Risk and the Technology Content of FDI: A Dynamic Model

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Abstract

This paper incorporates risk into the FDI decisions of firms. The risk of FDI failure increases with the gap between the South's technology frontier and the technology complexity of a firm's product. This leads to a double-crossing sorting pattern of FDI—firms of intermediate technology levels are more likely than others to undertake FDI. It is with the attempt to relax the upper bound of the technology content of FDI, we argue, that many FDI policies are created. The theory's predictions are consistent with the empirical patterns of FDI in China by US and Taiwanese manufacturing firms.

Key Words: Foreign Direct Investment; Technology; Risk; Spillover; Dynamic

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1. INTRODUCTION

Risk assessment plays an important role in practice when firms decide whether or not to undertake foreign direct investment (FDI). When firms contemplate FDI in a relatively backward Southern country, they face the risk of failure in product quality control. The higher the technology content of their production blueprints, the higher the risk. Such risk consideration may outweigh the conventional cost-saving consideration and eliminate all FDI incentives. Analyses on how risk affects firms' FDI decisions, however, are generally absent from modern FDI theories with firm heterogeneity. This paper aims to fill this gap.

We introduce the risk of quality control failure into the Melitz-model with firm heterogeneity. To formalize the risk associated with FDI, we extend the idea of the O-ring theory by Kremer (1993). In essence, production using a more complex technology requires a greater number of intermediate steps. The risk of quality control failure by producing in the South, as a result, increases with the complexity of a firm's production technology, but decreases with the South's technology capacity. Thus, although a firm with a more advanced technology has a larger market share and gains more from the cheap labor in the South compared with a lower-technology firm, such an advantage is weakened by the higher likelihood of FDI failure. This offsetting factor can be strong enough to completely wipe out a firm's incentive to invest in the South.

Our model predicts a double-crossing sorting pattern of FDI by firm technology levels (endogenously equivalent to firm productivity levels). Specifically, the incorporation of risk consideration implies an upper bound on the technology content of FDI, in addition to the lower cutoff predicted by the conventional model: only firms of intermediate technology levels find FDI profitable. The determination of the lower cutoff for FDI is largely based on the conventional tradeoff between fixed and variable costs, as firms in the lower range of the technology spectrum face minimal risks of quality control failure. The risk consideration, however, plays a critical role in the determination of the upper bound when the quality control failure becomes a binding concern.

This double-crossing property of our model helps rationalize the underlying goals of high-tech targeted FDI policies. In particular, the aforementioned upper bound confines the technology content of multinationals and casts a limit on the extent to which the South can catch up through inward FDI. It is with the attempt to relax these upper bounds (but not the lower bounds, as inadvertently follows from the conventional model), we argue, that many FDI policies and interventions are created. See, for example, the industrial parks for

IT in China[1] and for biotechnology in Singapore.[2]

This prediction of a double-crossing FDI sorting pattern is in spirit consistent with the literature investigating the origin of comparative advantage. See, for example, Costinot (2009), Jones (2008), Krishna and Levchenko (2009), Nunn (2007), and Berkowitz et al. (2006), among others. They show that the South, limited by its environment of inadequate institutions, insufficient human capital, or incomplete contract enforcement, has a comparative disadvantage in producing goods requiring the use of more complex technologies.

Built on the risk factor, we go one step further to formalize the development process of the South along the ladder of technology capacity. Specifically, the South improves its technology capacity as its exposure to multinational production activities increases. If the South's initial technology capacity exceeds a minimum threshold such that the risk factor is not prohibitive, the first wave of FDI inflows takes place. This first wave helps the South build up experiences of producing for multinationals and pushes forward the technology frontier in the South. As the frontier moves out, the probability of FDI success rises, which relaxes the risk constraint and triggers another wave of FDI led by technologically more advanced firms. Our model thus predicts a self-reinforcing agglomeration process,[3] along which the spectrum of technology contents of FDI expands over time.

This self-reinforcing process leads to two important policy implications. First, the positive externality generated by firms leading in FDI is not internalized by individual firms when making FDI decisions, which justifies the use of intervention policies; see, for example, similar arguments (for government interventions based on externalities) made by Hausmann and Rodrik (2003), Hausmann et al. (2007), and others surveyed in Pack and Saggi (2006). Second, the agglomeration process amplifies the effectiveness of FDI promoting policies. It implies a potential persistent impact of one-time industrial policies on development as their initial effects are reinforced through the endogenous dynamic process. Overlooking this self-reinforcing feature could lead to a biased cost and benefit assessment of FDI policies.

We show that the set of steady state(s) of the above dynamic process is a lattice. It implies that if there are multiple steady states, the momentum propelling the South's technology frontier stops at the least element of the lattice, and the South is trapped at a relatively low level of technology frontier. Thus, an active FDI policy by the South could actually pull the South out of the development trap toward one of the higher steady-state development levels.

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[1]http://www.globalmanufacture.net/home/IndustrialLocation/index.cfm

[2]http://www.edb.gov.sg/edb/sg/en_uk/index/industry_sectors/pharmaceuticals_/industry_background.html

[3]This self-reinforcing process is well documented by empirical studies. For example, Head et al. (1995) found that the location choice of FDI by Japanese firms in the U.S. is driven by the mass of existing Japanese firms in the same industry. Similarly, Cheng and Kwan (2000) found that FDI in China exhibits a strong self-reinforcing effect: existing FDI stock in a region tends to attract further FDI inflows.

We work out the effects of several important policies on the South's technology frontier at the steady state.

Our theory leads to two major predictions: 1) among the firms that exist in an industry in an advanced Northern country, it is the firms with intermediate productivity levels (or intermediate technology levels) that make an FDI entry in a relatively backward Southern country at any given point in time; 2) as the risk level decreases with a greater presence of multinationals in the South, the productivity spectrum of the intermediate firms that undertake FDI expands over time. We compile two data sets to verify our theoretical predictions. They consist of annual observations on the incidence of FDI entries into China by US manufacturing firms during 1980–2010, and quarterly observations of Taiwanese manufacturing firms' FDI entries into China during 1991Q1–2009Q4, respectively. We find that the empirical patterns of FDI entries into China made by the US and Taiwanese firms are consistent with the predictions of our model.

2. MODEL

2.1 Production Technology and Risk

Consider a world consisting of two countries, the North and the South, with the world population normalized to be one. Consumer preferences are identical in the two countries and imply an isoelastic demand for a variety (good) i of an industry j as:

$$x_j(i) = p_j(i)^{-\frac{1}{1-\alpha}}, \ 0 < \alpha < 1, \tag{1}$$

where $p_j(i)$ is the price of variety i of industry j, and $\frac{1}{1-\alpha}$ corresponds to the price elasticity of demand for each variety of an industry.[4] We will often drop the variety and the industry index below to simplify presentation.

The production function for each variety in each industry is modeled after the O-ring theory of Kremer (1993). In particular, the production of each variety requires a continuum of steps $s \in [0, \theta]$, where θ is the measure of intermediate steps to be performed. The magnitude of θ thus reflects the complexity of the production technology. It is assumed that the blueprints of all production technologies are developed in the North. Each firm in the North is associated with one type of production technology θ, which is distributed according

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[4]The demand function in (1) can be derived from a CES utility function, and the partial equilibrium framework presented below can be embedded in a general equilibrium framework to allow free entry without affecting the main predictions of the paper. The partial equilibrium framework is presented here for the sake of simplicity. The general equilibrium analysis can be obtained upon request from the authors.

to a cumulative distribution function $G(\theta)$ with $\theta \geq 1$.

For there to be valuable output and positive revenues, all steps must be performed successfully; otherwise, the final good is of no market value. That is,

$$x = \begin{cases} \left[\int_0^\theta \lambda(s)^\rho ds\right]^{\frac{1}{\rho}}, & \text{in case of success;} \\ \\ 0, & \text{in case of failure,} \end{cases} \qquad 0 < \rho < 1, \qquad (2)$$

where $\lambda(s)$ denotes the intensity of effort used to carry out step s, and $\frac{1}{1-\rho}$ corresponds to the elasticity of substitution between any two steps.

It is assumed that labor is the only factor of production and the wage rate in the North w^N is higher than in the South w^S.[5] One unit of labor is required for each unit intensity used to carry out a step regardless of the production location. Thus, conditional on the production location $l \in \{N, S\}$, a firm with a production technology θ chooses the intensity of each intermediate step to minimize its production cost, $\int_0^\theta w^l \lambda(s) ds$. The symmetry of the steps in their cost structure and in their contributions toward the final output implies that $\lambda(s) = \lambda = x\theta^{-1/\rho}$, $\forall s \in [0, \theta]$. Substituting $\lambda(s)$ into the cost function, one derives the minimized unit production cost as:

$$c^l(\theta) = w^l \theta^{\frac{\rho-1}{\rho}}, \qquad (3)$$

where $\frac{\partial c^l(\theta)}{\partial w^l} > 0$, and $\frac{\partial c^l(\theta)}{\partial \theta} < 0$. These properties imply that firms enjoy a greater cost advantage either by relocating their production to the South or when they possess a more sophisticated production technology.

