses.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

the extensive and intensive margins of trade.

Columns (1) to (4) of Table 9 show four different model specifications in which results of each stage, as Probit and NLS, of the HMR model are reported for the impact of PRs differences (PRD). The estimates in Columns (1) and (3) show that export elasticity is around −0.88 to −0.96, i.e., a 10% reduction in PRs differences between Taiwan and a destination country with lower PRs protection level (PRDP) results in a range of 8.8% to 9.6% increase in Taiwan's semiconductor exports. On the other hand, the impact of patent rights difference between Taiwan and a destination country with higher PRs protection level (PRDN) on Taiwan's semiconductor exports is negative but insignificant, as shown in Columns (1) and (3). Generally, differences in PRs between Taiwan and the trading countries with lower PRs level (PRDP) do not have a significant effect on Taiwan's semiconductor exporting firms' binary decision to export semiconductor goods in the first stage. However, in stage two, firms already engaging in semiconductor trade will increase the volume of semiconductor exports as the patent regime in the trade partner countries becomes stronger or more similar to Taiwan's. An increase in the volume of trade could correspond to an introduction of new high-tech varieties or an increase in the volume of existing varieties. When adding HX in Columns (2) and (4), the impact of PRDN becomes significant and the magnitude of PRDP coefficients change substantially, increasing from −0.88 in Column (3) to −1.82 in Column (4). This finding implies the estimates of PRDP and PRDN are quite sensitive to the inclusion of the new variable when the importer fixed-effect is not controlled.[8] On the other hand, the results in all specifications of Table 10 support a positive and significant impact of PRs protection level of the destination country (PR) on Taiwan's semiconductor exports, no matter whether HX is included or the time fixed-effect is controlled. These findings further confirm the positive impact of PR and a negative impact of PRDP on the semiconductor exports, as illustrated in results from PPML and OLS, although the magnitude of the impact changes.

Country size has a positive influence on exports, while distance has a negative sign. The impacts of FTA are negative and significant in all model specifications of Tables 9 and 10. In Columns (1) and (3) of both tables, the significant coefficient of the inverse Mill's ratio (imr) confirms that correcting for sample selection bias is justified. The estimated results show that the significant coefficient of (P+imr),

8 Unlike in the PPML and fixed effect models, we are unable to control for the importer fixed-effect in the HMR model. STATA program stops when it excludes some importer fixed-effect for particular countries in the first-stage estimation and results in some missing observations, which consequently renders the second-stage estimation.

δ, is positive, which indicates that heterogeneity matters and that higher trade volumes are driven by a greater proportion of exporters to a particular destination.

These results from subsections 5.2 to 5.4 also provide two interesting empirical insights. First, in the traditional gravity model, the results with lnY and ln(Y + 1)

Table 9: HMR Estimation of the Impact of the Differences in PRs Protection

Model specification	(1)		(2)		(3)		(4)	
	Probit	NLS	Probit	NLS	Probit	NLS	Probit	NLS
Dependent variable	EX	lnY	EX	lnY	EX	lnY	EX	lnY
PRDP	−0.11	−0.96***	0.19*	−1.29***	−0.09	−0.88***	0.22**	−1.82***
	(0.08)	(0.12)	(0.10)	(0.39)	(0.08)	(0.13)	(0.11)	(0.64)
PRDN	2.18**	−1.01	2.16**	−9.41**	2.59***	−0.49	2.81**	−18.78**
	(0.88)	(0.91)	(1.06)	(4.46)	(1.00)	(1.08)	(1.27)	(8.02)
lnGDP	0.75***	1.27***	0.95***	−3.05	0.77***	1.13***	0.98***	−5.71**
	(0.05)	(0.31)	(0.07)	(1.98)	(0.05)	(0.32)	(0.07)	(2.82)
lnPOP	−0.34***	−0.47***	−0.39***	1.51*	−0.35***	−0.39**	−0.41***	2.62**
	(0.04)	(0.15)	(0.05)	(0.83)	(0.04)	(0.16)	(0.05)	(1.18)
lnDIST	−0.52***	−2.44***	−0.64***	0.93	−0.53***	−2.46***	−0.70***	2.91
	(0.10)	(0.24)	(0.14)	(1.37)	(0.11)	(0.25)	(0.14)	(2.04)
FTA	0.94*	−1.03**	0.88*	−4.64**	1.05**	−1.58***	1.03*	−8.50***
	(0.49)	(0.47)	(0.52)	(1.87)	(0.49)	(0.52)	(0.53)	(2.98)
REL	2.79**		0.44		2.82**		0.31	
	(1.25)		(1.46)		(1.24)		(1.48)	
HX			0.11	5.64***			0.03	6.06***
			(0.49)	(0.52)			(0.51)	(0.45)
imr		−1.42***		4.12*		−0.91**		6.78**
		(0.45)		(2.10)		(0.45)		(2.90)
P + imr		0.78***		−0.75		0.41**		−2.00
		(0.13)		(0.54)		(0.18)		(2.73)
Time FE	No	No	No	No	Yes	Yes	Yes	Yes
Importer FE	No	No	No	No	No	No	No	No
Observations	1902	1472	1634	1353	1902	1472	1634	1353
R^2	0.444	0.761	0.481	0.801	0.463	0.765	0.504	0.813

