Foreign Firm Entry, Domestic Firm Productivity: theory, evidence and policy*

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Abstract

While many papers focus on entry mode choices (exporting, licensing, FDI) by multinational firms into a host country, most papers focus on the multinationals themselves, or treat the multinational entry decision as exogenous and consider the effects on the productivity of domestic firms. These latter effects are limited to competition and spillover effects that are effectively exogenous to a domestic firms decision making.

Here we take a more general approach involving interdependent decisions by a domestic and multinational firm. Exogenous characteristics are base productivity/cost parameters of the two firms. The multinational's endogenous decision is its mode choice, and the domestic firm's endogenous variable is an investment decision that determines its ex-post productivity.

The paper begins with an empirical exercise using Chilean plant-level data which motivates and informs the theory to follow. We show that plants that are foreign owned have higher productivity, sales and value added than those that are linked to a foreign firm through licensing, and that the latter in turn have higher productivity and larger size than domestic unaffiliated firms.

Using this evidence, the theory builds a two-firm model where the foreign multinational has a higher productivity than the base (ex-ante) level of the domestic firm. Small, medium and large ex-ante productivity advantages of the foreign firm lead it to choose licensing, exporting and FDI respectively. The domestic firm's investment level and hence it's ex-post productivity are highest under licensing, lower under exporting, and lowest under FDI. Moving from the multinational having a low to a high advantage, the domestic firm's co-determined productivity level falls and drops discretely at each mode switch. This in turn has an associated anti-competitive effect which has been hypothesized but not explicitly modeled in the spillovers literature.

Co-determining the mode and investment decisions in turn leads to novel welfare implications. Mandatory licensing is beneficial to the host firm and country because it improves technical efficiency, both base productivity and via a secondary investment effect, and it produces a pro-competitive effect. We also add a spillover to the domestic firm when the multinational enters by FDI, something that has been extensively treated in the literature but which has a more subtle mode-choice effect here. The spillover improves the attractiveness of FDI to the host, but it also discourages FDI by the foreign firm over an intermediate range of productivity advantages, so that the foreign firm chooses the welfare-inferior option of exporting instead of allowing the spillover by choosing FDI.

1 Introduction

Our objective in this paper is to provide an integrated treatment of two phenomena which have invariably been treated as independent, in the sense that the analysis of one treats the other as exogenous. First, many papers have considered the entry mode decision of a foreign firm into a host country. An analysis typically focuses either on exporting versus FDI (the offshoring decision) or on FDI versus some type of contracting such as licensing (the outsourcing decision). Domestic firms which will compete with the foreign multinational or receive a technology license are generally treated as passive beyond possibly adjusting output, price or entry decisions.

The second phenomenon, which has also received wide attention, is the effect of multinational entry on the productivity of domestic (host country) firms. In this literature, the most common approach is to take the multinational's entry as exogenous. Most of the relevant papers are empirical and typically do not try to model and identify the sources of the productivity effects, just their sign and magnitude. Discussions typically suggest two factors that can influence host firms' productivity: competition effects on these local firms and technology/knowledge spillover effects when the multinational enters by FDI. But beyond adjusting output (or perhaps exiting) in response to competition or cost conditions, active responses to foreign entry by domestic firms are not considered: domestic firms cannot choose their marginal cost. A literature review is postponed until later in this introduction.

Here we treat a foreign multinational's mode choice and the productivity of a competing domestic firm as interdependent, and allow for all three mode choices: licensing, exporting and FDI. Base or ex-ante productivity parameters of the two firms are exogenous. But we give the domestic firm an active role in determining its productivity by allowing it to make (or not make) a productivity improving investment, optimizing in response to the multinational's mode choice. The size of the multinational's productivity advantage is a key measure of interest, as it will simultaneously determine the mode choice of the multinational and the investment level of the domestic firm.

In terms of positive theory, we show that small, medium and large ex-ante productivity advantages of the foreign firm lead it to choose licensing, exporting and FDI respectively. The domestic firms investment level and hence its ex-post productivity are highest under licensing, lower under exporting, and lowest under FDI. This endogenous investment effect on the domestic firm is associated with an anti-competitive effect which has not been explicitly modeled in the spillovers literature.

Toward the end of the paper, we also consider normative policy implications. Mandatory licensing is beneficial to the host firm and country because it improves technical efficiency, both base productivity and via a secondary investment effect, and it produces a pro-competitive effect. We also add a spillover to the domestic firm when the multinational enters by FDI. This has been extensively treated in the literature, but by assuming that multinational entry is exogenous, the literature misses subtle mode-choice effect. The spillover improves the attractiveness of FDI to the host, but it also discourages FDI by the foreign firm over an intermediate range of productivity advantages, so that the foreign firm chooses the welfare inferior option of exporting instead of allowing the spillover by choosing FDI.

We are particularly interested in the productivity level of the firms in the host country, so we begin with an empirical exercise using Chilean plant-level data $2001 - 2007$ which motivates and informs the theory to follow. This data includes more than 5000 plants belonging to 111 different ISIC 4-digit manufacturing industries each year and the information of both foreign linkages - licensing and FDI, which allows us to look for a relationship between firm type (unaffiliated domestic, licensee, or subsidiary) and productivity.

Our analysis shows that firms which are foreign owned have higher productivity, sales and value added than those that are linked to a foreign firm through licensing. The licensees in turn have higher productivity and larger size than domestic unaffiliated firms. Across industries, those with larger differences between the productivity of domestic firms and foreign subsidiaries are industries with a larger share of foreign affiliates.

The theory model has two firms (firm F and firm H) located in different countries (country f - foreign and country h - host), and the two firms compete in both markets. The foreign multinational F has a fixed marginal cost which is lower than the ex-ante level for firm H, and firm F keeps a productivity advantage for any given level of investment by firm H.

The model is a three-stage game. In the first stage, the more productive firm F makes its mode choice (exporting, licensing or FDI). Under the exporting choice, both firms choose to serve both markets and bear a symmetric variable trade cost. If firm F prefers licensing, firm H gets a part of firm Fs productivity technology and can further improve on that by investing. We assume that firm F extracts all rents from granting the license. Under the FDI choice, firm F pays a fixed cost and sets up a (horizontal) subsidiary in country h to avoid any variable trade costs, while firm H exports to country f and still bears the variable trade costs.

In the second stage, firm H chooses its optimal cost-reducing investment level endogenously. In the final third stage, the two firms compete against each other by choosing their optimal output levels for both foreign and host-country markets. Importantly, we assume that licensing cannot block output competition in this third stage. Thus the final stage always involves two Cournot competitors in each market: under licensing, firm F exports to country h in competition with its own licensee for example.

The central experiment with the model is to increase productivity of firm F holding the ex-ante technology of firm H constant. Subject to some parameter restrictions and moving from a small to a high advantage for firm F, the multinational initially chooses licensing and then switches to exporting. This switch to exporting to country h as firm F becomes more productive is due to the third-stage output competition effect. Under licensing, firm F makes firm H more competitive. At some point, the lost profits to firm F outweigh the licensing fee that firm F can extract so it switches to exporting. This switch discretely harms the domestic firm: its base technology is now worse and this is exacerbated by reducing investment.

The switch from exporting to FDI at a higher level of ex-ante productivity for firm F is more intuitive. As firm F gets more productive, firm H reduces investment, shifting total sales and market share to firm F. At some point, this makes it optimal for firm F to switch from exporting, a high variable-cost option, to FDI, a high fixed-cost option. The switch makes firm F more competitive in country h, which causes firm H to further reduce investment, leading to an even lower ex-post productivity.

Using licensing as a reference point, the results have implications for the economy as a whole. The switches to exporting or to FDI not only have an adverse effect on the productivity of the host firms, but they raise the price of the good and lower the welfare of country h relative to licensing (though FDI may be welfare-superior to exporting). This is due to a simultaneously determined productivity effect and an anti-competitive effect, where the latter is due to the shift in market share toward firm F which then raises F's markup. As indicated earlier, these results then motive us to consider mandatory licensing and the effects of adding a productivity spillover when firm F chooses FDI.

Turning now to a short review of a very large literature, it is almost always the case that theoretical papers focus either on the offshoring (location) decision or on the outsourcing (ownership) decision, in part because the technical tools needed are quite different in the two cases. Offshoring models focusing on exporting versus FDI are typically general-equilibrium models and do not involve decisions on technology investment and choice that we are adding here. Models often use large-group monopolistic competition, including almost all heterogeneous firm models, in which firms enter and exit but do not change their output levels when producing. Examples include Markusen and Venables (2000) and Helpman, Melitz and Yeaple (2004). Others have oligopolistic competition such as Cournot and involve variable markups. Examples include Horstmann and Markusen (1992, 1996) and Markusen and Venables (1998). The latter do have firms' average cost and markups changing as firm scale changes, but even this effect is absent in monopolistic competition models.

All these models do allow the number of domestic firms to change when trade costs or

investment costs fall, but the individual domestic firms do not alter investment or marginal cost. There are a few exceptions such as Saggi (1999) and Gosh and Saha (2007) that allow firms to change their R&D levels to determine their productivity, but the focus is on the multinationals themselves and not on the effects of the mode choice on domestic firms.

Outsourcing models often assume that a multinationals decision to produce in a foreign country is given, and focuses on whether the firm chooses to own a subsidiary via FDI or chooses some contractual arrangement with a local firm such as licensing. An important example is Antràs (2003). Several papers do consider elements of location and ownership decisions together in the same model, including Ethier and Markusen (1996) and Antràs and Helpman (2004). The interested reader will find a much more comprehensive review in Antràs and Yeaple (2014).

As in the case of the theoretical literature, many empirical papers focus on the multinationals themselves and study the interactions between export decision, mode choice and firm-level productivity. Clerides, Lach and Tybout (1998), Pavcnik (2002), De Loecker (2007, 2013), Aw, Roberts and Xu (2008) and Bustos (2011) have studied the effect of ex-ante firm-level productivity on the export decision and the impact of export decision firms' ex-post productivity levels in different ways. Helpman, Melitz and Yeaple (2004) illustrates the firm-level productivity ranking between different mode choices (FDI and exporting) in their empirical part. Tomiura (2007) applies the Japanese firm-level data and finds that firms that conduct FDI are more productive than exporters and licensors. Due to the lack of licensing information in most datasets, licensing hasn't been well studied in the existing empirical literature.

Another strand of the empirical literature considers foreign entry as exogenous, and analyze its effects on local independent firms. The literature on this is large and a review is beyond the scope of this paper.[1] Aitken and Harrison (1999), Javorcik (2004), Görg and Greenaway (2004) and Lu et al. (2017) apply data from different countries, look at spillovers

[1] A search in the Social Science Citation Index under "FDI Spillovers" yields 53 pages of results.

from FDI along the supply chain and created a lot of further interest. Important subsequent work includes Keller and Yeaple (2009)[2]. A relevant recent paper is Haller (2013) which finds negative effects of foreign entry on domestic firms in some sectors. These papers focus on the evidence whether or not FDI spillovers exist, and none of them find consistent empirical support for FDI spillovers to the domestic firms in the same industry.

Section 2 presents an analysis of plant-level Chilean data. Section 3 develops the model and shows how mode choice and the productivity of the domestic firm are intertwined. It also presents extensions of the model to mandatory licensing and to FDI spillovers. Section 4 concludes.