Note that the unit cost is incurred regardless of the quality of the output. A firm only learns whether or not the output is marketable after production is completed. The probability $\gamma^l(\theta)$ of successfully completing all intermediate steps for technology θ in a given

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[5]Wage rates are taken to be given exogenously here, although they can be justified endogenously by introducing a freely traded numeraire good y_0, in which the North has an absolute advantage. Specifically, let the Northern (Southern) unit labor requirement in producing y_0 be $a^N(a^S)$, and $a^N < a^S$. Also assume that y_0 is produced in both countries. Then, the wages in the North and the South are "endogenously" pinned down at $w^N = \frac{1}{a^N}$ and $w^S = \frac{1}{a^S}$, respectively, with $w^N > w^S$. This modeling technique has been used by Antràs and Helpman (2004, p. 557) and Helpman et al. (2004, pp. 301 and 303, and footnote 11), and suggested by Melitz (2003, footnote 19).

production location l is assumed to take the following functional form:

$$\gamma^N(\theta) \triangleq 1, \qquad \forall\, \theta, \text{ where } 1 \leq \theta, \tag{4}$$

$$\gamma^S(\theta) = \begin{cases} 1, & \text{if } 1 \leq \theta \leq T^S, \\ \left(\frac{T^S}{\theta}\right)^z, & \text{if } T^S < \theta, \end{cases} \tag{5}$$

where T^S ($T^S \geq 1$) denotes the South's technology frontier, and z ($z \geq 0$) measures the degree of risk sensitivity. In (4), we assume that there is no risk of failure if production is undertaken in the North. On the other hand, in (5), by choosing to carry out the production in the South via FDI, firms bear a risk of quality control failure if the South's technology frontier is lower than the required production technology level ($T^S < \theta$). The larger the technology gap ($\frac{\theta}{T^S}$), the smaller the probability of successfully producing the good in the South.

The risk sensitivity z reflects the elasticity of the success probability to the technology gap. Given a technology gap ($\frac{T^S}{\theta} < 1$), the higher the risk sensitivity z, the lower the success probability of production. In particular, the success probability approaches zero as z tends to infinity, and one as z reduces to zero. The degrees of risk sensitivity may differ across industries. For example, an accidental power failure is likely to have a much smaller impact on the yields of a firm in the textile industry than in the wafer fabrication industry.[6]

In practice, anecdotal examples abound where a firm from the North with an advanced technology blueprint encounters risks of quality control failure when producing in the South. For example, *The Economist* (2004) reported that Kenwood of Japan shifted its production of mini-disc players from Malaysia back to Japan in 2002, and as a result, saw its product's defect rate fall by 80%.

Firms of all technology levels also incur a fixed setup cost (in Northern labor units) to start production. By assumption, the fixed setup cost is higher in the South than in the North, $f^N < f^S$. Suppose as well that firms are risk neutral. Then, given the production location $l \in \{N, S\}$, the optimal output level that maximizes a firm's expected profit,

$$\max_x \pi^l(\theta) = \gamma^l(\theta)x^\alpha - c^l(\theta)x - w^N f^l, \tag{6}$$

is $x^l(\theta) = \left(\frac{\alpha\gamma^l(\theta)}{c^l(\theta)}\right)^{\frac{1}{1-\alpha}}$. It has an intuitive interpretation: a firm's output level decreases in its unit cost of production and increases in its success rate of production. Substituting (3),

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[6]In a more general setting, we could allow z to be a function of θ or a random variable drawn jointly with θ. The qualitative results of the model will continue to hold so long as z is positively correlated with θ and takes on positive values.

(4), and (5) into $x^l(\theta)$, the optimal output level is:

$$x^N(\theta) = \Omega^N \theta^\nu, \qquad\qquad \forall\, \theta, \text{ where } 1 \le \theta, \tag{7}$$

$$x^S(\theta) = \begin{cases} \Omega^S \theta^\nu, & \text{if } 1 \le \theta \le T^S, \\ \Omega^S \left(\frac{T^S}{\theta}\right)^{\frac{z}{1-\alpha}} \theta^\nu, & \text{if } T^S < \theta, \end{cases} \tag{8}$$

where $\nu \equiv \left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{1-\alpha}\right) > 0$, and $\Omega^l \equiv \left(\frac{\alpha}{w^l}\right)^{\frac{1}{1-\alpha}}$ with $\Omega^N < \Omega^S$. In the scenario where there is no FDI risk (either due to $z = 0$ or $\theta \le T^S$), a firm with a more advanced blueprint will command a larger market share, and FDI always induces production expansion. With the possibility of FDI risk, however, firms will scale back their outputs from the risk-free scenario; this offsetting effect becomes larger, the more advanced a firm's production technology is. The resulting optimal expected profit is:

$$\pi^N(\theta) = \psi^N \theta^{\nu\alpha} - w^N f^N, \qquad\qquad \forall\, \theta, \text{ where } 1 \le \theta, \tag{9}$$

$$\pi^S(\theta; T^S, z) = \begin{cases} \psi^S \theta^{\nu\alpha} - w^N f^S, & \text{if } 1 \le \theta \le T^S, \\ \psi^S \left(\frac{T^S}{\theta}\right)^{\frac{z}{1-\alpha}} \theta^{\nu\alpha} - w^N f^S, & \text{if } T^S < \theta, \end{cases} \tag{10}$$

where $\psi^l \equiv (1-\alpha)\left(\Omega^l\right)^\alpha$ with $\psi^N < \psi^S$.

2.2   FDI Decision: To Stay or To Go?

A firm decides whether or not to undertake FDI by comparing $\pi^N(\theta)$ and $\pi^S(\theta; T^S, z)$. Such a comparison is shown in Figure 1. For illustrative purposes, we have converted the scale of production technology with $\tilde{\theta} = \theta^{\nu\alpha}$ and $\tilde{T}^S \equiv \left(T^S\right)^{\nu\alpha}$, and plotted the transformed profit functions $\tilde{\pi}^N(\tilde{\theta})$ and $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z)$. The mapping from θ to $\tilde{\theta}$ (or from T^S to $\tilde{T}^S$) is a one-to-one, monotonic transformation; thus, we will often discuss results in the original scale even as we refer to the figure. It is immediately clear that $\tilde{\pi}^N$ is a linear function and increases in $\tilde{\theta}$. By choosing to produce in the North, firms face no risk of failure, and their profit increases monotonically with the technology level. On the other hand, the shape of $\tilde{\pi}^S$ depends on z and T^S. Panels (a)-(d) in Figure 1 illustrate the potential sorting patterns under different combinations of risk sensitivity and technology frontier in the South.

In the standard FDI literature, the risk of FDI failure is often assumed away. Examples include Antràs and Helpman (2004) and Helpman et al. (2004). This corresponds to the special case with $z = 0$ in our model. As shown in Figure 1(a), the profit function of producing in the South $\tilde{\pi}^S$ is a linear schedule, which crosses $\tilde{\pi}^N$ once from below at $\tilde{\theta}_{NS}$.

We will refer to this scenario as the risk-free case.[7] It follows that firms are sorted according to their technology levels into firms of the lowest technology levels, with $\theta \in [1, \theta_N]$, who exit the market; firms of the lower technology levels, with $\theta \in [\theta_N, \theta_{NS}]$, who produce in the North; and firms of the highest technology levels, with $\theta \in [\theta_{NS}, \infty)$, who undertake FDI in the South.

This 'single-crossing' property in the risk-free case has some undesirable implications. First, it implies that firms of the highest technology levels are the ones to relocate production facilities to the South. Second, any policies by the South aimed to enhance FDI incentives only serve to attract firms of marginally lower technology levels than the existing inward FDI. Both predictions are contrary to what is observed in practice and what is aimed for by governments when providing FDI subsidies.

For example, *The Economist* (2004) reported that Canon of Japan, with a high-tech product line (ranging from precision photocopiers to optical components for digital cameras) was observed to maintain a majority of its worldwide production at home; similarly, at a time when other Japanese firms were shifting their manufacturing activities to China, Sharp chose to open its new "sixth-generation" plant (to make flat panels for televisions) in Japan in 2004.

Once FDI risk is incorporated into the standard model, richer implications are obtained. As suggested by (10), firms with a sufficiently low level of technology ($1 \leq \theta \leq T^S$) incur no FDI risk. These firms thus face the same tradeoff (between fixed and variable costs of FDI) as in the risk-free case. For firms with a relatively high level of production technology ($\theta > T^S$), the saving in unit cost by producing in the South is offset by the higher risk of quality control failure. The larger the technology gap is, the larger the offset relative to the risk-free scenario. Thus, the curve $\tilde{\pi}^S$ is linear and increasing in $\tilde{\theta}$ before $\tilde{T}^S$, coinciding with the risk-free case; it becomes a concave function after $\tilde{T}^S$. Hence, the expected profit from FDI will eventually be dominated by the profit of producing in the North for firms with sufficiently advanced technology. This implies an upper bound on the technology level of inward FDI.

As shown in Figure 1(b), for relatively low levels of technology capacity in the South and relatively mild levels of risk sensitivity, the curve $\tilde{\pi}^S$ crosses the curve $\tilde{\pi}^N$ twice, first from below at θ_0 and then from above at θ_1. Firms are sorted according to their technology levels into those of the lowest technology levels, with $\theta \in [1, \theta_N]$, who exit the market; those

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[7]To ensure that, in the risk-free case, some firms will still produce in the North, the literature typically assumes that $\theta_N < \theta_{NS}$, where $\theta_N \equiv \left(w^N f^N / \psi^N\right)^{\frac{1}{\nu\alpha}}$ corresponds to the technology level where a firm will break even by producing in the North; $\theta_{NS} \equiv \left(w^N (f^S - f^N)/(\psi^S - \psi^N)\right)^{\frac{1}{\nu\alpha}}$ corresponds to the technology level where a firm will be indifferent between producing in the North and in the South.

of relatively low and relatively high technology levels, with $\theta \in [\theta_N, \theta_0] \cup [\theta_1, \infty)$, who stay behind in the North; and those of the intermediate technology levels, with $\theta \in [\theta_0, \theta_1]$, who undertake FDI.