Notes: Robust standard errors are reported in parentheses.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

Table 10: Robustness Check for HMR Estimation

Model specification	(1)		(2)		(3)		(4)	
	Probit	NLS	Probit	NLS	Probit	NLS	Probit	NLS
Dependent variable	EX	lnY	EX	lnY	EX	lnY	EX	lnY
PR	0.21***	0.90***	−0.00	0.72***	0.18**	0.87***	−0.10	0.97***
	(0.06)	(0.11)	(0.08)	(0.09)	(0.07)	(0.11)	(0.09)	(0.25)
lnGDP	0.76***	1.23***	0.93***	−2.71	0.79***	1.22***	1.00***	−2.98
	(0.05)	(0.26)	(0.06)	(2.12)	(0.05)	(0.28)	(0.07)	(2.25)
lnPOP	−0.34***	−0.43***	−0.39***	1.38	−0.36***	−0.43***	−0.41***	1.47
	(0.04)	(0.13)	(0.05)	(0.88)	(0.04)	(0.14)	(0.05)	(0.94)
lnDIST	−0.55***	−2.50***	−0.68***	0.80	−0.54***	−2.51***	−0.71***	0.96
	(0.10)	(0.23)	(0.14)	(1.57)	(0.11)	(0.23)	(0.14)	(1.62)
FTA	0.82*	−1.13***	0.81	−4.17**	1.01**	−1.45***	0.99*	−5.38**
	(0.48)	(0.40)	(0.51)	(1.87)	(0.49)	(0.46)	(0.53)	(2.23)
REL	3.28**		0.41		3.27**		0.39	
	(1.30)		(1.56)		(1.30)		(1.61)	
HX			0.07	5.71***			−0.04	6.40***
			(0.48)	(0.47)			(0.51)	(0.43)
imr		−1.33***		3.53		−1.14***		3.73*
		(0.39)		(2.28)		(0.40)		(2.25)
P+imr		0.65***		−0.24		0.52***		−0.64
		(0.14)		(0.31)		(0.15)		(0.51)
Time FE	No	No	No	No	Yes	Yes	Yes	Yes
Importer FE	No	No	No	No	No	No	No	No
Observations	1902	1472	1634	1353	1902	1472	1634	1353
R^2	0.443	0.767	0.476	0.806	0.459	0.766	0.498	0.810

Notes: Robust standard errors are reported in parentheses.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

are very different, and this occurs because the traditional gravity model does not handle zeros well, simply assuming ln(Y+1) and ignoring the nonlinearity associated with Y=0. Second, the HMR specification might have trouble dealing with incorporating the importer fixed-effect, but the fixed-effect is more easily included in a PPML framework.

VI. Concluding Remarks

Most previous studies employ a traditional gravity model to examine empirically the impact of PRs protection on international trade. However, they ignore firm-level extensive and/or intensive margin changes. Although the HMR model has the advantage of correcting potential biases embodied in the standard gravity estimation of trade flows, the PPML methodology is suggested to address the heteroscedasticity problem, which the HMR model is unable to handle.

This paper investigates comprehensively how differences in PRs protection between countries influences Taiwan's semiconductor exports to 119 destination countries from 1995 to 2010 by utilizing the HMR model and the PPML method. The empirical results presented in our study show that patent reform in an importing country acts first as a stimulus for attracting new semiconductor exports from Taiwan and later as a stimulus for expanding the export activity of firms already active in the market. We confirm the effectiveness of an importing country's patent coordination in increasing importation of high-tech goods from Taiwan under different model specifications. By investigating Taiwan's semiconductor exports, we provide important empirical evidence on the linkage between PRs protection and international trade.

For future research, further exploration into different industries would certainly be a start, the outcomes of which would be fruitful for providing beneficial policies to support synchronization of patent regimes around the world.