2 Motivation Evidence

The Encuesta Nacional Industrial Anual (ENIA, translated as "Annual National Industrial Survey") of Chile is a plant-level dataset and includes both licensee and foreign subsidiary information which allows us to take a glance at how different types of host-country firms behave and perform differently in their productivities and market shares. We refer to the unit as firms because nearly ninety percent of the plants are single-plant firms. The version of ENIA that we access covers the years 2001-2007, includes 111 4-digit level manufacturing industries (ISIC, Rev.3), and reports firm-level statistics such as location (administrative region), ownership, total sales, value added, total employment and etc.

While this dataset has great advantages, particularly with respect to ownership and licensing, it has limitations that do not allow explicit testing or estimation of hypotheses derived from the theoretical model to follow. Specifically, there are few switches of firms between unaffiliated, licensees, and foreign owned and new entry of multinationals in our short time series. We cannot differentiate the ex-ante productivity from the ex-post productivity in the way they are modeled in the theory. What we are observing is essentially ex-post produc-

[2]Keller and Yeaple (2009) finds that FDI spillovers only exist in high-tech sectors, but are absent in low-tech sectors.

tivity in terms of the model. All we can say is that these ex-post observations are consistent with the theory, and will avoid the temptation to assume or infer causality. As noted in the introduction, we can also say that the theory is consistent with a body of evidence showing that multinational entry does have negative effects on independent host-county firms.

We treat Chile as a host country (country h in our theory) and find three sets of empirical results. First, within industries, firms that are foreign subsidiaries have higher productivities, larger sizes, and larger market shares than licensees, which in turn have higher values of these variables than independent (unaffiliated) domestic firms. Second, across industries, those that have higher productivity differences between unaffiliated domestic firms and foreign affiliates are industries in which there are more foreign affiliates and fewer domestic licensees. Accordingly, a larger productivity advantage of multinational firms also links to a larger share of total sales of foreign affiliates and a smaller amount of paid licensing fees. Third, the literature has shown that the existence of foreign subsidiaries and its host-country domestic competitors' productivity are either negatively related or not correlated at all. Similar evidence is found with our Chilean firms. The existence of foreign subsidiaries and the extent of foreign ownership in one industry is not associated with the productivity of Chilean domestic firms.

2.1 Foreign Linkages, Productivity and Market Share

In order to take a look at the productivity and market share between different types of firms in Chile, we categorize the data into three different groups. The first group (Group 1) includes unaffiliated domestic firms without any license. The second group (Group 2) includes all domestic licensees. The third group (Group 3) is the foreign subsidiary group. The cut-off for domestic and foreign firms in our empirical part is 100% capital share.[3]

Panel A of table 1 shows the number and the proportion of firms belonging to different groups across time. On average, there are more than 5300 firms each year, and among them,

[3] 10% capital share is a widely accepted definition for foreign subsidiaries in the multinational literature. All our empirical results still hold if we apply the 10% capital share definition for foreign subsidiaries.

about 93% of the firms are unaffiliated domestic firms (group 1), 4% of them are domestic licensees (group 2) and 3% of them are foreign subsidiaries (group 3).

The productivity measure, the logarithm of total factor productivity (TFP), is estimated using the Ackerberg-Caves-Frazer (ACF; 2015) method, which builds on the earlier approaches of Olley-Pakes (1996) and Levinsohn-Petrin (2003)[4]. We use skilled labor, unskilled labor and capital stock as our primary inputs. Electricity consumption is our choice of intermediate input. Panel B of table 1 illustrates the statistics for firm-level measured productivity. Figure 1 shows the Kernel density of the natural log of total factor productivity by different groups. Firms in group 1 (unaffiliated domestic firms) have a larger proportion in low-productivity firms and a smaller proportion in high-productivity firms indicated by the green solid line, while group 3 (foreign subsidiaries) has a smaller proportion in low-productivity firms and a larger proportion in high-productivity firms (black long dashed line). Group 2 (blue dashed line) which includes all domestic licensees has a distribution in the middle.

The first question we raise here tries to reveal the relationship between different foreign linkages and firm-level productivity. Do foreign subsidiaries or domestic licensees exhibit higher productivity compared to unaffiliated domestic firms?

We assume that foreign subsidiaries and domestic licensees in Chile can reflect the corresponding productivity levels of their parent firms or licensors. Column (1) in table 2 presents the results for the following regression. In the following equation, i stands for firm index i, j stands for industry j, r stands for region r and t stands for time t:

$$ln(TFP_{ijrt}) \quad = \quad \alpha_1 + \beta_1 \times FDI_{ijrt} + \beta_2 \times Licensee_{ijrt} + \Upsilon_1 \times Controls + \epsilon_{ijrt_1}. \quad (1)$$

The left-hand side variable is the natural log of the total factor productivity of each firm,

[4]Calculations of TFP using such methods are widely used in the trade literature. See, for example, Amiti and Konings (2007), Goldberg, Khandelwal, Pavcnik, and Topalova (2010), and Greenaway, Guariglia and Kneller (2007). In particular, for uses of the ACF method, see Arnold, Javorcik, Lipscomb and Mattoo (2008), Javorcik and Li (2008), and Petrin and Sivadasan (2011).

and the key right-hand side variables are two mutually exclusive dummy variables: FDI and *Licensee*. FDI equals one if a firm belongs to the foreign subsidiary group (group 3) and zero otherwise. *Licensee* only considers the domestic licensees that it equals one if a firm is domestic and pays a positive licensing fee to some foreign firm. We control 4-digit industry, time, region, industry-time and region-time fixed effects in the regression in order to make comparisons between different groups of firms in the same industry-year and in the same region-year.

The coefficients of FDI and *Licensee* are both positive and significant. Compared to unaffiliated domestic firms (the reference group in the regression), being a foreign subsidiary on average is 76.3% more productive, and getting access to foreign licenses is 42.5% more productive. Moreover, the coefficient of FDI is significantly larger in magnitude than the coefficient of *Licensee*. Foreign subsidiaries on average exhibit higher productivity than domestic licensees.

Besides the firm-level productivity, we are also interested in whether foreign subsidiaries or domestic licensees have larger sizes (larger market shares) than unaffiliated domestic firms.

Three left-hand side variables (y_{ijrt}) reflecting firm size are tested in the following: first is the logarithm of real total sales, second is the logarithm of real value added, and third is the logarithm of total employment. Panel B of table 1 shows the summary statistics for these firm size variables by groups. Similar to productivity measure, unaffiliated domestic firms are relatively smaller than domestic licensees and foreign subsidiaries in Chile.

These left-hand side variables can be considered as market share indicators by adding the industry fixed effects in the regressions. The following regression equation is as followed:

$$ln(y_{ijrt}) \;=\; \alpha_2 + \beta_3 \times FDI_{ijrt} + \beta_4 \times Licensee_{ijrt} + \Upsilon_2 \times Controls + \epsilon_{ijrt_2}. \qquad (2)$$

The regression results are reported in column (3), (5) and (7) of table 2. Both the coefficients of FDI and *Licensee* are positive and significant at 1% level which indicates

that firms with foreign linkages on average are significantly larger (have significantly larger market shares) than unaffiliated domestic firms belonging to group 1. In addition, the magnitude of the coefficient of FDI is significantly greater than that of *Licensee* for both total sales and value added variables, which means that foreign subsidiaries enjoy larger market shares than domestic licensees.

Further, we look into whether the rankings of the productivity and market share among different groups of firms are sensitive to the market structure, so we add the 4-digit industry concentration level HHI (Herfindahl-Hirschman index) and its interaction terms with FDI and *Licensee* ($FDI * HHI$ and $Licensee * HHI$) to our benchmark regressions eq.(1) and eq.(2).

The mean and standard deviation of the 4-digit HHI are shown by panel C of table 1. Most manufacturing industries in Chile are not very competitive with the mean of HHI as high as 2500. Many 4-digit industries exhibit the feature of oligopolistic competition instead of perfect competition or monopolistic competition[5], though recently most trade models assume monopolistic competition market for simplicity.

Column (2), (4), (6) and (8) of table 2 show the regression results. The positive coefficients of the two interaction terms illustrate the fact that both domestic licensees and foreign subsidiaries in a more concentrated industry show an even larger advantage in measured productivity and market share versus domestic unaffiliated firms. Take $\ln(TFP)$ as an example by column (2), one standard deviation increase in the HHI is associated with 17% higher in productivity for foreign subsidiaries and 15% higher for domestic licensees[6]. The relationship between firm size (market share) and the foreign linkages are stronger for more concentrated industries as well by column (4), (6) and (8).

[5]The Antitrust Division of the Department of Justice considers HHI above 2500 to be "highly concentrated" in the United States.

[6]The standard deviation of 4-digit HHI is 2148. The coefficient of the interaction term between FDI and HHI is 0.00008. And therefore, the additional effect brought by a higher HHI is $2148 \times 0.00008 = 0.17$. Similarly, the additional effect by one standard deviation higher HHI on domestic licensees' productivity is $2148 \times 0.00007 = 0.15$

2.2 Productivity Advantage of Multinationals and Mode Choice

Besides the clear ranking of the productivity and market share of the three groups of firms, we are also interested in the relationship between FDI/licensing mode choice and the productivity advantage of foreign subsidiaries compared to unaffiliated domestic firms.

We aggregate the firm-level data into 4-digit industry level to construct the foreign-domestic productivity advantage. We calculate the weighted average total factor productivity of each group by weighting their group-level real total sales at each 4-digit industry level, that is, $\ln(TFP_{jt}) = \frac{sales_{ijt}}{\sum_i sales_{ijt}} \times \ln(TFP_{ijt})$. According to the previous literature[7] and figure 1, multinational firms usually exhibit higher productivity than domestic firms. So we use the average productivity of Chilean unaffiliated domestic firms (group 1) to represent the domestic "low" productivity, while foreign subsidiaries (group 3) represent the foreign "high" productivity. And therefore the productivity advantage of multinationals for a given industry is calculated by the difference between the weighted average industry-level productivity of foreign subsidiaries and that of unaffiliated domestic firms. The productivity difference is expressed by "$\ln(TFP^3_{jt}) - \ln(TFP^1_{jt})$" where superscripts 3 and 1 indicate the group number (3 for foreign subsidiary and 1 for unaffiliated domestic firm). We further take the 7-year average of this foreign-domestic productivity advantage for each 4-digit industry.

We measure the existence and extent of foreign subsidiaries and domestic licensees at the 4-digit industry level by two sets of variables. First set includes the total number of foreign subsidiaries and the total number of domestic licensees at 4-digit industry level. Second set includes the average industry-level foreign shares and average industry-level licensing fees, both weighting by the sales share of each firm, specifically, they are generated by $\frac{sales_{ijt}}{\sum_i sales_{ijt}} \times foreign\ share_{ijt}$ and $\ln\left(\frac{sales_{ijt}}{\sum_i sales_{ijt}} \times licensing\ fee_{ijt}\right)$. Again we take the 7-year average of these four variables.

The mean and standard deviation of the four variables, together with the measure of productivity advantage of multinational firms, are shown in Panel C of table 1. On average,

[7] See Helpman, Melitz and Yeaple (2004), Javorcik (2004), and etc.

there are about 2 domestic licensees and 1.6 foreign subsidiaries in each industry-year pair, with no foreign subsidiaries in some industry-year, and therefore the measure of productivity advantage of multinational firms is only available for fewer industry-year observations.

In figure 2, we show how the productivity advantage of multinationals is associated with the existence and extent of foreign subsidiaries and domestic licensees by comparing the productivity advantage of multinationals to the number of foreign subsidiaries, the number of domestic licensees, the average industry-level foreign shares and the average licensing fees paid.