The intuition behind this double-crossing property is straightforward. For firms of relatively low technology levels, $\theta \in [\theta_N, \theta_0]$, they face relatively low (or zero) probability of FDI failure; however, their market share is so small that they do not gain enough in variable profits to pay off the higher fixed setup cost by shifting production to the South. On the other hand, for firms of relatively high technology levels, $\theta \in [\theta_1, \infty)$, they gain relatively more from the lower wage in the South; however, their production technology levels are so advanced above the South's technology frontier that the higher likelihoods of FDI failure more than offset the wage saving. Hence, it is the firms of intermediate technology levels that may find FDI profitable.[8]

Figure 1(c) shows the scenario when the curve $\tilde{\pi}^S$ lies everywhere below the curve $\tilde{\pi}^N$, and as a result, no firms find it profitable to relocate production to the South. This occurs when the technology capacity in the South is relatively low but the degree of risk sensitivity is relatively high. Finally, when the South's technology frontier is relatively high ($T^S > \theta_{NS}$) as indicated in Figure 1(d), a double-crossing sorting pattern emerges as in Figure 1(b), except that now the lower bound coincides with the cutoff level in the risk-free case (θ_{NS}).

The discussions above suggest an interplay between the South's technology frontier and the degree of risk sensitivity in determining the profitability of FDI. This is formalized in the following proposition:

Proposition 1 *(i) For relatively low levels of technology frontiers $T^S \in [1, \theta_{NS}]$ in the South, there exists a unique risk sensitivity ceiling $z^*(T^S)$, such that positive amounts of FDI take place if and only if $z < z^*(T^S)$; for relatively high levels of technology frontiers $T^S \in (\theta_{NS}, \infty)$ in the South, FDI occurs regardless of z. (ii) Alternatively, for any given degree of risk sensitivity z, there exists a unique threshold $T^{S*}(z)$ for the technology frontier in the South, such that $T^{S*}(z)$ weakly increases in z and that positive amounts of FDI take place if and only if $T^S > T^{S*}(z)$.*

Proof of Proposition 1. The proof is provided in the appendix. ∎

Proposition 1 is illustrated in Figure 2. The schedule $T^{S*}(z)$ partitions the (z, T^S) pa-

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[8]This finding that FDI occurs in the middle range of the productivity spectrum shares some similarity with the product-cycle trade theory of Vernon (1966), Glass and Saggi (1998), Feenstra and Rose (2000), Antràs (2005), and Lu (2007). In essence, they argue that products/industries requiring the use of more advanced or skill-intensive technologies are not necessarily more profitable to be produced in the South, and as a result, product-cycle trade only occurs when a good's production technology becomes standardized or in industries with intermediate technology intensity.

rameter space into two areas—the upper-left area that implies a positive measure of FDI, and the lower-right area that implies a zero measure of FDI. Intuitively speaking, the higher the risk sensitivity, the higher the required minimum level of T^S for a positive measure of FDI to occur. The mapping from z to $T^{S*}(z)$ outlined by the curve CC' corresponds to the condition for a tangency between the South and the North profit functions. Relative to the tangency condition, a higher T^S or a lower z will make FDI more profitable than producing in the North for a positive measure of firms. The corner solutions occur in the scenarios where z is very low and T^S is not binding ($T^{S*}(z) = 1$), or where z is very high ($z \geq \bar{z} \equiv (1 - \psi^N/\psi^S)\nu\alpha(1 - \alpha)$) and T^S has to meet the risk-free cutoff level θ_{NS} in order to ensure a positive measure of FDI.[9]

The implication that inward FDI in an industry will take place only if the South's technology frontier achieves a certain minimum threshold is consistent with the location choice of multinational firms documented by Kellenberg (2007), Fung et al. (2004), Globerman and Shapiro (2003), Wei (2000), and Cheng and Kwan (2000). Proposition 1 also implies a positive correlation between the risk sensitivity level and the required threshold of the South's technology frontier in order for FDI to take place. This implication fits well with the product-cycle (flying-geese) FDI pattern observed in empirical studies: for example, Feenstra and Rose (2000) document that more sophisticated industries often start production in the more advanced countries before moving to the less advanced countries; similarly, Makino et al. (2004) find that firms with a higher R&D intensity tend to choose the more developed countries as their FDI destination.

2.3 Extensive and Intensive Margins of FDI

In what follows, we focus on the cases where the technology capacity of the South meets the minimum threshold and FDI does take place. These are scenarios illustrated in Figures 1(b) and 1(d). Let $\Theta^S \equiv [\theta_0, \theta_1]$ denote the technology content of inward FDI. The upper and lower bounds of the technology content Θ^S can be defined formally as follows:

$$\pi^N(\theta_1) = \pi^S(\theta_1; T^S, z), \quad \text{with} \quad \pi_\theta^N(\theta_1) > \pi_\theta^S(\theta_1), \tag{11}$$

$$\pi^N(\theta_0) = \pi^S(\theta_0; T^S, z), \quad \text{with} \quad \pi_\theta^N(\theta_0) < \pi_\theta^S(\theta_0), \tag{12}$$

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[9]The details are shown in the appendix. In essence, $\bar{z}$ is the risk sensitivity level such that the South's profit function has the same slope as the North's profit function at $\theta = T^S$. Since the slope of the South's profit function decreases with θ for $\theta > T^S$, the South's profit function will have a gentler slope than the North's profit function for all $\theta > T^S$ with $z \geq \bar{z}$. Thus, in order for FDI to occur, T^S cannot be lower than θ_{NS}.

where $\pi_\theta^l \equiv \partial \pi^l / \partial \theta$ for $l \in \{N, S\}$, and the signs follow from the fact that the curve $\tilde{\pi}^S$ crosses the curve $\tilde{\pi}^N$ from below at θ_0 and from above at θ_1 as seen in Figures 1(b) and 1(d).

Lemma 2 *The upper bound θ_1 of the technology content Θ^S of inward FDI increases, while the lower bound θ_0 of the technology content Θ^S of inward FDI decreases weakly, with the South's technology frontier T^S:*

$$\frac{\partial \theta_1}{\partial T^S} = \left[\pi_\theta^N(\theta_1) - \pi_\theta^S(\theta_1)\right]^{-1} \pi_{T^S}^S(\theta_1) > 0, \tag{13}$$

$$\frac{\partial \theta_0}{\partial T^S} \begin{cases} = \left[\pi_\theta^N(\theta_0) - \pi_\theta^S(\theta_0)\right]^{-1} \pi_{T^S}^S(\theta_0) < 0 & \text{if } 1 \le T^S < \theta_{NS} \\ = 0, & \text{if } \theta_{NS} \le T^S \end{cases} \tag{14}$$

where $\pi_{T^S}^S \equiv \partial \pi^S / \partial T^S$.

Proof of Lemma 2. Note that $\pi_\theta^N(\theta_1) - \pi_\theta^S(\theta_1) > 0$, $\pi_\theta^N(\theta_0) - \pi_\theta^S(\theta_0) < 0$. Also note that $\pi_{T^S}^S > 0$ for $\theta > T^S$ and $\pi_{T^S}^S = 0$ for $\theta \le T^S$. The results therefore follow. ∎

Let $X^S \equiv \chi(\theta_0, \theta_1, T^S) = \int_{\theta_0}^{\theta_1} x^S(\theta) dG(\theta)$ denote the aggregate production of the multinationals in the South in a given industry. Assume a Pareto distribution with shape k for the cumulative distribution function $G(\theta)$ such that $G(\theta) = 1 - (1/\theta)^k$ for $\theta \ge 1$ with $k > \nu$.[10] Given (8), it follows that

$$\chi(\theta_0, \theta_1, T^S) = \begin{cases} \frac{\Omega^S k}{a} \left(T^S\right)^{\frac{z}{1-\alpha}} \left[(\theta_0)^{-a} - (\theta_1)^{-a}\right], & \text{if } 1 \le T^S < \theta_{NS}, \\[2mm] \frac{\Omega^S k}{(k-\nu)} \left[(\theta_0)^{-(k-\nu)} - \left(T^S\right)^{-(k-\nu)}\right] \\ \quad + \frac{\Omega^S k}{a} \left(T^S\right)^{\frac{z}{1-\alpha}} \left[\left(T^S\right)^{-a} - (\theta_1)^{-a}\right], & \text{if } \theta_{NS} \le T^S, \end{cases} \tag{15}$$

where $a \equiv \frac{z}{1-\alpha} + k - \nu > 0$ holds under the parameter restriction $k > \nu$, and hence the aggregate output in all scenarios is well defined.

Proposition 3 *The aggregate production X^S of the multinationals in a given industry increases with the South's technology frontier T^S:*

$$\frac{dX^S}{dT^S} = \left(\frac{\partial \chi}{\partial \theta_0}\frac{\partial \theta_0}{\partial T^S} + \frac{\partial \chi}{\partial \theta_1}\frac{\partial \theta_1}{\partial T^S} + \frac{\partial \chi}{\partial T^S}\right) \equiv \Lambda > 0. \tag{16}$$

Proof of Proposition 3. It is straightforward to verify that $\frac{\partial \chi}{\partial \theta_0} < 0$, $\frac{\partial \chi}{\partial \theta_1} > 0$, and $\frac{\partial \chi}{\partial T^S} > 0$. The result therefore follows by Lemma 2. ∎

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[10] The restriction on the shape parameter k ensures that the aggregate output of all firms is finite regardless of their production location even in the risk-free case.

Note that the aggregate production X^S of the multinationals increases with the South's technology frontier T^S at the rate Λ. This amount includes the increase in the production of the existing multinationals, $\frac{\partial \chi}{\partial T^S}$ (an intensive margin), because of the improved risk condition, as well as the increase in production due to new FDI entrants, $\frac{\partial \chi}{\partial \theta_0} \frac{\partial \theta_0}{\partial T^S} + \frac{\partial \chi}{\partial \theta_1} \frac{\partial \theta_1}{\partial T^S}$ (an extensive margin). Both margins work in the same direction to raise the aggregate output of the multinationals, with an improved technology capacity in the South.