Appendix

List of Sample Countries

ID	Code	Country Name	Income	Religion	PR 1995	PR 2000	PR 2005	Y 1995	Y 2003	Y 2010
1	AGO	Angola	2	0.030888	0.88	1.08	1.20	36115	0	187
2	ARG	Argentina	3	0.036660	2.73	3.98	3.98	737008	977220	8118491
3	AUS	Australia	4	0.028830	4.17	4.17	4.17	17197229	9730424	17188256
4	AUT	Austria	4	0.030693	4.21	4.33	4.33	31543407	13450078	58567891
5	BDI	Burundi	1	0.033540	2.15	2.15	2.15	0	0	0
6	BEL	Belgium	4	0.021534	4.54	4.67	4.67	15046394	21898290	17847420
7	BEN	Benin	1	0.018915	1.78	2.10	2.93	0	0	0
8	BFA	Burkina Faso	1	0.011620	1.98	2.10	2.93	0	0	0
9	BGD	Bangladesh	1	0	1.87	1.87	1.87	74678	181390	279326
10	BGR	Bulgaria	3	0.023829	3.23	4.42	4.54	266855	34865836	46936227
11	BOL	Bolivia	2	0.033033	2.37	3.43	3.43	0	2058	20498
12	BRA	Brazil	3	0.034281	1.48	3.59	3.59	17981775	18108658	110325243
13	BWA	Botswana	3	0.030849	2.08	3.32	3.52	0	0	0
14	CAF	Central African Republic	1	0.019500	1.98	2.10	2.93	0	0	0
15	CAN	Canada	4	0.030091	4.34	4.67	4.67	23330544	32709845	82744349
16	CHE	Switzerland	4	0.026520	4.21	4.33	4.33	43960127	11442507	26436874
17	CHL	Chile	3	0.032799	3.91	4.28	4.28	75341	115710	757771
18	CHN	China	2	0.088135	2.12	3.09	4.08	4470508	3039436881	14748267061

List of Sample Countries (continued)

ID	Code	Country Name	Income	Religion	PR 1995	PR 2000	PR 2005	Y 1995	Y 2003	Y 2010
19	CIV	Ivory Coast	2	0.012558	1.90	2.36	3.06	15072	0	0
20	CMR	Cameroon	2	0.026988	2.10	2.23	3.06	19229	0	0
21	COG	Congo	2	0.029367	1.90	2.23	3.06	0	59	0
22	COL	Colombia	3	0.036270	2.74	3.59	3.72	88129	306353	247046
23	CRI	Costa Rica	3	0.030537	1.56	2.89	2.89	21451	644330	229366
24	CYP	Cyprus	4	0.040190	2.78	3.48	3.48	66067	1086	77082
25	CZE	Czech Republic	4	0.004840	2.96	3.21	4.33	525379	3284078	56529784
26	DEU	Germany	4	0.022581	4.17	4.50	4.50	140377099	268021660	1160402479
27	DNK	Denmark	4	0.029640	4.54	4.67	4.67	2336204	5750520	7481463
28	DOM	Dominican Republic	3	0.037050	2.32	2.45	2.82	59569	29851	112569
29	DZA	Algeria	3	0.000000	2.74	3.07	3.07	39461	82678	2492
30	ECU	Ecuador	3	0.033384	2.04	3.73	3.73	1459	11625	51870
31	EGY	Egypt	2	0.003900	1.73	1.86	2.77	301059	3579373	2115724
32	ESP	Spain	4	0.026442	4.21	4.33	4.33	6310202	9032731	398595943
33	ETH	Ethiopia	1	0.024453	0.00	2.00	2.13	0	0	0
34	FIN	Finland	4	0.028080	4.42	4.54	4.67	1925713	10616930	11964474
35	FJI	Fiji	3	0.025155	2.20	2.40	2.40	91532	20809	145274
36	FRA	France	4	0.027361	4.54	4.67	4.67	87531615	69006365	266633635
37	GAB	Gabon	4	0.031980	2.10	2.23	3.06	0	0	940
38	GBR	United Kingdom	4	0.023205	4.54	4.54	4.54	155549217	58354220	245462859
39	GHA	Ghana	2	0.027768	2.83	3.15	3.35	2259	0	8908

List of Sample Countries (continued)