The real data are shown by the black dots with industry codes listing beside. The downward sloping blue solid lines indicate the overall inverse relationship between licensing behaviors and multinationals' productivity advantage. And the upward sloping red long dashed line present the positive relationship between FDI activities and their productivity advantage. We find that industries in which foreign subsidiaries have larger productivity advantage over unaffiliated domestic firms have more inward FDI activities and fewer licensing transactions.

2.3 Foreign Subsidiaries and Domestic Firms' Productivity

It has been a long debating question on the technology spillovers through the existence of foreign subsidiaries and the extent of foreign ownership to the domestic competitors in the same industry[8]. We use the lagged number of FDI firms at each 4-digit industry to measure the existence of foreign subsidiaries and the lagged weighted average foreign share to measure the extent of foreign ownership. We apply firm-level fixed effects regressions to check on the relationship between the foreign ownership in one industry and the productivity of domestic Chilean firms:

$$ln(TFP_{ijrt}) = \alpha_3 + \beta_5 * Ex_{jt-1}^{FDI} + \gamma * HHI_{jt} + \tau_t + \rho_r + \sigma_j + \omega_i + \epsilon_{ijrt_3}. \quad (3)$$

[8]It was defined as horizontal spillover as in Javorcik (2004).

The dependent variable is the natural log of the total factor productivity of each domestic Chilean firm. We also include the time, industry and region fixed effects and 4-digit industry concentration level (Herfindahl-Hirschman index) in the regressions[9]. We test the unaffiliated domestic firms (Group 1) and domestic licensees (Group 2) separately. Table 3 reports the regression results. We can see that neither the existence of foreign subsidiaries nor the extent of foreign ownership is related to unaffiliated domestic firms' productivity (column (1) and (3) in table 3); and neither of them is correlated with the productivity of domestic licensees (column (2) and (4) in table 3). Our findings show no significant productivity spillovers from FDI firms to their domestic competitors, which aligns well with the FDI horizontal spillover literature for many other countries, eg. Indonesia, China and etc.

3 Theoretical Framework

Driven by these interesting empirical findings, we develop a theoretical model with a three-stage game to explain the mode choice decision of multinational firms and productivity differences among unaffiliated domestic firms, licensees and foreign subsidiaries.

3.1 Model Set-up

There are two countries f and h with the same domestic inverse demand function which is

$$P = \alpha - \beta X, \tag{4}$$

where P stands for the price of the good and X for the quantity. In each country there is a monopoly firm. Firm F is the domestic firm for Country f (foreign country) and firm H is the domestic firm for Country h (host country). Both firms have exogenous closed-economy marginal cost c_H^a and c_F respectively. We assume firm F is much more productive compared to firm H ($c_H^a >> c_F$).

[9]The results are robust if we include different fixed effects.

In the open economy, firm F and H which sell homogeneous goods compete by choosing their optimal quantities (Cournot competition) in both country f and country h. When firm H faces foreign competition from firm F, in order to maximize its profit, firm H chooses its cost-reducing investment level first and then determines its marginal cost level by its given cost function:

$$c_H = c_H^a - \theta_H I_H^{\frac{1}{2}}. \tag{5}$$

The cost function captures the relationship between firm H's marginal cost c_H and its cost reducing investment level I_H. The exogenous closed-economy marginal cost c_H^a is the base marginal cost. θ_H is positive and indicates the investment to productivity transformability. We leave firm F's marginal cost c_F constant[10] and assume that firm H's choice of marginal cost c_H is bounded by c_F ($c_H > c_F$).

There is a symmetric variable trade cost which equals t if either firm chooses to export to the other country[11]. Firm H can pay a licensing fee (L) to firm F to replace its base marginal cost c_H^a with a lower base marginal cost ηc_F, which is proportional to firm F's marginal cost c_F so that $c_F < \eta c_F < c_H^a$. Firm F can choose to invest a fixed amount D (horizontal FDI) in country h so that it can sell goods to country h directly without incurring trade cost. Suppose this fixed investment is large enough so that firm H cannot afford the FDI cost given its productivity disadvantage in the closed economy.

There are three possible cases that may end up as the equilibrium.[12] First, both firms choose to export to the other country with no licensing or FDI. In this case, firm H chooses its optimal investment level and determines its marginal cost to compete against firm F. Second, firm F accepts the offer from firm H and licenses its production technology lower

[10]If we let firm F invest to change its ex-post marginal cost (productivity) as well, it leads to a mathematically more complicated equilibrium, but makes no significant difference for either firm F's mode choice or firm H's investment and productivity choice. However, if firm F is allowed to invest as well, the ex-post productivity difference between two firms will be enlarged.

[11]The total marginal cost for firm F to export one unit of its goods to country h is $c_F + t$.

[12]In the theoretical model, it is possible that more productive firm F acquires less productive firm H and becomes a monopolist in the world market (both country f and country h). However, in real life there are usually either legal or political restrictions on M&A to exclude the possibility of this situation, so this potential equilibrium will not be considered in this model.

marginal cost) to firm H. After paying the licensing fee, firm H gains a new base marginal cost ηc_F with $\eta > 1$ and $\eta c_F < c_H^a$. We assume that licensing cannot block any output competition[13] so that the two firms will compete in both markets (country f and country h) just like the exporting case (i.e., firm F continues to export to country h under licensing). Third, firm F chooses to conduct FDI to get rid of the variable trade cost while firm H chooses to export.

In order to solve this model, we use a three-step backward induction process. In the first step, we derive the intra-industry allocation results including output quantities, market prices, profits and social welfare levels of two firms in two countries under all three cases given the open-economy marginal costs of two firms (c_F and c_H). In the second step, we maximize the profit of firm H by choosing its optimal investment level and determining its marginal cost under different cases. In the third step, the mode choice of firm F can be determined by comparing its profits of these three cases.

3.1.1 Case 1: Exporting

Both firms compete against each other in country f and h under the exporting mode and incur a variable trade cost t if they export to the other market. The model reduces to a two-stage game given that the mode choice has been determined to be exporting. Firm H chooses its investment level and thus its marginal cost first. Then two firms figure out their best response functions in the Cournot competition and determine their quantities, market prices and maximized profits.

By backward induction, suppose that firm H has decided its investment and marginal cost, two firms' profit-maximizing quantities, profits and two countries' market prices can be expressed as a function of the marginal costs as following. Superscript E stands for the

[13]Since we only have two firms in the open economy, so we make this assumption to ensure there exists competition in the output decision stage. Besides, this assumption is realistic as well. For example, some firms may start as an OEM (Original Equipment Manufacturer), and after they learn from the foreign technology, they invest and become an OBM (Original Brand Manufacturer) when they are still licensed and produce products for their licensors. This phenomena exist in many industries such as electronic equipment, bicycle, and etc.

exporting mode choice, subscripts F and H indicate firm F and firm H respectively, and subscripts f and h stand for country f and h.

Quantities:

$$X_{Ff}^{E} = \frac{1}{3\beta}\left(\alpha - 2c_F + c_H^E + t\right), \tag{6a}$$

$$X_{Fh}^{E} = \frac{1}{3\beta}\left(\alpha - 2c_F + c_H^E - 2t\right), \tag{6b}$$

$$X_{Hf}^{E} = \frac{1}{3\beta}\left(\alpha - 2c_H^E + c_F - 2t\right), \tag{6c}$$

$$X_{Hh}^{E} = \frac{1}{3\beta}\left(\alpha - 2c_H^E + c_F + t\right). \tag{6d}$$

Prices: (same in both countries)

$$P_f^E = P_h^E = \frac{1}{3}\left(\alpha + c_F + c_H^E + t\right). \tag{7}$$

Profits:

$$\pi_F^E = \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^E + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^E - 2t\right)^2, \tag{8a}$$

$$\pi_H^E = \frac{1}{9\beta}\left(\alpha - 2c_H^E + c_F + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^E + c_F - 2t\right)^2 - I_H^E. \tag{8b}$$

Welfare levels:

$$w_f^E = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^E - t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^E + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^E - 2t\right)^2, \tag{9a}$$

$$w_h^E = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^E - t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^E + c_F + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^E + c_F - 2t\right)^2 - I_H^E. \tag{9b}$$

In order to maximize the profit, we determine firm H's optimal cost-reducing investment level and also calculate its marginal cost:

$$I_H^E = \left[\frac{4\theta_H}{9\beta - 8\theta_H^2}\left(\alpha - 2c_H^a + c_F - 0.5t\right)\right]^2; \tag{10}$$

$$c_H^E = \frac{9\beta}{9\beta - 8\theta_H^2}c_H^a - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha + c_F - 0.5t\right). \tag{11}$$

3.1.2 Case 2: Licensing

There are four assumptions in this model related to the licensing case with superscript O standing for licensing (international outsourcing). The first assumption is that firm F is the more productive firm with an exogenous cost c_F. If the optimal mode choice is licensing, firm F should be the licenser that licenses its production technology to firm H which is the licensee.

The second assumption of the licensing case is that firm F only transfers its technology partially. The new base marginal cost that firm H gains is still greater than firm F's marginal cost, that is, $\eta c_F > c_F$. With this additional base productivity advantage compared to the other two cases, firm H has a larger incentive to invest to further reduce its marginal cost. This second assumption tries to capture the incomplete technology transfer from licensing.

The third assumption lets firm F have all the bargaining power to determine the licensing fee.[14] With the simplification of the bargaining process, firm F gains such a licensing fee L that firm H will enjoy exactly zero extra profit from the licensing compared to its second best choice. If the exporting profit is greater than the FDI profit for firm F, the licensing fee is the entire extra profit firm H can earn under the licensing case compared with the profit in the exporting case which can be expressed by $L = \pi_H^{BO} - \pi_H^E$. However, if the FDI profit is greater than the exporting profit for firm F, then the second best choice for firm H is the FDI case and the licensing fee can be expressed by $L = \pi_H^{BO} - \pi_H^M$. Superscript B indicates

[14] If we relax the licensing fee bargaining power assumption which can allow firm H does not completely give away its extra profit, this will not change the mode choice decision qualitatively as long as the licensing fee is not zero.

the before-licensing-fee-paid situation.

The fourth assumption is that the licensing cannot block any output competition, which means that firm F cannot set up a pre-licensing contract with firm H to exclude the possibility of firm H using the better production technology to compete against it in either country f or country h (i.e., firm F can export to country h under licensing and vice versa). However, we will assume that firm F cannot open a subsidiary (FDI in country h) to compete against its licensee to limit the number of cases, though it is not clear it would ever want to do so.

We can derive the prices, the outputs, and the profits before the licensing fee is paid as following.