2.4 Risk Evolution and the Dynamics of FDI

We next present a theory of how the technology frontier of the South may evolve endogenously, which determines the dynamic process of the risk condition in the South and thus the extensive and intensive margins of FDI. In particular, we focus on the effect of FDI inflows in propelling the development of the South, and model the process in the spirit of the learning function of Matsuyama (2002) in the following reduced form:[11]

$$T_t^S \equiv T_0^S + \Gamma(Q_t^S), \qquad t = 1, 2, \ldots \tag{17}$$

where T_t^S is the technology frontier of the South at time t, $Q_t^S \equiv \sum_{\tau=0}^{t} [1/(1+\delta_D)]^{t-\tau} X_\tau^S$ is the aggregate discounted production activities of the multinationals in the South at time t, and the function $\Gamma()$ is the mapping from Q_t^S to the improvement in the technology frontier with the properties that $\Gamma(0) = 0$, $\Gamma_Q \equiv d\Gamma/dQ^S > 0$, and $\lim_{Q^S \to \infty} \Gamma(Q^S) \to \infty$. The above specification indicates that Q_t^S constitutes the base of technology spillover and that the base depreciates at a rate $\delta_D > 0$. In other words, the South improves its technology frontier as its exposure to multinational production activities increases and the more recent production activities of the multinationals play a more important role.[12]

Given (17), we can derive the dynamics of FDI at the extensive and intensive margins. This is illustrated in Figure 3. Starting from period $t = 1$ with a zero amount of prior FDI, it follows that $Q_0^S = 0$. Suppose that the South's initial technology frontier is at $T_0^S \in [1, \theta_{NS}]$ and the risk sensitivity z is smaller than the ceiling $z^*(T_0^S)$. The first wave of FDI, $\Theta_1^S \equiv [\theta_{0,1}, \theta_{1,1}]$, takes place. The stock of multinational production activities starts to accumulate: $Q_1^S = X_1^S = \chi(\theta_{0,1}, \theta_{1,1}, T_0^S)$. Through the technology catch-up process (17), the South moves onto a higher level of technology frontier T_1^S. In period $t = 2$, as $T_1^S > T_0^S$,

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[11]Matsuyama (2002) aims to formalize the rise of mass consumption in a closed economy; he introduces the learning function to model the process of an industry to upgrade its productivity.

[12]Such FDI spillover effects may occur through several possible channels: i) through labor turnover by workers who have worked for multinationals, ii) through backward linkages that improve the quality of the upstream suppliers for multinationals, and iii) through the feedback of incumbent multinationals to the local industries/governments who respond by investing in the types of infrastructure and human capital sought by multinationals.

the risk condition in the South improves, and the expected profit of producing in the South strictly increases for all firms with $\theta > T_0^S$. This triggers a second wave of FDI entries made by a wider range of firms $(\Theta_2^S \supset \Theta_1^S)$, and the process repeats itself. At the same time, the aggregate production by the multinationals increases at both the extensive and intensive margins. In the case where the technology frontier is high to begin with such that $T_0^S > \theta_{NS}$, the dynamic process is similar except that the expansion of the extensive margins will take place only at the upper bound right from the beginning.[13]

The above process implies a two-way causality between FDI inflows and the South's technology capacity. The amount of FDI inflows and the South's technology capacity reinforce each other: FDI inflows improve the South's technology capacity through the spillover effect; the higher technology capacity of the South in turn attracts further FDI inflows due to an improved risk condition. There thus arises a self-reinforcing agglomeration process.

Note that at a steady state, $Q^S = \delta X^S$ where $\delta \equiv (1 + 1/\delta_D)$. Substitute δX^S for Q^S in (17) and the solutions implied by (11) and (12) into (15). The steady state of the dynamic system introduced above can be summarized by the following two simultaneous equations:

$$T^S = T_0^S + \Gamma\left(\delta X^S\right), \tag{18}$$

$$X^S = \chi(\theta_0(T^S), \theta_1(T^S), T^S). \tag{19}$$

This is illustrated in Figure 4(a), where the LL and PP schedules depict the relationships characterized by (18) and (19), respectively. Let $\underline{X}^S$ and $\bar{X}^S$ be the aggregate production levels of the multinationals at $T^S = T_0^S$ and at $T^S \to \infty$, respectively.[14] It is straightforward to see that the LL schedule as a function of X^S has the following properties: (i) it reaches the lower bound T_0^S if there were no FDI ($X^S = 0$); (ii) it increases in X^S at a rate $\delta\Gamma_Q$; and (iii) it reaches the upper bound $\bar{T}^S \equiv T_0^S + \Gamma(\delta\bar{X}^S)$ if all firms above the cutoff level θ_{NS} were to undertake FDI as in the risk-free case. On the other hand, the PP schedule as a function of T^S has the following characteristics: (i) it reaches the lower bound $\underline{X}^S > 0$ at $T^S = T_0^S$, (ii) it increases in T^S at a rate $\Lambda > 0$ (as shown in Proposition 3); and (iii) it approaches $\bar{X}^S$ as T^S tends to infinity. As the LL curve starts below the PP curve and ends up above it, the two curves must cross at least once, which guarantees the existence of

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[13]The positive spillover effect among multinationals implied by the above dynamic process are consistent with the research findings of some well-known empirical studies. For example, Javorcik (2004) presents robust evidence of positive FDI spillover through backward linkages, and the estimates in Aitken and Harrison (1999) suggest positive spillover effects among *foreign affiliates* in the same industry.

[14]Note that $\underline{X}^S \equiv \chi(\theta_0(T_0^S), \theta_1(T_0^S), T_0^S) > 0$ since by setup we are interested in the scenario where T_0^S meets the minimum threshold, so FDI (and its subsequent dynamic process) does take place. Next, note that $\bar{X}^S \equiv \frac{\Omega^S k}{(k-\nu)}(\theta_{NS})^{-(k-\nu)}$, which is the largest amount of production that can ever take place by multinationals, equivalent to that in the risk-free scenario.

a steady state.

As illustrated in Figure 4(a) by point I, the unique steady state is also stable. In general, there could be multiple steady states, as illustrated in Figure 4(b), and the set of steady states is a lattice. Note that starting with the initial technology frontier T_0^S, the aggregate production of the multinationals and the South's technology frontier grow (following the arrows) and converge to I, which is the least element of the lattice. Thus, the South is trapped into the lowest steady state with a relatively low level of inward FDI and technology frontier. This implies that in the presence of multiple steady states, a deliberate government intervention that shifts the LL or PP schedule could actually pull the South out of its development trap toward a higher steady state. In Chang and Lu (2011), we work out the effects of important parameters on the steady-state value of $(T^S, X^S, \theta_1, \theta_0)$. Here, we discuss their policy implications and refer the readers to the above working paper for formal propositions and proofs.

First, a policy directing resources in infrastructure investment to raise the initial technology frontier by the South (T_0^S) will help attract a larger initial mass of multinational production at both the extensive and intensive margins. The larger initial base of spillover will then generate a bigger step forward by the South on the technology frontier and a steeper decline in the perceived risk of FDI failure. Thus, the effect of the initial difference in the technology frontier is persistent and amplified by the self-reinforcing dynamics.[15] These policy implications can be illustrated by a rightward shift of the LL curve in Figure 4.

Second, a lower δ_D enlarges the base of technology spillover for any given amount of FDI inflows and thus has a positive long-run effect on the extent to which the South can catch up and the mass of multinational production. The policies that have an impact on this parameter in practice may correspond to education or training programs that improve the human capital of the work force. The comparative static effects can be illustrated by a clockwise rotation of the LL curve around the pivot $(T_0^S, 0)$ in Figure 4

Third, an FDI subsidy that lowers the marginal labor cost, w^S, or the fixed setup cost, f^S, in the South will lead to an increase in the aggregate production at the extensive margin by encouraging more FDI entrants. A reduction in w^S, in addition, will also stimulate production by all existing multinationals at the intensive margin. Similar to our earlier discussions, this initial increase in aggregate production will generate a magnified long-term effect fueled by the agglomeration process. Using Figure 4 as the status quo, the effects of a decrease in w^S or f^S could be illustrated by an upward shift of the PP curve.

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[15]This prediction of ours differs from Findlay (1978), who argues that a bigger development gap between the South and the North implies more unexploited opportunities and hence stimulates more FDI inflows; at the same time, the existing development gap is regarded as an indicator of growth *potential* and hence a bigger gap is translated into a faster speed of catch-up.

Last but not least, we find that the industry-specific risk sensitivity z has important effects on the South's industrial development. A lower z has very similar qualitative effects as a lower w^S and leads to an upward shift of the PP curve in Figure 4. An industry with a lower degree of risk sensitivity experiences a higher success rate of FDI and thus is able to attract more FDI inflows at both margins. This implies that the extent to which the South can catch up will vary across industries, and that an FDI-promoting policy uniformly applied to all industries may be inefficient as it would be too generous for industries with a low degree of risk sensitivity while possibly not sufficient for highly risk-sensitive industries. This provides justifications for industry-targeted FDI policies. Moreover, a technologically backward country may want to adopt industry-targeted FDI policies according to its development level, as aiming at high-tech industries may be too costly and unrealistic when its technology frontier lags far behind the North's.