ID	Code	Country Name	Income	Religion	PR 1995	PR 2000	PR 2005	Y 1995	Y 2003	Y 2010
40	GRC	Greece	4	0.033150	3.47	3.97	4.30	2978202	2365349	3704072
41	GRD	Grenada	3	0.033696	1.76	2.48	3.02	0	0	0
42	GTM	Guatemala	2	0.039000	1.08	1.28	3.15	109	2077	3112
43	GUY	Guyana	2	0.024960	1.13	1.33	1.78	0	0	0
44	HKG	Hong Kong	4	0.095400	2.90	3.81	3.81	1506313312	8861675612	16644414024
45	HND	Honduras	2	0.033930	1.90	2.86	2.98	0	0	22534
46	HTI	Haiti	4	0.032448	2.58	2.90	2.90	17049	0	0
47	HUN	Hungary	3	0.020592	4.04	4.04	4.50	300260	29334869	165049276
48	IDN	Indonesia	2	0.007038	1.56	2.47	2.77	13581914	57635163	65497178
49	IND	India	1	0.000812	1.23	2.27	3.76	18692729	43002581	214270826
50	IRL	Ireland	4	0.031668	4.14	4.67	4.67	22298636	122620920	23345866
51	IRN	Iran	3	0.000117	1.91	1.91	1.91	221023	1883448	2333358
52	IRQ	Iraq	2	0.000390	2.12	2.12	1.78	0	0	12817
53	ISL	Iceland	4	0.030654	2.68	3.38	3.51	94249	80795	93774
54	ISR	Israel	4	0.000780	3.14	4.13	4.13	5512837	17006405	35779920
55	ITA	Italy	4	0.031200	4.33	4.67	4.67	5389428	22130604	452168759
56	JAM	Jamaica	3	0.026871	2.86	3.06	3.36	0	0	0
57	JOR	Jordan	2	0.000858	1.08	3.03	3.43	13622	72122	1718655
58	JPN	Japan	4	0.236389	4.42	4.67	4.67	716937520	2329353126	6242143159
59	KEN	Kenya	2	0.032370	2.43	2.88	3.22	241920	747279	97470
60	KOR	Korea (South)	4	0.065479	3.89	4.13	4.33	396476791	1637002486	5095668806

List of Sample Countries (continued)

ID	Code	Country Name	Income	Religion	PR 1995	PR 2000	PR 2005	Y 1995	Y 2003	Y 2010
61	LBR	Liberia	1	0.033384	2.11	2.11	2.11	170961	13012	0
62	LKA	Sri Lanka	2	0.250692	2.98	3.11	3.11	106800	1615909	153552
63	LTU	Lithuania	3	0.032019	2.69	3.48	4.00	3346	338700	559285
64	LUX	Luxembourg	4	0.027456	3.89	4.14	4.14	17168441	32720107	32982125
65	MAR	Morocco	2	0	1.78	3.06	3.52	61390	1191974	7317533
66	MDG	Madagascar	1	0.015990	1.85	2.31	2.31	552	0	0
67	MEX	Mexico	3	0.035373	3.14	3.68	3.88	6738885	20477516	170322288
68	MLI	Mali	1	0.000936	1.98	2.10	2.93	0	0	0
69	MLT	Malta	4	0.035100	1.60	3.18	3.48	64238	1863189	8875051
70	MMR	Burma (Myanmar)	1	0.312705	0.20	0.20	0.20	2537	38931	121526
71	MOZ	Mozambique	1	0.021879	0.00	1.06	2.52	6011	0	0
72	MRT	Mauritania	2	0.000000	1.98	2.43	3.27	0	0	0
73	MUS	Mauritius	3	0.012758	1.93	1.93	2.57	73137	608655	291655
74	MWI	Malawi	1	0.033774	2.03	2.15	2.15	1824	0	906
75	MYS	Malaysia	3	0.074782	2.70	3.03	3.48	237285689	752864608	1736609425
76	NER	Niger	1	0.007800	1.78	2.10	2.93	31252	0	0
77	NGA	Nigeria	2	0.015600	2.86	2.86	3.18	542	113334	893004
78	NIC	Nicaragua	2	0.032448	1.12	2.16	2.97	37	0	3864
79	NLD	Netherlands	4	0.015288	4.54	4.67	4.67	476580491	453532872	369540330
80	NOR	Norway	4	0.030498	3.88	4.00	4.17	788133	2667094	4098389
81	NPL	Nepal	1	0.032316	1.79	1.79	2.19	148050	116	23123

List of Sample Countries (continued)