Quantities:

$$X_{Ff}^{O} = \frac{1}{3\beta}\left(\alpha - 2c_F + c_H^{O} + t\right), \tag{12a}$$

$$X_{Fh}^{O} = \frac{1}{3\beta}\left(\alpha - 2c_F + c_H^{O} - 2t\right), \tag{12b}$$

$$X_{Hf}^{O} = \frac{1}{3\beta}\left(\alpha - 2c_H^{O} + c_F - 2t\right), \tag{12c}$$

$$X_{Hh}^{O} = \frac{1}{3\beta}\left(\alpha - 2c_H^{O} + c_F + t\right). \tag{12d}$$

Prices: (same in both countries)

$$P_f^{O} = P_h^{O} = \frac{1}{3}\left(\alpha + c_F + c_H^{O} + t\right). \tag{13}$$

Profits: (before licensing fee paid)

$$\pi_F^{O} = \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^{O} + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^{O} - 2t\right)^2, \tag{14a}$$

$$\pi_H^{O} = \frac{1}{9\beta}\left(\alpha - 2c_H^{O} + c_F + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^{O} + c_F - 2t\right)^2 - I_H^{O}. \tag{14b}$$

Licensing fee is the extra profit that firm H can gain through this licensing transaction according to the third assumption, which is

$$L = \pi_H^{BO} - \pi_H^E, \text{ if } \pi_H^E \geq \pi_H^M; \tag{15a}$$

$$L = \pi_H^{BO} - \pi_H^M, \text{ if } \pi_H^E < \pi_H^M. \tag{15b}$$

After the licensing fee is determined, the profits of two firms after licensing fee paid can be expressed as:

Profits: (after licensing fee paid)

$$\pi_F^O = \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^O + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^O - 2t\right)^2 + L, \tag{16a}$$

$$\pi_H^O = \frac{1}{9\beta}\left(\alpha - 2c_H^O + c_F + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^O + c_F - 2t\right)^2 - I_H^O - L. \tag{16b}$$

Welfare levels:

$$w_f^O = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^O - t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^O + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^O - 2t\right)^2 + L, \tag{17a}$$

$$w_h^O = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^O - t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^O + c_F + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^O + c_F - 2t\right)^2 - I_H^O - L. \tag{17b}$$

Firm H's cost-reducing investment is

$$I_H^O = \left[\frac{4\theta_H}{9\beta - 8\theta_H^2}\left(\alpha - 2\eta c_F + c_F - 0.5t\right)\right]^2, \tag{18}$$

with the marginal cost level

$$c_H^O = \frac{9\beta}{9\beta - 8\theta_H^2}\eta c_F - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha + c_F - 0.5t\right). \tag{19}$$

3.1.3 Case 3: FDI

Firm F chooses to conduct FDI. It incurs a fixed exogenous FDI cost D and sets up a subsidiary in country h. In this case, firm F does not have the variable trade cost when it sells goods in country h. Since we assume that this fixed FDI cost is too large for ex-ante less efficient firm H to afford, firm H can only export to country f. The intra-industry allocation results for this FDI case are shown below with superscript M indicating the existence of a multinational firm.

Quantities:

$$X_{Ff}^M = \frac{1}{3\beta}\left(\alpha - 2c_F + c_H^M + t\right), \tag{20a}$$

$$X_{Fh}^M = \frac{1}{3\beta}\left(\alpha - 2c_F + c_H^M\right), \tag{20b}$$

$$X_{Hf}^M = \frac{1}{3\beta}\left(\alpha - 2c_H^M + c_F - 2t\right), \tag{20c}$$

$$X_{Hh}^M = \frac{1}{3\beta}\left(\alpha - 2c_H^M + c_F\right). \tag{20d}$$

Prices:

$$P_f^M = \frac{1}{3}\left(\alpha + c_F + c_H^M + t\right), \tag{21a}$$

$$P_h^M = \frac{1}{3}\left(\alpha + c_F + c_H^M\right). \tag{21b}$$

Profits:

$$\pi_F^M = \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^M + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^M\right)^2 - D, \tag{22a}$$

$$\pi_H^M = \frac{1}{9\beta}\left(\alpha - 2c_H^M + c_F\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^M + c_F - 2t\right)^2 - I_H^M. \tag{22b}$$

Welfare levels:

$$w_f^M = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^M - t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^M + t\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^M\right)^2 - D, \tag{23a}$$

$$w_h^M = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^M\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^M + c_F\right)^2 + \frac{1}{9\beta}\left(\alpha - 2c_H^M + c_F - 2t\right)^2 - I_H^M. \tag{23b}$$

Firm H's optimal investment levels is

$$I_H^M = \left[\frac{4\theta_H}{9\beta - 8\theta_H^2}\left(\alpha - 2c_H^a + c_F - t\right)\right]^2; \tag{24}$$

and its marginal cost is

$$c_H^M = \frac{9\beta}{9\beta - 8\theta_H^2}c_H^a - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha + c_F - t\right). \tag{25}$$

3.2 Investment and Productivity

The marginal cost of firm F (c_F) affects firm H's cost-reducing investment level (I_H) and thus its ex-post marginal cost (c_H) differently under different mode choices.

Lemma 1: Given the same demand and cost parameters for exporting, licensing and FDI modes, I_H^M and I_H^E are monotonic increasing in firm F's marginal cost c_F, while I_H^O is monotonic decreasing in c_F. And accordingly c_H^O is monotonic increasing in c_F, while c_H^E and c_H^M are monotonic decreasing in c_F.

A more efficient firm F under both exporting mode and FDI mode means a stronger

competitor for firm H, and thus the productivity of firm F adversely affects the ex-post investment and productivity choice of firm H. However, licensing allows firm H to make use of firm F's more productive technology legally, a more efficient firm F leads to a ex-post more productive host-country firm H.

In addition, there exists a clear ranking of the cost-reducing investment levels and productivity under three different modes by comparing (11), (18) and (24).

Lemma 2: Given the same demand and cost parameters for exporting, licensing and FDI modes, $I_H^M < I_H^E < I_H^O$ and accordingly $c_H^O < c_H^E < c_H^M$.

The incentive for firm H to conduct cost reducing investment is largest under the licensing mode because it enjoys a better base marginal cost by paying firm F a licensing fee. Firm H invests least to improve its productivity under the FDI mode since its competitor firm F enhances its advantage FDI facilities by reducing its variable trade cost to zero.

The marginal cost of firm H is monotonic decreasing in its cost-reducing investment level I_H, and thus Firm H is most productive under the licensing mode together with the most efficient base marginal cost. The productivity level firm H chooses is the lowest under the FDI mode.

From the functional form of the investment levels under different modes, the cost-reducing investment of firm H is also monotonic increasing with firm H's investment to productivity transformability θ_H. At the end of this paper, we will briefly consider a case where FDI from firm F can spillover its more advanced technology through improving firm H's investment to productivity transformability to illustrate how a potential FDI spillover affects firm H's investment and etc.

3.3 Mode Choice Decision

The FDI fixed cost (D) is high enough relative to its productivity to exclude firm H from choosing FDI, so firm H exports to country f under all circumstances. The mode choice is simplified to comparing firm F's maximum profits listed below among the three cases.

Exporting case:

$$\begin{aligned}\pi_F^E &= \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^a + t - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha - 2c_H^a + c_F - 0.5t\right)\right)^2 \\ &\quad + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^a - 2t - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha - 2c_H^a + c_F - 0.5t\right)\right)^2; \qquad (26)\end{aligned}$$

Licensing case:

$$\begin{aligned}\pi_F^O &= \frac{1}{9\beta}\left(\alpha - 2c_F + \eta c_F + t - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha - 2\eta c_F + c_F - 0.5t\right)\right)^2 \\ &\quad + \frac{1}{9\beta}\left(\alpha - 2c_F + \eta c_F - 2t - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha - 2\eta c_F + c_F - 0.5t\right)\right)^2 + L; \qquad (27)\end{aligned}$$

FDI case:

$$\begin{aligned}\pi_F^M &= \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^a + t - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha - 2c_H^a + c_F - t\right)\right)^2 \\ &\quad + \frac{1}{9\beta}\left(\alpha - 2c_F + c_H^a - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\left(\alpha - 2c_H^a + c_F - t\right)\right)^2 - D. \qquad (28) \\ & \qquad (29)\end{aligned}$$

The profits of firm F yield the same ordering of mode choices as the multinational firm F becomes more advantaged (lower c_F). Beginning with a low advantage, lowering c_F or raising c_H^a moves firm F from licensing to exporting to FDI. However, for some parameter values (e.g., α, β, D and t), one or possibly two modes may not be chosen for any cost and productivity advantage. For example, as the trade cost t goes to zero, FDI will never be

chosen. A very low value of fixed FDI cost D and high trade cost t implies that exporting will never be chosen: firm F jumps from licensing to FDI as its advantage rises.

In a short appendix to the paper, we present a set of parameter restrictions such that all three modes are chosen for different values of firm F's cost parameters. These involve, for example, an intermediate level of t and a level of D that is not "too small". Again, we do not believe that these restrictions affect the ordering of mode choices, only whether or not all three exist. Subject to these restrictions, it is always the case that firm F's best "outside option" or "threat point" to determine the licensing fee is the exporting option. That is, in the region of productivity parameters where firm F chooses licensing, its next best alternative is always exporting, not FDI. Thus the licensing fee L in (15) is determined on this basis. Our parameter restrictions then lead to the following result.[15]

Proposition 1: Given firm H's cost function efficiency parameters c_H^a and θ_H, with the change of firm F's marginal cost c_F, there exists $\underline{c}_F$ and $\overline{c}_F$ that the mode choice of firm F can be expressed as following:

when $\overline{c}_F \leq c_F < c_H^a$, the optimal mode choice is Licensing;

when $\underline{c}_F \leq c_F < \overline{c}_F$, the optimal mode choice is Exporting;

when $c_F < \underline{c}_F$, the optimal mode choice is FDI.

Licensing yields the largest profit for firm F when the ex-ante difference between the two firms' marginal costs is small. The extra market share and extra mark-up that firm F can gain from output competition against a weaker rival under the case of exporting or FDI yields a smaller increase in profit than the licensing fee.

The key to understanding why firm F switches from licensing to exporting as its cost advantage rises, in spite of capturing all rents created under licensing, lies in our assumption that licensing cannot prevent duopoly output competition in the final stage of the game. Li-

[15] If the parameter restrictions fail, we have different types of corner solutions: one mode dominates all the other choices, licensing switches to FDI directly, or exporting switches to FDI.

censing makes firm H more competitive in the output decision stage and this effect increases in the size of the cost advantage that firm H gets from using firm F's technology. Furthermore, getting lower base marginal cost increases firm H's ex-post cost-reducing investment and competitiveness. Licensing is analogous to firm F creating a negative externality to itself. As firm F's advantage increases, the total two-firm (industry) profit from licensing increases slower than under the exporting case, with exporting yielding higher industry profit at some point: exporting is "anti-competitive" and thus good for the joint profit. So even though firm F captures all additional profits under licensing, it still switches to exporting.

The switch from exporting to FDI is more intuitive. Briefly, as firm F gets more productive, it increases its output and market share. At some point, it is optimal to switch from exporting, a high variable cost option, to FDI, a high fixed-cost option.

3.4 Welfare Analysis

The market price is the highest in country h under the exporting mode due to a combination of the lower ex-post productivity that firm H chooses and a higher variable trade cost that firm F incurs. The market price is lowest in country h under the licensing mode because higher ex-post productivity for firm H encourages both firms to produce more under the Cournot competition. Accordingly, the market output is the lowest under the exporting mode and highest under the licensing mode.

Lemma 3: Given the same demand and cost parameters for exporting, licensing and FDI modes, country h has the highest consumer surplus under the licensing mode and the lowest consumer surplus under the exporting mode.

With a low price (high output) under the licensing mode, consumer surplus is the largest. Since we leave firm H indifferent between the licensing mode and the other two modes, the total welfare of country h is the largest under the licensing mode. When there is a shift from

licensing mode to exporting mode by firm F, the profits should be the same at the shifting point for firm H; however consumer surplus will have a large decrease due to the market price increase and market output decrease with the mode choice change. The welfare is very likely to increase in country h if there is a shift from the exporting mode to FDI mode in a relatively smaller magnitude since the increase in the consumer surplus in country h usually outweighs the profit decrease of firm H.