3. EMPIRICAL EVIDENCE

Our theory leads to two major predictions: 1) among the firms that exist in an industry in an advanced Northern country, it is the firms with intermediate productivity levels (or intermediate technology levels) that make an FDI entry in a relatively backward Southern country at any given point in time; 2) as the risk level decreases with a greater presence of multinationals in the South, the productivity spectrum of the intermediate firms that undertake FDI expands over time. The first prediction follows from our static model and the second from our dynamic extension of the model.

In contrast, the conventional FDI models without risk predict that at any given point in time, the more productive firms are more likely to undertake FDI. If dynamics were built into these models and similar spillover effects were present, the conventional models would also imply an expanding productivity spectrum of FDI firms but only at the lower bound.

To examine the validity of these predictions, we collect firm-level data on FDI in China from two source countries, the US and Taiwan. For each source country, we collet a panel of individual firms' FDI entry decisions and their productivity measures. Specifically, the first data set consists of annual observations on US manufacturing firms' FDI entries into China during 1980–2010. The beginning time period is chosen based on the fact that China opened its doors to FDI in 1979. The information on FDI entries into China by US firms is compiled from the *China Business Review* (CBR), a bi-monthly trade journal published by the US-China Business Council that archives foreign business activities in China. The financial data of firms including assets and gross profits are retrieved from the Compustat database. More details of the US data set are explained in the appendix.

We use the annual return on assets (ROA) as a proxy for a firm's productivity level. The annual ROA is defined here as the ratio of annual gross profits to total assets at the end of the period. The accounting definition of gross profits corresponds closely to the definition of variable profits in our model. In our theory, a firm's variable profit is positively correlated with its productivity (technology) level θ. In the model, each firm incurs the same level of fixed costs; in practice, this is not the case. Thus, we normalize the empirical measure of gross profits by total assets to remove possible scale effects. To minimize the possibility of reverse causality, the lagged annual ROA (from the one-year period before the time when the FDI decision is made) is used as a measure of a firm's productivity level prior to FDI entry decisions.

The second data set we compile consists of quarterly observations on Taiwanese manufacturing firms' FDI entries into China during 1991Q1–2009Q4. Following the civil wars in the 1940s, Taiwan and mainland China remained in a hostile relationship. It was only in 1991 that the Taiwanese government lifted its historical ban on westward FDI into mainland China. This policy change serves as a natural experiment and starting point for examining Taiwanese firms' FDI entry decisions. The sample includes all Taiwanese manufacturing firms that are listed on the Taiwan Stock Exchange (TSE) or the over-the-counter (OTC) market. The information on FDI entries is compiled from the *Directory of Companies Investing in China* published by the Investment Commission, Taiwan Ministry of Economic Affairs (MOEA). The financial information of firms is retrieved from the Taiwan Economic Journal (TEJ) database. More details on the Taiwanese data set are provided in the appendix.

Similarly, we use the lagged annual ROA (spanning four quarters) as the proxy for a firm's productivity level prior to FDI entry decisions. For example, if the current quarter of FDI entry decision is 2001Q3, then the lagged annual ROA is calculated from the total gross profits of the previous four quarters—2000Q3, 2000Q4, 2001Q1, and 2001Q2—divided by the stock of total assets at the end of 2001Q2. We opt to use the annual ROA, instead of the quarterly ROA, even in the case of quarterly observations, because of the concern that the quarterly ROA may be heavily influenced by seasonality in sales and hence a noisy measure of firm productivity.

In addition to providing extra empirical verification, the case of Taiwan presents a potentially interesting contrast with the US as a source of FDI. First, Taiwan is in many respects 'closer' to mainland China—in terms of geographical distance, language similarity, cultural background, and ethnic groups. In our theory, such a closer economic and social distance may imply an overall lower level of perceived FDI risk by firms in the static model (reflecting, e.g., a lower level of z) and a greater speed of spillover in the dynamic model (reflecting, e.g., a higher level of δ). Second, by 1991 when the Taiwanese firms were allowed to go west, it

is likely that the overall technology frontier in mainland China had improved relative to its original state in 1980. These two factors suggest that relative to the US, a greater proportion of firms from Taiwan are likely to undertake FDI in the initial periods when FDI becomes possible; and firms that eventually have made FDI entries are likely to be the majority rather than the exception in Taiwan (as compared to the US). As we will see, these contrasts are observed in the two data sets.

We focus on the manufacturing industries here, because a disproportionate number of FDI entries into China are made by firms from these sectors (810 out of 1,198 FDI entries with NAICS information in the US data set; 2,769 out of 3,116 FDI entries in the Taiwanese data set). The manufacturing sectors also fit more closely with our model in terms of the production process or the incentives for undertaking FDI than the other industries (such as construction and finance).

The association between FDI propensity and firm productivity for US firms is shown in Figure 5 for each year during 1981-2010. A salient pattern is evident from the diagram: FDI entries are made by firms of intermediate productivity levels (and not by the most or least productive firms). This is consistent with our static model's prediction. Figure 6 presents the case of Taiwan. Note that observations are quarterly, but they are grouped together by years in the diagrams due to space constraint.[16] Again, the association between FDI propensity and firm productivity has the same pattern as seen in the case of the US: firms making the FDI entries at each point in time tend to be of intermediate productivity levels. This presents further evidence in support of our static model's prediction.

Comparing Figures 5 and 6, it is clear that FDI entries into China are rare among US firms. In detail, there are a total of 7,867 firms/96,400 observations in the US sample, among which there are 352 firms/810 observations with FDI entries (that amounts to 4.5% of all firms and 0.8% of all annual observations). Most (7,515) of the US firms do not make any FDI entry into China. In contrast, by the end of 2009, most Taiwanese firms have made FDI entries into China. Of the 1,097 firms/42,357 observations in the sample, 854 firms/2,769 observations have FDI entries (that is 77.8% of all firms and 6.5% of all quarterly observations). Given the detailed counts of observations and FDI entries in the footnotes to Figures 5 and 6, we can also verify that the likelihood of FDI entries into China is much higher by Taiwanese than US firms right from the initial periods (say, 1982 for the US and 1992 for Taiwan), and throughout the years. The higher likelihood is reflected in a wider productivity spectrum of Taiwanese firms making FDI entries (relative to the population productivity distribution). Bearing in mind the fact that the US-China wage gap

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[16]The findings based on quarterly diagrams are similar and can be verified by referring to Chang and Lu (2011).

is much bigger than that between Taiwan and China, the above observations confirm our earlier conjecture that risk is likely an important and dominant predictor of the difference in FDI propensity between the two sources of direct investment in China.[17,18]

Turning to the dynamic prediction of our theory, in Figure 6, we notice a visible widening of the productivity spectrum of Taiwanese firms making FDI entries over time at both the lower and upper bounds. This provides suggestive evidence for our dynamic prediction. In comparison, in Figure 5, the dynamic FDI effect seemed to have taken off at a relatively slow pace among US firms from the 1980s to the 1990s, and then showed a cutback in the 2000s. The relatively mild FDI spillover effect in the case of the US might be rationalized by the greater distance between the US and China (in terms of culture, language, and geography) as conjectured earlier. On the other hand, the setback in the expansion of the FDI extensive margin among US firms in the recent decade might be due to the two major recessions in the US in the early and the late 2000s.

The discussions above suggest that in a formal analysis of the dynamic agglomeration effect, one would need to take into account time-specific effects by possibly incorporating time dummies. Perceivably, this will make it difficult to distinguish our dynamic predictions from time trends: even if there were a genuine spillover effect that increases the likelihood of FDI for all firms over time, the time dummies could pick up most of the time trends, making it difficult to discern the true FDI dynamic effect from time trends driven by other factors. Thus, one might need a better measure of time-specific shocks to FDI incentives (such as policy or macroeconomic conditions) than the blanket sweeping time dummies. On the other hand, more accurate measures of the base of FDI spillover need to be discovered and relied upon in place of a time trend. For example, this could be cumulative past FDI stock in a specific industry, across industries, or across sources of investment. Due to the difficulties discussed above, the empirical support for our dynamic predictions is suggestive but inconclusive. Further research with better data might provide a more definite answer.

As a robustness check, we also break down the data by sectors.[19] This may help to deal with possible industry-specific effects in two respects. First, the distribution of firm productivity across industries may be systematically different, so that the ROA of firms from one sector (say food manufacturing) may not be comparable with that from another sector (say electronics manufacturing). Second, FDI propensity may differ across industries

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[17]The total sample size reported in Figure 5 or 6 is smaller than suggested by the numbers above, as some observations have missing ROA information.

[18]We set the frequency of study at one year for the US data and one quarter for the Taiwanese data because of the much lower propensity of FDI entries into China by US firms. There are very few observations with FDI entries (relative to the large number of firms) in any given quarter in the US data set.

[19]The list of sectors and the number of firms in each sector are given in the appendix.

in a systematic manner. For example, in some sector, the degree of risk sensitivity, z, or the fixed setup cost of FDI, f^S, may be inherently higher than others, which will discourage FDI by firms from the sector in general.

The caveat of looking at the FDI pattern by sectors is that: a lot of industries have very few FDI entry observations in the US data (15 out of 22 industries have less than 20 FDI entries in three decades); alternatively, some industries have very few firms in the Taiwanese data (four out of 13 industries have less than 10 firms). By focusing on the industries with larger numbers of FDI entries in the US data or the larger industries in the Taiwanese data, the finding in general continues to support our prediction based on the static model. The predicted pattern is in particular pronounced in the largest sector of both data sets—the computer and electronic product manufacturing sector in the US (with 2,213 firms and 199 FDI entries across years), and the electronics industry in Taiwan (with 752 firms and 1,868 FDI entries across quarters). Their diagrams can be found in the working paper, Chang and Lu (2011).