ID	Code	Country Name	Income	Religion	PR 1995	PR 2000	PR 2005	Y 1995	Y 2003	Y 2010
82	NZL	New Zealand	4	0.022219	4.01	4.01	4.01	1597926	1876220	1017311
83	PAK	Pakistan	2	0.001404	1.38	2.20	2.40	66172	491076	537551
84	PAN	Panama	3	0.039000	1.46	3.64	3.64	1034	10627	36131
85	PER	Peru	3	0.036582	2.73	3.32	3.32	35648	39575	28976
86	PHL	Philippines	2	0.034086	2.56	3.98	4.18	57647159	697511753	1854702317
87	PNG	Papua New Guinea	2	0.037596	0.00	1.40	1.60	55350	0	21123
88	POL	Poland	3	0.034671	3.46	3.92	4.21	231245	17884107	213837339
89	PRT	Portugal	4	0.032877	3.35	4.01	4.38	513522	824315	86429806
90	PRY	Paraguay	2	0.034554	1.53	2.39	2.89	9795659	135115	20027
91	ROM	Romania	3	0.036114	3.52	3.72	4.17	145019	649338	4095598
92	RUS	Russia Federation	3	0.007605	3.48	3.68	3.68	1121524	3938852	18893932
93	RWA	Rwanda	1	0.036348	1.95	2.28	2.28	0	0	0
94	SAU	Saudi Arabia	4	0	1.83	1.83	2.98	1334128	279910	206960
95	SDN	Sudan	2	0	2.61	2.61	2.61	0	5894	5275
96	SEN	Senegal	2	0.001404	1.98	2.10	2.93	16691	63632	0
97	SGP	Singapore	4	0.157728	3.88	4.01	4.21	1191409474	2702152962	6985664431
98	SLE	Sierra Leone	1	0.008112	2.45	2.98	2.98	0	0	0
99	SLV	El Salvador	2	0.033540	3.23	3.36	3.48	0	6801	1622
100	SVK	Slovak Republic	3	0.028860	2.96	2.76	4.21	105634	530105	26303372
101	SWE	Sweden	4	0.024765	4.42	4.54	4.54	12419085	8317819	15713134
102	SWZ	Swaziland	2	0.035100	1.98	2.43	2.43	0	2831	0

List of Sample Countries (continued)

ID	Code	Country Name	Income	Religion	PR 1995	PR 2000	PR 2005	Y 1995	Y 2003	Y 2010
103	TCD	Chad	1	0.017199	1.78	2.10	2.93	0	0	0
104	TGO	Togo	1	0.011310	1.98	2.10	2.93	0	0	76641
105	THA	Thailand	3	0.334328	2.41	2.53	2.66	113991158	224961423	852714172
106	TTO	Trinidad And Tobago	3	0.021528	2.33	3.63	3.75	0	577	99
107	TUN	Tunisia	2	0	1.65	2.32	3.25	42070	37576	2034575
108	TUR	Turkey	3	0	2.65	4.01	4.01	1005383	25521471	106852955
109	TZA	Tanzania	1	0.025746	2.32	2.64	2.64	0	0	11587
110	UGA	Uganda	1	0.032916	2.85	2.98	2.98	0	0	429
111	UKR	Ukraine	2	0.039000	3.68	3.68	3.68	883456	1259316	720707
112	URY	Uruguay	3	0.022698	2.07	3.27	3.39	105316	28230	42940
113	USA	United States	4	0.029381	4.88	4.88	4.88	2411978866	1621301492	1731445379
114	VEN	Venezuela	4	0.038220	2.82	3.32	3.32	128336	139622	144670
115	VNM	Viet Nam	1	0.030812	2.90	2.90	3.03	1349216	4310891	120822742
116	ZAF	South Africa	3	0.031083	3.39	4.26	4.26	8140210	9258447	35506201
117	ZAR	Zaire (Dem Rep Congo)	1	0.027300	1.58	1.78	2.23	0	0	0
118	ZMB	Zambia	2	0.037245	1.62	1.74	1.94	0	0	0
119	ZWE	Zimbabwe	2	0.034086	2.28	2.60	2.60	1606	41783	1613

Notes: Income classifications: 1 for low-income (23 countries); 2 for lower-middle-income (32 countries); 3 for upper-middle-income (30 countries); 4 for high-income (34 countries).

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專利權保護與高科技產品出口：臺灣的新證據

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摘　　要

過去探討專利權保護與國際貿易間關係的實證研究大多使用傳統的引力模型，忽略廠商層級的效果。Helpman et al. (2008) 提出一個兩階段、非線性最小平方估計法 (HMR 模型)，修正引力模型的潛在偏誤問題，分析國家間專利權保護程度的差異對於廠商出口決策與出口數量之影響。然而，Santos Silva and Tenreyro (2015) 認爲 HMR 模型仍存在估計偏差，故提出 PPML 方法來解決異質變異問題。本文運用 HMR 模型和 PPML 方法，探討 1995 至 2010 年間，臺灣與 119 個進口國的專利權保護程度差異對臺灣半導體產品出口之影響。實證結果顯示，當進口國專利權保護程度提升時，對臺灣高科技產品出口確實產生顯著正向的影響。

關鍵字：專利權、高科技、半導體、出口、HMR 模型、PPML 方法

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