3.5 A Numerical Example

Considering that the cost-reducing investment and profit are affected by many parameters in the open economy such as market demand (α, β), firm F's cost (c_F) and cost function of firm H (c_H^a, θ_H), we give a numerical example to see how these parameters affect the mode choice of firm F, the productivity choice of firm H and the welfare of the host country.

In the example, the market inverse demand function for both countries is $P = 4 - 0.25X_i$, $i = f, h$. We set the cost function of firm H to be $c_H = 2 - 0.1I_H^{\frac{1}{2}}$ $(c_H^a = 2, \theta_H = 0.1)$. c_F decreases from 1.3 to 0.7. If firm F licenses its technology to firm H, firm H's cost function can be improved to $c_H = 1.1c_F - 0.1I_H^{\frac{1}{2}}$ $(\eta = 1.1, \theta_H = 0.1)$. The variable trade cost t is 0.25, and the FDI cost D is 1.8. The FDI cost is set to be high enough so that firm H will never choose to conduct FDI in country f.

In rest of the figures in this paper, red (solid) line indicates the exporting case (case 1), , the blue (dashed) line indicates the licensing case (case 2) and the black (long dashed) line shows the FDI case (case 3) . We first check how different c_F's (firm F's marginal cost) affect its exporting, licensing or FDI decision in the open economy. After the optimal mode choice is determined, we show the optimal cost-reducing investment level of firm H. Then we illustrate the market output, price and welfare of country h (host country). The last two parts of this example allow us to discuss the effects of mandatory licensing policy and the potential FDI technology spillover.

3.5.1 Firm F's mode choice

Figure 3 shows the mode choice (exporting, licensing, or FDI) made by firm F with its profit on the vertical axis. The results give the pattern that **Proposition 1** states: as the cost function advantage of firm F increases from a relatively low level, firm F first chooses licensing, then exporting, and then FDI. The (maximal or envelop) profit curve is continuous but kinked at the mode switching points where two curves for different modes cross.

3.5.2 Firm H's cost-reducing investment

Figure 4 presents the investment choice of firm H under different optimal mode choices. Firm H invests most to reduce its marginal cost under the licensing mode while its investment is the lowest under the FDI mode. Firm H's cost-reducing investment under the licensing mode is much larger in magnitude than the other two modes. Since firm H's marginal cost is an inverse function of its cost-reducing investment, firm H is ex-post most productive under the licensing mode and least productive under the FDI mode.

There are two jumps in firm H's investment — both happen when there is a mode choice switch. The first jump happens when firm F changes from licensing to exporting. When firm F switches from licensing to exporting, firm H makes its investment decision based on its less efficient cost function, and thus it reduces its investment. The second jump shows up when firm F starts to choose FDI instead of exporting. The magnitude of this jump is much smaller than that of the previous one since there is no change in firm H's cost function. It is the elimination of the variable trade cost for firm F due to FDI that enhances the advantage for firm F in country h and therefore induces this downward investment jump for firm H.

3.5.3 Price, output and welfare in country h

Figure 5 shows the market price in the host country (country h). The market price is the highest under the exporting case and the lowest under the licensing case for both countries. The upward price jump caused by the switch from licensing mode to exporting mode is large

in magnitude mainly due to a negative effect on the investment and productivity of firm H. The downward jump between exporting and FDI modes is relatively smaller because the price decrease under FDI mode is caused by the elimination of the variable trade cost of firm F.

The market output has an inverse relationship with the market price, and therefore the total output by both firms in country h is the highest under licensing mode and the lowest under exporting mode.

The total welfare of country h is presented by figure 6. The total welfare is highest under licensing mode since both consumer surplus and producer surplus are the highest for country h. The first welfare decrease happens when the mode switches from licensing to exporting. The profits generated under licensing mode and exporting mode are the same at the switching point for firm H, so at this point the total welfare decrease is completely caused by the loss in the consumer surplus due to an increase in market price (a decrease in market output) shown by figure 5. The welfare in country h increases when there is a switch from exporting mode to FDI mode. At this second mode choice switching point, firm H's profit decreases. However, the consumers in country h no longer need to pay any variable trade cost under the FDI mode, the consumer surplus increases much more than the profit decrease, and thus the total surplus increases.

3.5.4 Mandatory licensing policy

These results, particularly the welfare results in figure 6, suggest a role for a policy of mandatory licensing on the part of country h. But there are a number of interpretations as to what this might mean. These alternatives affect the definition of firm F's outside option, which affects firm H's profits if no license is agreed upon, which in turn affects the licensing fee.

In order to maintain continuity with the earlier sections, we will therefore define "mandatory licensing" in a specific way. The government of country h calculates a license fee as

the difference between what firm H would earn competing against firm F's exports using its own technology versus competing against firm F's exports using firm F's technology. If firm F rejects this offer, it cannot serve country h. If firm F accepts this offer, it then exports to country h in the output game. While noting that this is only one of several ways of modeling "mandatory"[16], it does have the advantage that the licensing curves in figures 4 to 6 for voluntary licensing do not change under our definition of mandatory.

Under this definition, the dotted blue lines in figures 4 to 6 indicate the mandatory licensing case. Firm H invests more to improve its productivity under the mandatory licensing case compared to the exporting or FDI mode (figure 4), and accordingly has a higher ex-post productivity under the mandatory licensing case.

The mandatory licensing policy lets country h enjoy a lower market price (figure 5) and higher market output, and thus the total welfare is much higher (figure 6).

The mandatory licensing policy helps the host-country firm to improve the production efficiency and increase its competitiveness in the world market, and thus benefits both the consumers and producers in the host country.

3.5.5 FDI technology spillover effect

In the last part of this numerical example we try to show how FDI technology spillover effect affects firm F's mode choice, firm H's investment and country h's welfare. We assume that the potential FDI technology spillover to the host-country firm can improve firm H's investment to productivity transformability, that is, θ_H increases from 0.1 to 0.15. Quite a number of mechanisms under which such spillovers might occur have been discussed both theoretically and empirically in the literature. A few of these papers are mentioned in the last section of the introduction, but one mechanism, for example is through worker mobility: employees/managers learn from working at the foreign firm and then take their knowledge to domestic firms.

[16]The "mandatory licensing" policy in this paper is an exogenous policy imposed by the government without making any optimization decision.

The FDI technology spillover effect only affects the FDI mode and the mode switching between exporting and FDI, so we only show the exporting versus FDI modes in the following figures. The solid red exporting line and the long dashed black FDI line indicate the mode choice without the spillover effect, while the red dashed exporting line and the dotted FDI line show the mode choice with the spillover effect.

Figure 7 shows the different mode choice decisions of firm F with and without the FDI technology spillover effect. Since the spillover effect gives firm H an indirect advantage and makes it more competitive in the world market, the productivity threshold for firm F to conduct FDI in country h increases. Firm F is more likely to stay at the exporting mode unless it is very productive with the spillover effect.

Figure 8 indicates firm H's investment level. Contrary to the case without spillover effect, firm H invests more under FDI mode when there is FDI technology spillover effect, and thus it is ex-post more productive. This increase in the productivity is completely caused by the FDI technology spillover effect[17].

Figure 9 and figure 10 illustrate the market price and total welfare of country h. Besides the avoidance of the variable trade cost for firm F, FDI technology spillover effect makes firm H ex-post more productive, and therefore the market price is even lower under the FDI mode with spillover effect. The spillover effect offers additional gains for both consumer surplus and producer surplus for country h under the FDI mode, so the total welfare increases more under the FDI mode with spillover effect compared to the case without spillover effect.

To put it the other way, the existence of FDI spillovers hurts country h at intermediate levels of firm F productivity, since the spillovers deter F from switching from exporting to FDI. While we will not present a detailed policy analysis here, it seems clear that a country h's policy that encourages (by carrot or stick) FDI over exporting is especially beneficial under spillovers, not just because of the spillovers per se, but because spillovers deter the

[17]It is not necessary that the productivity increase led by the FDI spillover effect would outweighs the productivity decrease caused by the competition effect when there is a mode switch from exporting to FDI. In this numerical example, the θ_H increase due to the spillover effect is quite large, which makes the spillover effect larger than the competition effect.

beneficial switch from exporting to FDI when it would have occurred without spillovers.

4 Conclusion

By holding the market size same for both countries to analyze the interaction between productivity choice and mode choice, we get the following conclusions. As to mode choice, licensing is the mode choice for multinational firm F when ex-ante productivity advantage of the multinational is small while FDI is chosen when this ex-ante advantage is large. Although more productive firm F can successfully extract the entire extra profit that less productive firm H can earn under the licensing case, still licensing is not always the optimal mode choice. Licensing makes firm H more competitive in the output decision stage, and this adversely dissipates the joint profit and leads to a switch to exporting or FDI at some point.

The mode choice interacts with the ex-post productivity and competitiveness outcomes and thus affects the welfare levels. Specifically, the switch from licensing to exporting leads to a significantly lower productivity and output for firm H, with the further anti-competitive effect in the output decision stage. The former effect reduces the producer surplus of country h, the latter effect causes the loss of consumer surplus due to the higher price in country h, and together the total welfare decreases when firm F switches. The welfare in h improves under the FDI mode relative to exporting, with consumer surplus gain outweighing a small loss in the profit of firm H.

The model offers some theoretical explanations for three sets of the empirical findings that we discover in the Chilean plant-level data. First, foreign linkages (licensing and FDI) are associated with higher firm-level productivity compared to unaffiliated domestic firms. Foreign subsidiaries are even more productive than domestic licensees. The foreign linkage effect also carries to firm size (market share) that both foreign subsidiaries and domestic licensees are larger in size than unaffiliated domestic firms. Second, a larger productivity advantage of multinational firms encourages FDI and discourages licensing. Third, the entry

of foreign subsidiaries is not quite related to unaffiliated domestic firms' productivity from the data since the competition effect and the productivity spillover effect may cancel each other out.

Thinking back on the era of strategic trade policy, when we eventually learned that almost any policy prescription can be generated by some combinations of assumptions, we are duly cautious about making recommendations here. With the narrow confines of this model, policies that encourage licensing deserve a look. The exporting outcome is the worst for country h due to both a negative productivity effect and an anti-competitive effect. FDI is preferred to exporting, but we are not confident that this last result is very robust.

Within the narrow confines of this model, a policy of mandatory licensing deserves consideration. The exporting outcome is the worst for country h due to both a negative productivity effect and an anti-competitive effect. FDI is preferred to exporting suggesting further policy implications, but mandatory licensing dominates FDI as well (at least in the absence of a very large spillover effect). As in the case of exporting, mandatory licensing carries productivity and pro-competitive benefits over FDI.

A final comment about our modeling of mandatory licensing compared to actual Chinese policy may be useful. It is our broad understanding that Chinese policy has focused more on joint ventures (which include technology transfer) rather than mandatory license to transfer technology. One important difference between the two is that we assume that mandatory licensing does not block output competition between the domestic and foreign firm in the output stage. It seems to us that the pro-competitive effect of mandatory licensing will likely be absent in an otherwise similar joint venture. So while technology transfer may be similar under the two, joint ventures may result in a less competitive, more collusive outcome: good for firm profits but not for consumer surplus and welfare. A detailed analysis would be interesting, but probably beyond the scope of this paper.