Overall, the empirical FDI patterns we observed in the US and Taiwanese data sets are supportive of our theory's prediction that firms with intermediate productivity levels are more likely than others to engage in FDI. In particular, the US and Taiwanese data showcase the highly and the intermediate risk-sensitive scenario, respectively. The evidence for our dynamic prediction is indicative but inconclusive; we leave its formal analysis for future research.

4.   CONCLUSION

This paper contributes to the FDI literature by modeling the effect of risk on the FDI decisions of firms. Contrary to conventional views, our model predicts an upper bound on the technology content of FDI. The presence of this upper bound highlights the rationale of many FDI-promoting policies used by the South—to attract firms of advanced production technologies constrained by the risk consideration. The effect of any one-time FDI policy is further reinforced through the agglomeration dynamics of FDI. The paper's critical prediction (of a double-crossing sorting pattern of FDI by firm productivity levels) is supported by US and Taiwanese firm-level data on FDI entries into China.

Admittedly, the model presented in the paper bears certain limitations. For example, for simplicity, we adopt a reduced-form formulation of the spillover effect, and for tractability, a stylized functional form of FDI risk. In future work, the ability to characterize the mechanisms of spillover effects will rely to a large extent on the advancement of empirical work in this area. On the other hand, our theory can be extended in several possible dimensions

to address other interesting issues. First, one could allow the degree of risk sensitivity to depend not only on industry characteristics but also to evolve over time. In particular, in line with the product-cycle theory, the degree of risk sensitivity is likely to decrease as the product matures. Provided that firms could have multiple product lines, such extension could help us to learn more about the endogenous length of product cycles and the optimal product scope of firms. Second, one could allow for firms to have multiple production stages in multiple countries and ask how the level of transaction cost affects the pattern of fragmentation. Third, one could allow for firms to modify the blueprint (in particular to water down the complexity of their production technology) to meet the technology frontier of the South and analyze the impact of this option on the industry aggregate productivity.

5. APPENDIX

Proof of Proposition 1. We first show the existence and uniqueness of $z^*(T^S)$ for given $T^S \in [1, \theta_{NS})$. The proof is equivalent to showing that there exists a unique z^* such that $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z)$ is tangent to $\tilde{\pi}^N(\tilde{\theta})$. Let $\tilde{\theta}^\dagger$ define the technology level where the two profit functions have the same slope. It follows that

$$\tilde{\theta}^\dagger(\tilde{T}^S, z) = \left[\left(1 - \frac{z}{\nu\alpha(1-\alpha)} \right) \frac{\psi^S}{\psi^N} \right]^{\frac{\nu\alpha(1-\alpha)}{z}} \tilde{T}^S. \tag{20}$$

Note that $\tilde{\theta}^\dagger$ exists (which implies $\tilde{\theta}^\dagger > \tilde{T}^S$) and is bounded if and only if $0 < z < \bar{z}$, where $\bar{z} \equiv \left(1 - \frac{\psi^N}{\psi^S} \right) \nu\alpha(1-\alpha)$. Let $\phi(\tilde{T}^S, z)$ denote the distance between $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z)$ and $\tilde{\pi}^N(\tilde{\theta})$ at the technology level $\tilde{\theta}^\dagger$; we have:

$$\phi(\tilde{T}^S, z) = \psi^N \tilde{\theta}^\dagger(\tilde{T}^S, z)/g(z) - w^N(f^S - f^N), \tag{21}$$

where $g(z) \equiv \frac{\nu\alpha(1-\alpha)}{z} - 1$. Note that for $\tilde{T}^S \in [1, \tilde{\theta}_{NS})$ and $z \in (0, \bar{z})$,

$$\frac{\partial\phi(\tilde{T}^S, z)}{\partial z} < 0, \ \lim_{z \to 0} \phi(\tilde{T}^S, z) \to \infty, \ \lim_{z \to \bar{z}} \phi(\tilde{T}^S, z) = \tilde{T}^S \left(\psi^S - \psi^N \right) - w^N(f^S - f^N) < 0, \tag{22}$$

where the first limit follows by applying L'Hospital's Rule to $\tilde{\theta}^\dagger$ and $g(z)$, and the sign of the second limit follows by the fact that $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z)$ is strictly dominated by $\tilde{\pi}^N(\tilde{\theta})$ at $\tilde{\theta} = \tilde{T}^S < \tilde{\theta}_{NS}$. Thus, by the fixed point theorem, there exists a unique $z^* \in (0, \bar{z})$, such that

$$\phi(\tilde{T}^S, z^*) = 0 \tag{23}$$

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and $\tilde{\pi}^S$ is tangent to $\tilde{\pi}^N$. For $z < z^*$, it follows from (22) that $\phi(\tilde{T}^S, z) > 0$, and as a result, a positive measure of FDI takes place.

For $T^S = \theta_{NS}$, the South profit function will lie everywhere below the North profit function with overlapping only at θ_{NS} when $z \geq \bar{z}$. In other words, if and only if $z < \bar{z}$, will the South profit function rise above the North profit function to the right of $T^S = \theta_{NS}$ so that a positive measure of firms undertake FDI. Thus, $z^*(\theta_{NS}) = \bar{z}$. For $T^S \in (\theta_{NS}, \infty)$, the South profit function lies strictly above the North profit function at least for $\theta \in (\theta_{NS}, T^S + \epsilon]$, where $\epsilon > 0$, so FDI occurs regardless of z.

We next show the existence and uniqueness of $T^{S*}(z)$ for all z. From the above, we know that $z^*(1)$ is the cap of the risk sensitivity when the South's technology frontier is at the lowest level ($T^S = 1$). For z below the cap $z^*(1)$, FDI takes place necessarily, which is equivalent to saying that $T^{S*}(z) = 1$ for $z \in [0, z^*(1)]$. For sufficiently large degrees of risk sensitivity such that $z \geq \bar{z}$, the South profit function is flatter than the North profit function for all $\theta > T^S$; thus, FDI will take place if and only if the technology frontier exceeds the risk-free cutoff level θ_{NS}, so $T^{S*}(z) = \theta_{NS}$ for $z \geq \bar{z}$.

For $z \in (z^*(1), \bar{z})$, to show the existence of a unique $T^{S*}(z)$ is equivalent to showing the existence of a unique technology frontier level $T^{S*} \in (1, \theta_{NS})$ such that $\tilde{\pi}^S$ is tangent to $\tilde{\pi}^N$, or equivalently,

$$\phi(\tilde{T}^{S*}, z) = 0. \tag{24}$$

One can verify that for $\tilde{T}^S \in (1, \tilde{\theta}_{NS})$ and $z \in (z^*(1), \bar{z})$,

$$\frac{\partial \phi(\tilde{T}^S, z)}{\partial \tilde{T}^S} > 0, \quad \lim_{\tilde{T}^S \to 1} \phi(\tilde{T}^S, z) < 0, \quad \lim_{\tilde{T}^S \to \tilde{\theta}_{NS}} \phi(\tilde{T}^S, z) > 0. \tag{25}$$

The sign of the first limit is implied by the fact that $\phi(1, z^*(1)) = 0$ and $\frac{\partial \phi(1, z)}{\partial z} < 0$. To obtain the sign of the second limit, note that $\phi(\tilde{T}^S, z)$ is the unique maximum of $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z) - \tilde{\pi}^N(\tilde{\theta})$. Because $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z) - \tilde{\pi}^N(\tilde{\theta}) = 0$ holds at $\tilde{\theta} = \tilde{T}^S = \tilde{\theta}_{NS}$ and that $\tilde{\theta}^\dagger > \tilde{T}^S$, the sign of the second limit follows. Thus, by the fixed point theorem, there exists a unique $\tilde{T}^{S*} \in (1, \tilde{\theta}_{NS})$ for $z \in (z^*(1), \bar{z})$, such that (24) is satisfied.

To show the relationship between T^{S*} and z, take the total differentiation of (24) to obtain:

$$\frac{d\tilde{T}^{S*}}{dz} = \left. -\frac{\frac{\partial \phi(\tilde{T}^S, z)}{\partial z}}{\frac{\partial \phi(\tilde{T}^S, z)}{\partial \tilde{T}^S}} \right|_{\tilde{T}^S = \tilde{T}^{S*}} > 0.$$

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It follows that $dT^{S*}/dz = \left(d\tilde{T}^{S*}/dz\right)\left(dT^{S*}/d\tilde{T}^{S*}\right) > 0$ for $z \in (z^*(1), \bar{z})$. It is obvious that $dT^{S*}/dz = 0$ for $z \in [0, z^*(1)]$ and for $z \geq \bar{z}$. ∎

Data Appendix: The US data set

The firm financial data are extracted from the "Compustat North America Fundamental Annual dataset". The range of data retrieved is from fiscal year 1980 to 2010, using the "search the entire database" option. An observation records a company's identification number, name (*conm*), North American Industry Classification (NAICS) code, fiscal year of the data, and financial information. Not all firms appear in all years, and even if they appear, some financial information can be missing. This search results in 26,557 firms/287,183 observations.

FDI entries into China by US firms during 1980–2010 are compiled from *China Business Review* (CBR), a bi-monthly trade journal published by the US-China Business Council that archives foreign business activities in China. There is a lag of about two months between the date of transactions and publishing (e.g., transactions in January are typically only reported in the Mar/Apr or later issue). In the 1980 issues, there was no section on FDI. From Jan/Feb 1981 to May/Jun 1987, FDI transactions are located under the "Joint Ventures/Direct Investments" heading. From Jul/Aug 1987 onwards, FDI transactions are located under the heading "Investments in China". Each entry in the journal includes a brief description of the transaction made, the parties involved, and the year and month of the transaction. We regard entries which describe "contracts signed", "facilities/factory built", "joint venture established" as an official FDI entry, and disregard entries that report negotiations in progress. For each observation, we record the name of the US firm (*firmname*), and the year and month of the FDI transaction, among other information. This results in an effective sample of 1,506 firms/2,560 observations, which indicates that some firms make multiple FDI entries over the years.

We then merge the two subsets of data by matching the company names. A firm from the CBR data set finds a matching firm from the Compustat data set if: 1) *firmname* = *conm*, or *firmname* is very similar to *conm* and there is no evidence to suggest that *firmname* is a separate entity; 2) *firmname* has undergone a name change (not due to a merger or acquisition) with its current name = *conm*, or *firmname* is an international brand name of *conm* outside the US; 3) *firmname* is a (local, regional, or international) subsidiary or business unit/division of *conm*; 4) *firmname* has undergone a merger/acquisition with the new entity known as *conm*. This matching process requires extensive search on the internet for company histories and organizational structures. Following this, 1,708 (out of 2,560) observations from CBR find a matching firm from Compustat, and most of them (1,502) fall

into the first and second categories of exact match. The remaining observations from CBR without a match from Compustat are dropped from the study, as their financial information is not available.

The merged data set consists of 26,209 firms/280,742 observations, among which there are 662 firms/1,348 observations with FDI entries. In manufacturing sectors alone, there are 7,867 firms/96,400 observations, among which there are 352 firms/810 observations with FDI entries. In the numbers reported above, we have dropped observations that correspond to subsequent FDI entries by the same firm in the same year, since in any case, these multiple FDI entries are associated with the same lagged annual ROA. We have also dropped the observations on FDI entries in 1980, as they do not have the corresponding entry on the lagged annual ROA. In any case, there is no FDI entry into China in 1980 by US manufacturing firms (and only one by US non-manufacturing firms).

We define sectors at the 3-digit NAICS level for the US data set. The list of manufacturing sectors (and the number of firms in each sector) are: 311–food manufacturing (314); 312–beverage and tobacco product manufacturing (128); 313–textile mills (79); 314–textile product mills (28); 315–apparel manufacturing (193); 316–leather and allied product manufacturing (59); 321–wood product manufacturing (84); 322–paper manufacturing (159); 323–printing and related support activities (106); 324–petroleum and coal products manufacturing (117); 325–chemical manufacturing (1,458); 326–plastics and rubber products manufacturing (220); 327–nonmetallic mineral product manufacturing (131); 331–primary metal manufacturing (223); 332–fabricated metal product manufacturing (276); 333–machinery manufacturing (713); 334–computer and electronic product manufacturing (2,213); 335–electrical equipment, appliance, and component manufacturing (296); 336–transportation equipment manufacturing (381); 337–furniture and related product manufacturing (94); 339–miscellaneous manufacturing (593); and 33–that cannot be classified into sub-sectors (2).

Data Appendix: The Taiwanese data set

The data on FDI entries into China by Taiwanese firms are based on a Chinese publication, the *Directory of Companies Investing in China*, published by the Investment Commission, Taiwan Ministry of Economic Affairs (MOEA).[20] The publication chronicles the date (e.g., 1991/7/16) when a TSE or OTC firm received approval from the MOEA for their outward FDI in China. For each FDI entry approved, the publication also provides details on the investment and company details. The data are available since 1991, until the end of January 2010 in the version of the file we downloaded. Thus, we set the study period to 1991Q1–2009Q4.

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[20]http://www.moeaic.gov.tw/system_external/ctlr?PRO=PublicationLoad&id=43

The firm financial data are retrieved from the "Taiwan Economic Journal (TEJ) Data Bank", combining the results from the "Company Basic Information" and the "Finance" data bank. In particular, the sample of study includes all Taiwanese firms listed on the TSE or the OTC market. Their unconsolidated (i.e., parent firm only) financial data are used, which are available at a quarterly basis from 1986Q1. An observation records a company's TSE identification number, ban code (Taiwanese company tax ID), name, TEJ industry classification, year and quarter of the data, financial information, and other company details.

We then merge the financial and FDI data at a quarterly basis by the company's ban code, which is available in both subsets of data and is a unique identifier of a Taiwanese company. This merging process results in 1,332 firms/53,692 observations, among which there are 959 firms/3,116 observations with FDI entries. In manufacturing sectors alone, there are 1,097 firms/42,357 observations, among which there are 854 firms/2,769 observations with FDI entries. Similarly to the US data set, subsequent FDI entries by the same firm in the same time period of analysis (quarter here) have been dropped in the tally above.

We define sectors at the 2-digit TEJ industry classification for the Taiwanese data set. By this classification, of the 1,097 firms in the manufacturing sectors, there is a large concentration of firms in the M2300–electronics industry (752), reflecting Taiwan's strong comparative advantage in this sector in this time period. The remaining 12 industries have relatively few firms each: M1100–cement (7), M1200–foods (22), M1300–plastics (27), M1400–textiles (56), M1500–electric machinery (62), M1600–electrical appliance and cable (15), M1700–chemical and biotechnology (88), M1800–glass and ceramics (5), M1900–paper and pulp (7), M2000–iron and steel (40), M2100–rubber (11), and M2200–automobile (5). The TEJ industry classification at the 3 or 4-digit level is available only for the two largest industries (i.e., M2300 and M1700).

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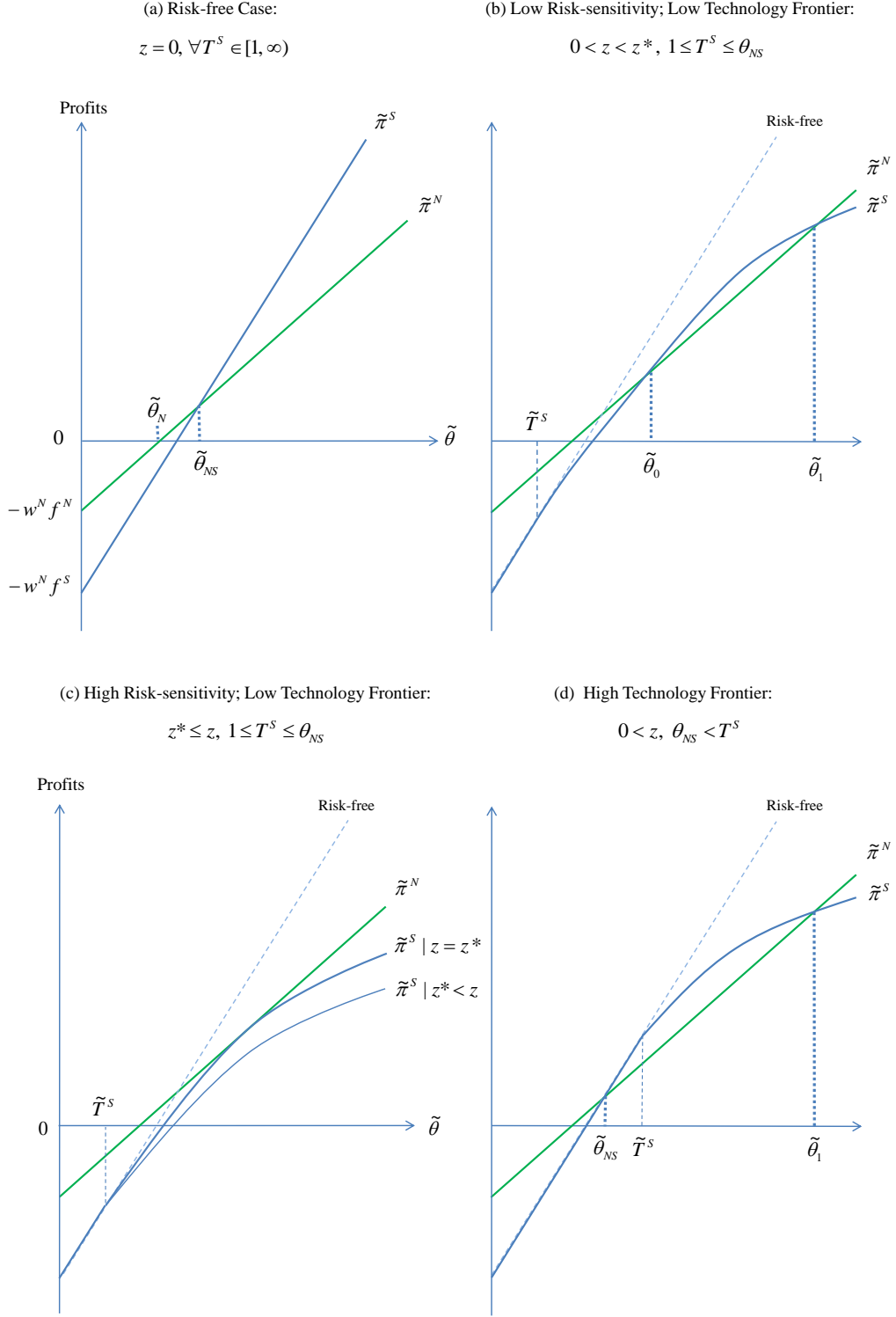# Figure 1: Expected Profits of FDI versus Production in the North