Table 1: Summary Statistics

Panel A: Number of firms by group

Year	FDI firms	Domestic licensees	Unaffiliated firms	Total firms
2001	149	198	4,741	5,088
	(2.93%)	(3.89%)	(93.18%)	(100.00%)
2002	170	199	5,047	5,416
	(3.14%)	(3.67%)	(93.19%)	(100.00%)
2003	171	238	4,968	5,377
	(3.18%)	(4.43%)	(92.39%)	(100.00%)
2004	181	250	5,169	5,600
	(3.23%)	(4.46%)	(92.30%)	(100.00%)
2005	169	247	5,100	5,516
	(3.06%)	(4.48%)	(92.46%)	(100.00%)
2006	176	215	4,882	5,273
	(3.34%)	(4.08%)	(92.58%)	(100.00%)
2007	153	196	4,688	5,037
	(3.04%)	(3.89%)	(93.07%)	(100.00%)

Panel B: Summary statistics for key variables – firm level

	All firms		FDI firms	Licensees	Unaffiliated
Variable	Mean	Std. dev.	Mean	Mean	Mean
$\ln(TFP)$	8.899	1.271	10.002	9.462	8.837
$\ln(Sales)$	12.385	3.602	15.271	14.720	12.183
$\ln(VA)$	12.557	1.908	14.972	14.494	12.390
$\ln(Emp)$	3.493	1.158	4.547	4.649	3.405

Panel C: Summary statistics for key variables – industry level

Variable	No. of obs.	Mean	Std. dev.
HHI (4-digit)	742	2487.755	2148.426
No. of Licensees	742	2.059	2.963
No. of FDI firms	742	1.566	3.272
ln(lincense fee)	742	4.708	4.663
Foreign capital share (%)	742	11.945	21.023
$\ln(TFP_{jt})^3$-$\ln(TFP_{jt})^1$	349	0.306	1.128

Note: 1. Panel A shows the number of firms by different groups, the share of each corresponding group is shown in parenthesis. 2. Panel B shows the summary statistics of the firm-level variables, including log of TFP, log of total sales, log of valued added and log of total employment. 3. Panel C shows the summary statistics of the 4-digit industry-level variables, including no. of licensees, no. of FDI firms, log of total licensee fees, foreign capital share, and productivity difference between foreign firms and unaffiliated domestic firms. Since in some industry-year there exists no FDI firms at all, the no. of observations are fewer for the measure of productivity difference.

Table 2: Effects of foreign linkages on TFP and market shares

Pooled-OLS Regressions

	Productivity		Market Shares					
Variables:	$\ln(TFP)$		$ln(Sales)$		$ln(VA)$		$ln(Emp)$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI	0.763***	0.659***	2.631***	2.012***	2.011***	1.622***	0.979***	0.757***
	(0.068)	(0.087)	(0.178)	(0.214)	(0.117)	(0.151)	(0.079)	(0.102)
$FDI * HHI$		0.00008**		0.00046***		0.00029***		0.00016***
		(0.00004)		(0.00015)		(0.00007)		(0.00005)
$Licensee$	0.425***	0.338***	2.126***	1.708***	1.784***	1.620***	1.124***	1.057***
	(0.040)	(0.048)	(0.115)	(0.181)	(0.080)	(0.103)	(0.055)	(0.072)
$Licensee * HHI$		0.00007***		0.00035**		0.00014**		0.00006
		(0.00002)		(0.00016)		(0.00006)		(0.00004)
HHI		−0.00007		0.00254**		−0.00058		−0.00031
		(0.00032)		(0.00118)		(0.00061)		(0.00035)
Fixed effects:								
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.378	0.379	0.255	0.256	0.298	0.299	0.218	0.219
No. of Firms.	8,180	8,180	8,212	8,212	8,180	8,180	8,212	8,212
No. of Obs.	36,502	36,502	36,845	36,845	36,502	36,502	36,845	36,845

Note: 1. The standard errors are clustered at the firm-level for the pooled OLS regression. Standard errors are presented in parentheses. ***, **, and * denote significance at 1%, 5%, and 10% respectively.
2. The coefficients of FDI are tested to be significantly larger than the coefficients of $Licensee$ for column (1) to (5).

Table 3: Domestic-firm productivity in relation to the existence and extent of FDI

Firm-level Fixed Effects Regressions

Dependent Variable: $\ln(TFP)$	Group 1 Unaffiliated Domestic Firms	Group 2 Domestic licensees	Group 1 Unaffiliated Domestic Firms	Group 2 Domestic licensees
	(1)	(2)	(3)	(4)
Lagged (No. of FDI firms)	0.002	−0.006		
	(0.003)	(0.011)		
Lagged 4-digit Industry Foreign Share			−0.0002	−0.002
			(0.0005)	(0.002)
4-digit HHI	Yes	Yes	Yes	Yes
Fixed effects				
Firm	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes
R^2	0.189	0.007	0.186	0.006
No. of firms	6,850	621	6,850	621
No. of Obs.	26,256	1,235	26,256	1,235

Note: Standard errors are presented in parentheses. ***, **, and * denote significance at 1%, 5%, and 10% respectively.

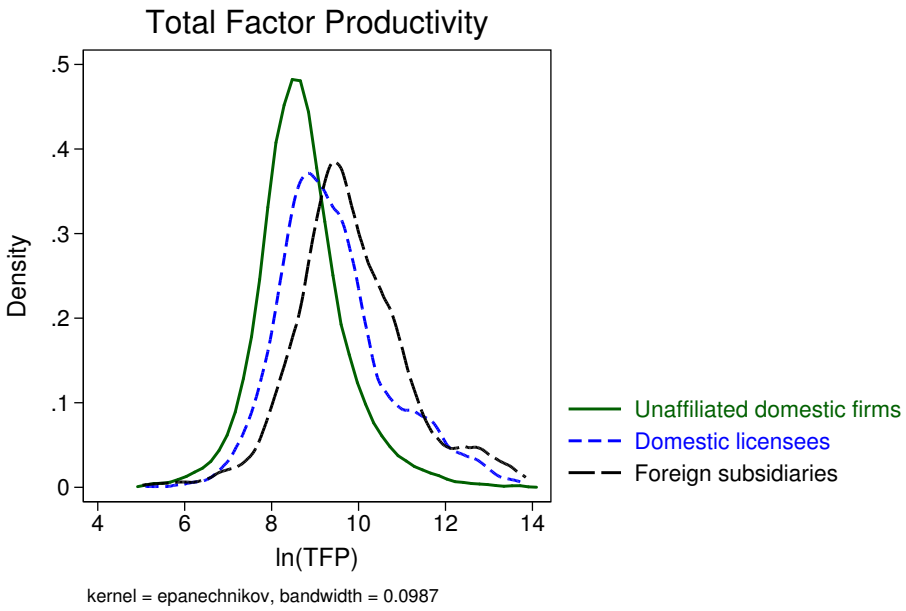

Figure 1: Total factor productivity by groups

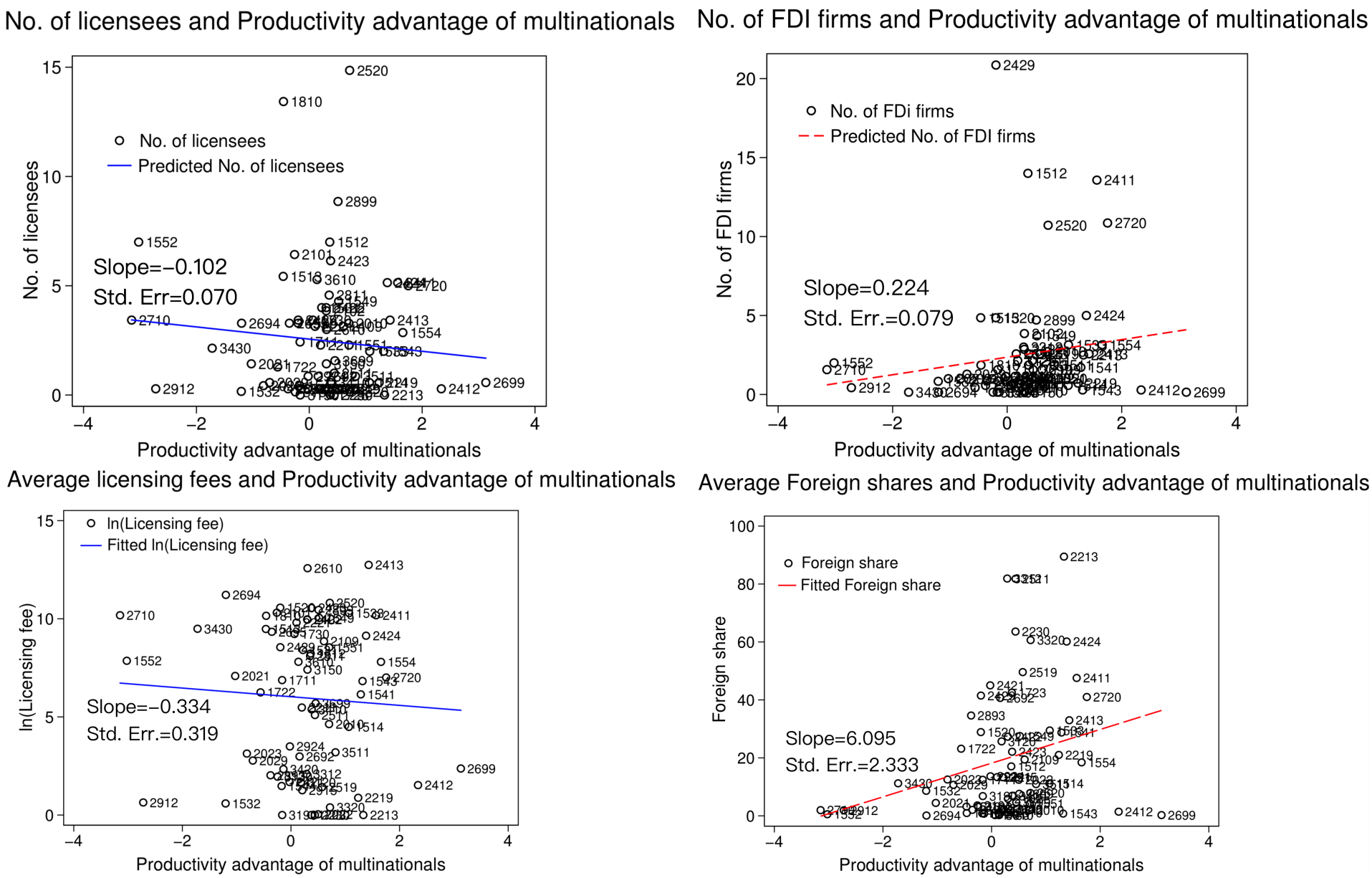

Figure 2: FDI firms and Domestic Licensees v.s. Productivity Advantage of Multinationals

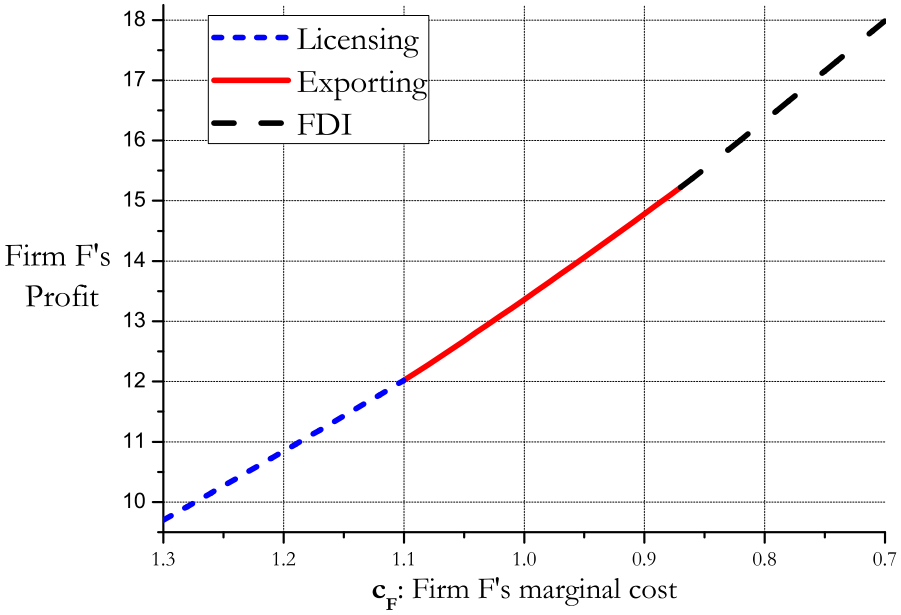

Figure 3: Exporting, Licensing and FDI choice

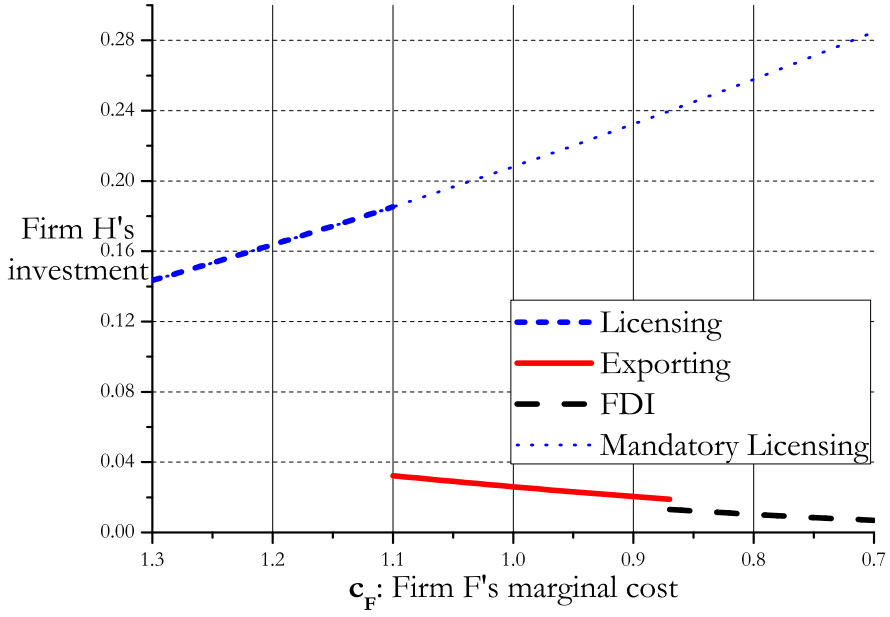

Figure 4: Cost-reducing investment of firm H

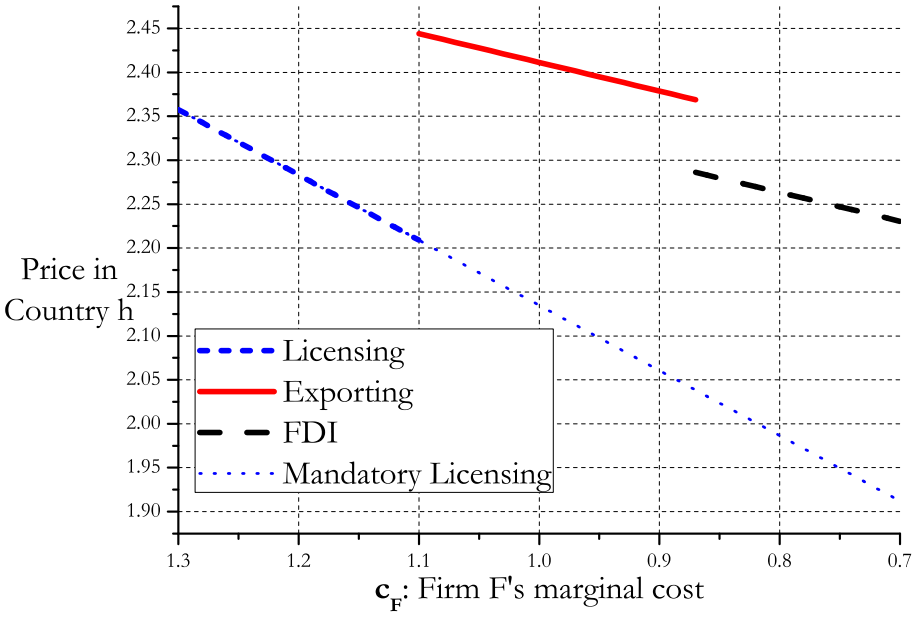

Figure 5: Market price in country h

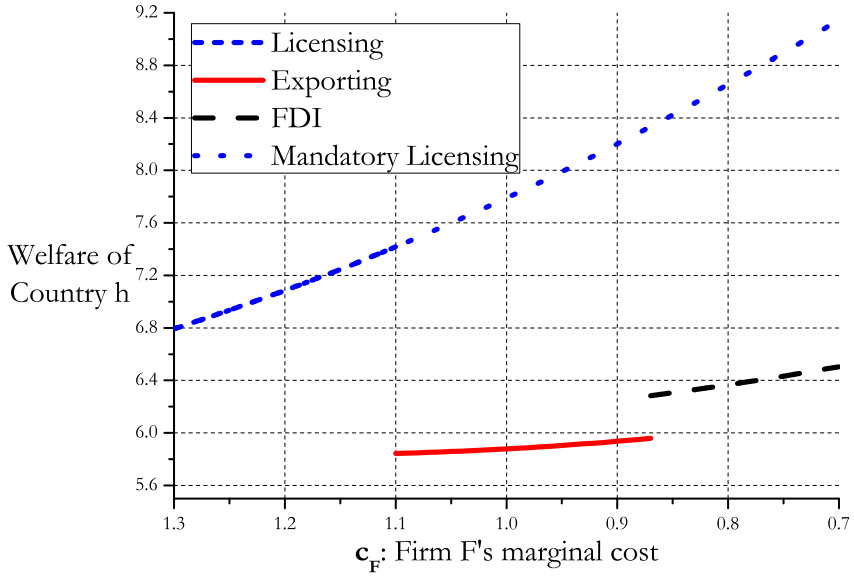

Figure 6: Welfare in country h

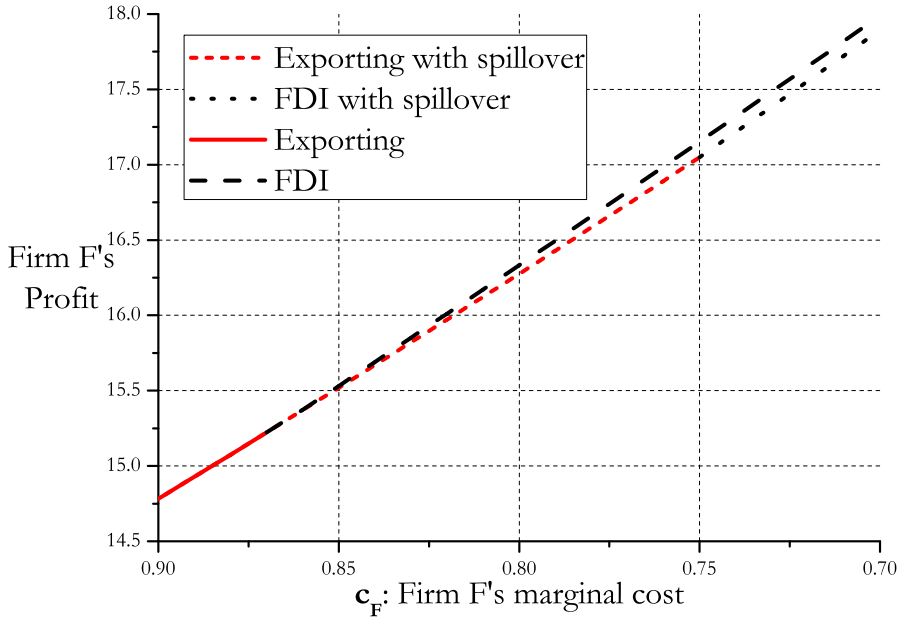

Figure 7: Exporting, Licensing and FDI choice (FDI technology spillover effect)

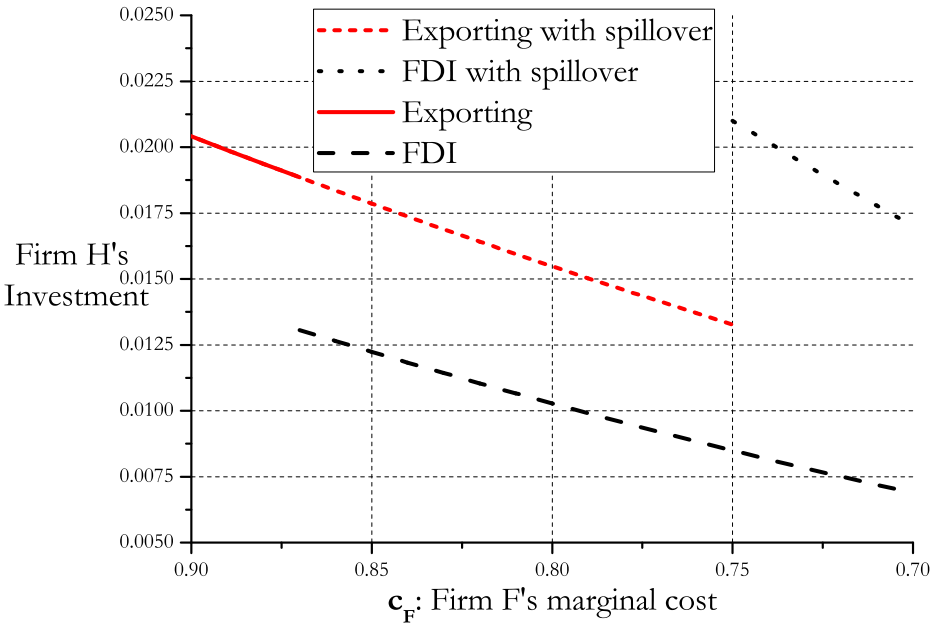

Figure 8: Cost-reducing investment of firm H (FDI technology spillover effect)

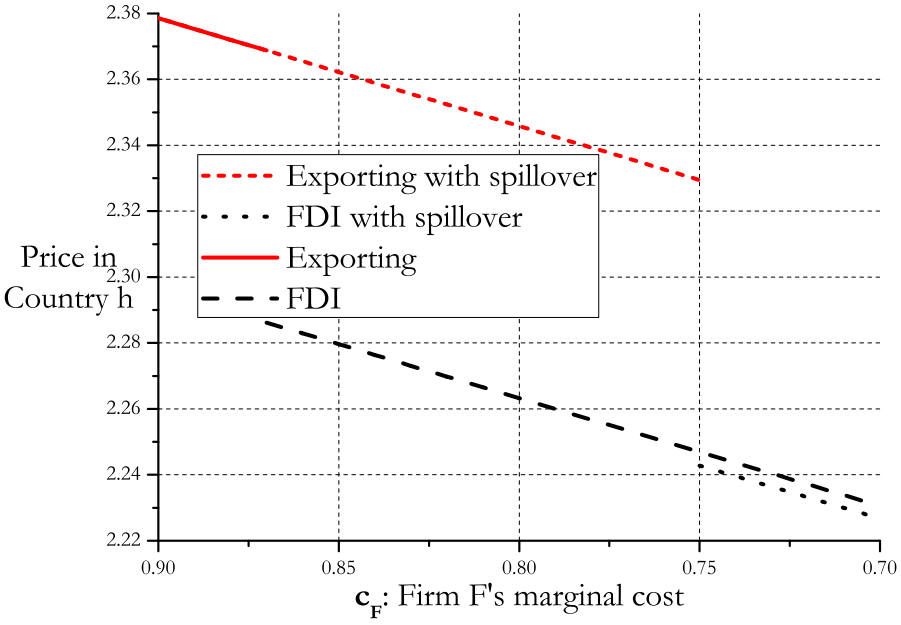

Figure 9: Market price in country h (FDI technology spillover effect)

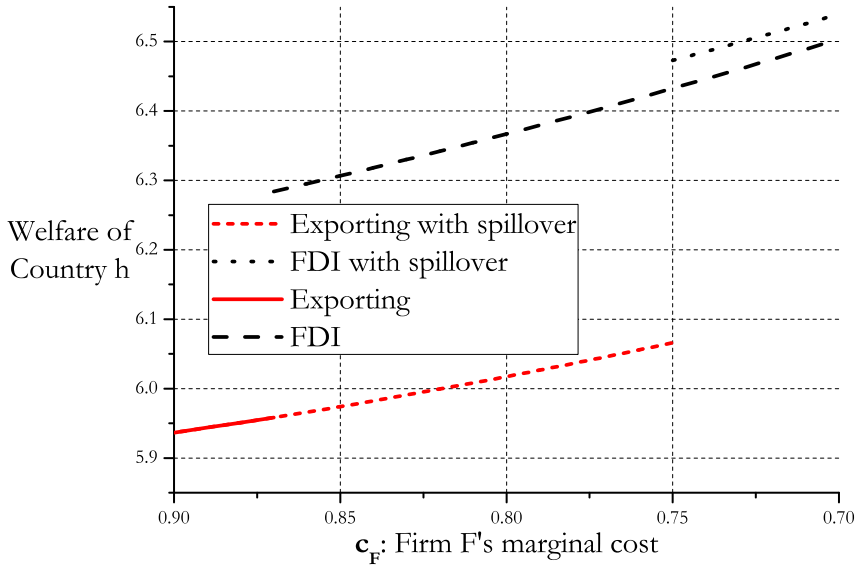

Figure 10: Welfare in country h (FDI technology spillover effect)

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Appendix

A Lemma 1

$$\frac{\partial I_H^E}{\partial c_F} = \frac{8\theta_H}{9\beta - 8\theta_H^2}\sqrt{I_H^E} > 0;\ \frac{\partial c_H^E}{\partial c_F} = \frac{\partial c_H^E}{\partial I_H^E}\frac{\partial I_H^E}{\partial c_F} < 0.$$
$$\frac{\partial I_H^M}{\partial c_F} = \frac{8\theta_H}{9\beta - 8\theta_H^2}\sqrt{I_H^M} > 0;\ \frac{\partial c_H^M}{\partial c_F} = \frac{\partial c_H^M}{\partial I_H^M}\frac{\partial I_H^M}{\partial c_F} < 0.$$
$$\frac{\partial I_H^O}{\partial c_F} = \frac{-8\theta_H(2\eta - 1)}{9\beta - 8\theta_H^2}\sqrt{I_H^M} < 0;\ \frac{\partial c_H^O}{\partial c_F} = \frac{\partial c_H^O}{\partial I_H^M}\frac{\partial I_H^O}{\partial c_F} > 0 \text{ as long as } \eta > 0.5.$$

B Lemma 2

$$\left.\begin{array}{l} t > 0.5t \Rightarrow I_H^M < I_H^E \\ \eta c_F < c_H^a \Rightarrow I_H^E < I_H^O \end{array}\right\} \Rightarrow I_H^M < I_H^E < I_H^O \Rightarrow c_H^M > c_H^E > c_H^O$$

C Parameter Restrictions

For c_F ($c_F >> c_H^a$)

Given α, β, t, c_H^a and θ_H, in the case of Licensing versus Exporting, $\bar{c}_F$ is implicitly defined by

$$\pi_F^E - \pi_F^{BO} - \left(\pi_H^{BO} - \pi_H^E\right) = \pi_F^E - \left(\pi_F^{BO} + L\right) = \pi_F^E - \pi_F^O = 0 \Rightarrow c_F = \bar{c}_F.$$

Given α, β, t, D, c_H^a and θ_H, in the case of Exporting versus FDI, $\underline{c}_F$ is implicitly defined by

$$\pi_F^M - \pi_F^E = 0 \Rightarrow c_F = \underline{c}_F.$$

In order to have all three modes are chosen for different values of c_F, we need to have

$$\underline{c}_F < \bar{c}_F.$$

D Proposition 1

1. Licensing V.S. Exporting

Step 1:

$$\frac{\partial \pi_F^E}{\partial \theta_F} < 0.$$

$$\frac{\partial \pi_F^E}{\partial c_F} = -\frac{2}{9\beta}\left(2 + \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\right)\left(2\alpha - 4c_F + 2c_H^a - t - 2\theta_H\sqrt{I_H^E}\right) < 0$$

Step 2:

$$\frac{\partial \pi_F^O}{\partial \theta_F} < 0.$$

$$\frac{\partial \pi_F^O}{\partial c_F} = -\frac{2}{9\beta}\left[2 - \eta + \frac{4\theta_H^2(2\eta - 1)}{9\beta - 8\theta_H^2}\right]\left(2\alpha - 4c_F + 2\eta c_F - t - 2\theta_H\sqrt{I_H^O}\right) < 0$$

Step 3:

$$\left|\frac{\partial \pi_F^E}{\partial c_F}\right| > \left|\frac{\partial \pi_F^O}{\partial c_F}\right|.$$

Since

$$2 + \frac{4\theta_H^2}{9\beta - 8\theta_H^2} > 2 - \eta + \frac{4\theta_H^2 (2\eta - 1)}{9\beta - 8\theta_H^2}, \text{ and } \sqrt{I_H^E} < \sqrt{I_H^O} \text{ according to Lemma 2,}$$

then

$$\left|\frac{\partial \pi_F^E}{\partial c_F}\right| > \left|\frac{\partial \pi_F^O}{\partial c_F}\right|.$$

Step 4: There exists an $L > 0$ so that $\pi_F^E > \pi_F^O$.

Compare Eq.(26) with Eq.(27).

Since $\eta c_F < c_H^a$, the profit of firm F under the exporting mode is more than the before licensing fee paid profit of firm F under the licensing mode, that is,

$$\pi_F^E > \pi_F^O - L.$$

And thus, there exists an $L > 0$ so that $\pi_F^E > \pi_F^O$.

According to Step 1 to 4, we can conclude that given c_H^a and θ_H, $\exists \bar{c}_F$, when $c_F \geq \bar{c}_F$, $\pi_F^O \geq \pi_F^E$; when $c_F < \bar{c}_F$, $\pi_F^E > \pi_F^O$.

Step 5: Solve $\bar{c}_F$
Given α, β, t, c_H^a and θ_H, in the case of Licensing versus Exporting,

$$y(c_F) = \pi_F^E + \pi_H^E - \pi_F^{BO} - \pi_H^{BO}$$
$$c_F = y^{-1}\left(\pi_F^E + \pi_H^E - \pi_F^{BO} - \pi_H^{BO}\right)$$
$$\bar{c}_F = y^{-1}(0)$$

2. Exporting V.S. FDI

Step 1:

$$\frac{\partial \pi_F^E}{\partial c_F} < 0.$$

$$\frac{\partial \pi_F^E}{\partial c_F} = -\frac{2}{9\beta}\left(2 + \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\right)\left(2\alpha - 4c_F + 2c_H^a - t - 2\theta_H\sqrt{I_H^E}\right) < 0$$

Step 2:

$$\frac{\partial \pi_F^M}{\partial c_F} < 0.$$

$$\frac{\partial \pi_F^M}{\partial c_F} = -\frac{2}{9\beta}\left(2 + \frac{4\theta_H^2}{9\beta - 8\theta_H^2}\right)\left(2\alpha - 4c_F + 2c_H^a + t - 2\theta_H\sqrt{I_H^M}\right) < 0$$

Step 3:

$$\left|\frac{\partial \pi_F^M}{\partial c_F}\right| > \left|\frac{\partial \pi_F^E}{\partial c_F}\right|.$$

Since

$$+t > -t, \text{ and } \sqrt{I_H^M} < \sqrt{I_H^E} \text{ according to Lemma 2,}$$

then

$$\left|\frac{\partial \pi_F^M}{\partial c_F}\right| > \left|\frac{\partial \pi_F^E}{\partial c_F}\right|.$$

Step 4: There exists a $D > 0$ so that $\pi_F^M > \pi_F^E$.

Compare Eq.(26) with Eq.(28).

Since $\alpha - 2c_H^a + c_F - t < \alpha - 2c_H^a + c_F - 0.5t$, the profit of firm F under the exporting mode is less than the total contribution margin (the profit before fixed FDI cost paid) of firm F under the FDI mode, that is,

$$\pi_F^E < \pi_F^M + D.$$

And thus, there exists a $D > 0$ so that $\pi_F^M > \pi_F^E$.

According to Step 1 to 4, we can conclude that given c_H^a and θ_H, $\exists \underline{c}_F$, when $c_F \geq \underline{c}_F$, $\pi_F^M \leq \pi_F^E$; when $c_F < \underline{c}_F$, $\pi_F^M > \pi_F^E$.

Step 5: Solve $\underline{c}_F$.

Given α, β, t, D, c_H^a and θ_H,

$$z\left(c_F\right) = \pi_F^M - \pi_F^E$$
$$c_F = z^{-1}\left(\pi_F^M - \pi_F^E\right)$$
$$\underline{c}_F = z^{-1}\left(0\right)$$

With **1** and **2**, as long as we have $\bar{c}_F = y^{-1}\left(0\right) < \underline{c}_F = z^{-1}\left(0\right)$, **Q.E.D.**

E Lemma 3

$$CS_h^E = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^E - t\right)^2$$
$$CS_h^O = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^O - t\right)^2$$
$$CS_h^M = \frac{1}{18\beta}\left(2\alpha - c_F - c_H^M\right)^2$$

We need to compare $c_H^E + t$, $c_H^O + t$ and c_H^M.

$$c_H^E + t = \frac{9\beta}{9\beta - 8\theta_H^2} c_H^a - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}(\alpha + c_F) + \frac{9\beta - 6\theta_H^2}{9\beta - 8\theta_H^2} t$$
$$c_H^O + t = \frac{9\beta}{9\beta - 8\theta_H^2} \eta c_F - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}(\alpha + c_F) + \frac{9\beta - 6\theta_H^2}{9\beta - 8\theta_H^2} t$$
$$c_H^M = \frac{9\beta}{9\beta - 8\theta_H^2} c_H^a - \frac{4\theta_H^2}{9\beta - 8\theta_H^2}(\alpha + c_F) + \frac{4\theta_H^2}{9\beta - 8\theta_H^2} t$$

$c_H^M < c_H^E + t$ if $9\beta - 10\theta_H^2 > 0$;

$c_H^O + t < c_H^M$ if $c_H^a - \eta c_F > \frac{9\beta - 10\theta_H^2}{9\beta} t$.

We can conclude that the $CS_h^E < CS_h^M < CS_h^O$.