(a) Risk-free Case:

$$z = 0, \forall T^S \in [1, \infty)$$

(b) Low Risk-sensitivity; Low Technology Frontier:

$$0 < z < z^*,\ 1 \leq T^S \leq \theta_{NS}$$

(c) High Risk-sensitivity; Low Technology Frontier:

$$z^* \leq z,\ 1 \leq T^S \leq \theta_{NS}$$

(d) High Technology Frontier:

$$0 < z,\ \theta_{NS} < T^S$$

Figure 2: Threshold Technology Frontier for Inward FDI
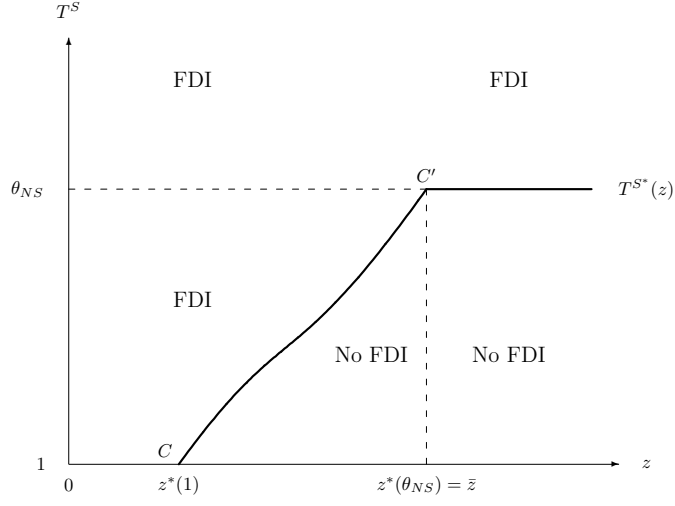
Figure 3: Dynamics of FDI
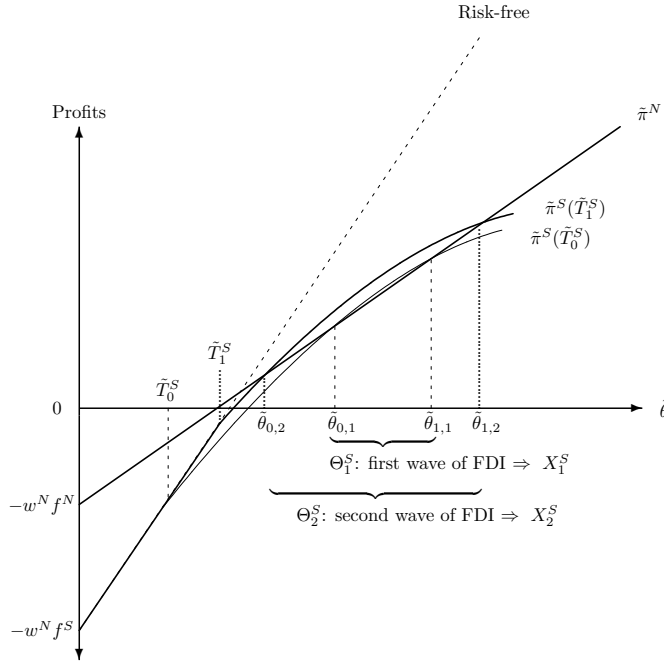
Figure 4: Existence and Stability of Steady State
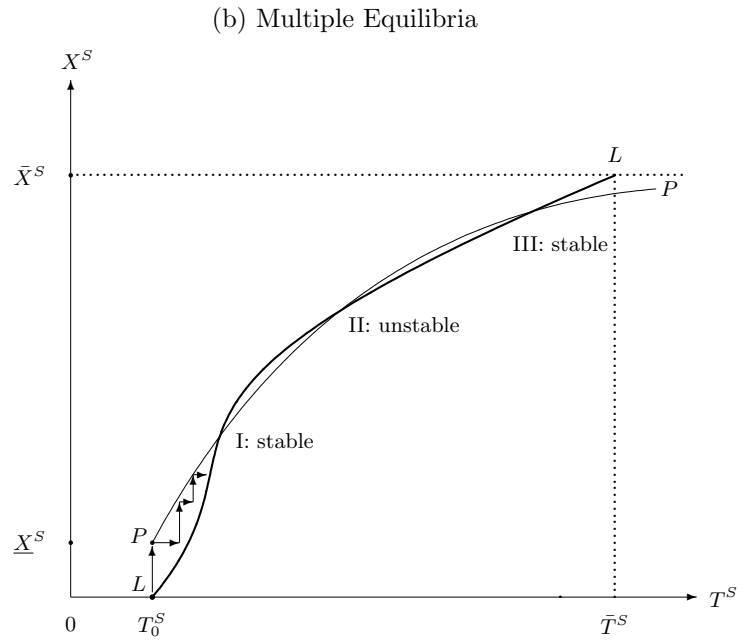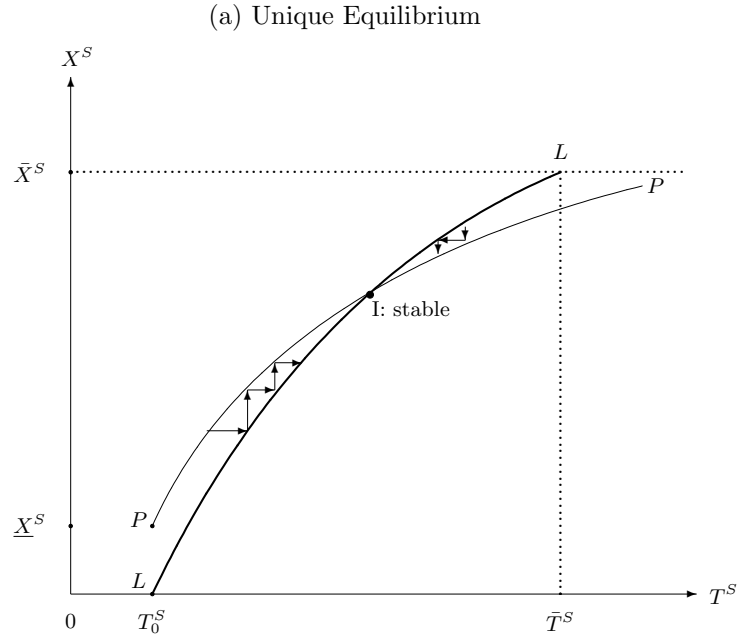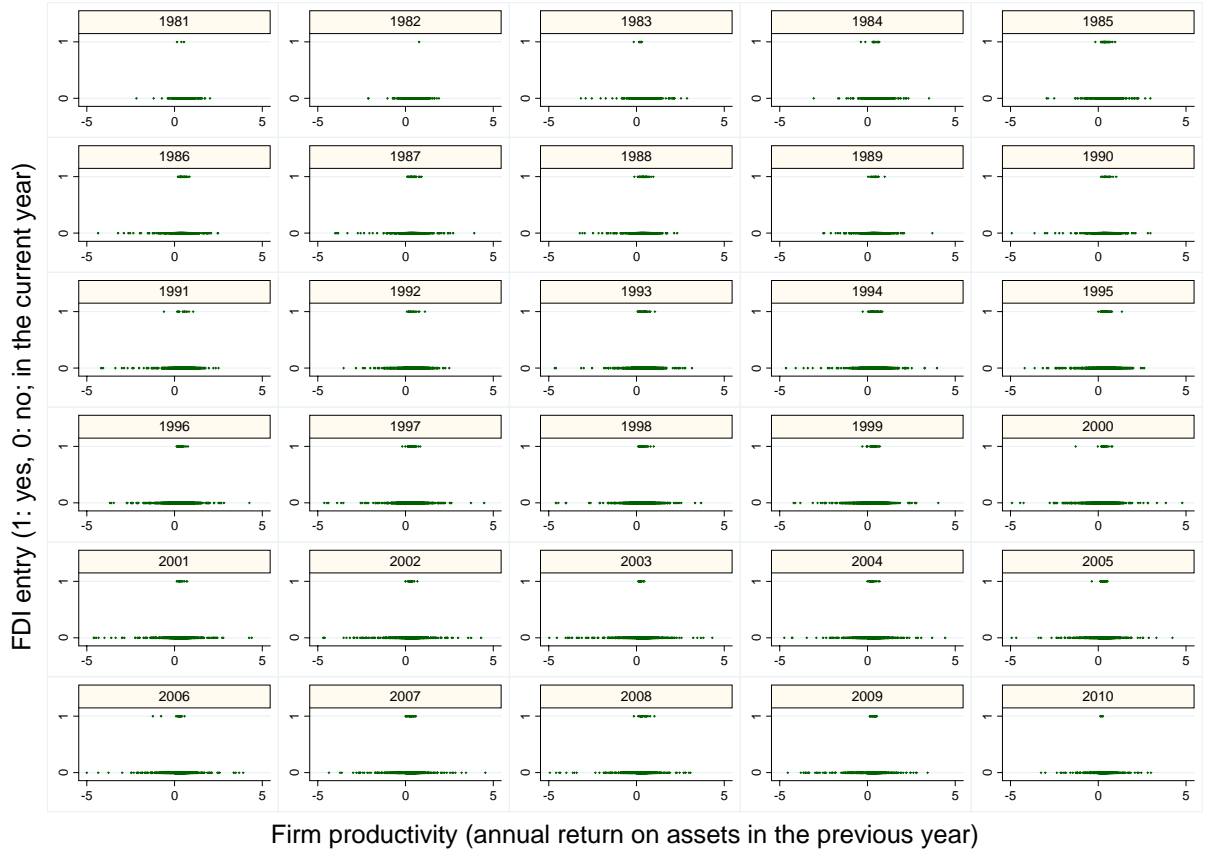
(a) Unique Equilibrium

(b) Multiple Equilibria

Figure 5: Incidence of FDI entries into China by US firms in the manufacturing industries

Firm productivity (annual return on assets in the previous year)

Note: In 1980, there is no FDI entry. The numbers of observations (and FDI entries) in each year are: 2,023 (3) in 1981; 2,115 (1) in 1982; 2,309 (7) in 1983; 2,451 (16) in 1984; 2,560 (28) in 1985; 2,666 (28) in 1986; 2,776 (30) in 1987; 2,757 (32) in 1988; 2,664 (17) in 1989; 2,644 (20) in 1990; 2,695 (15) in 1991; 2,779 (19) in 1992; 2,981 (39) in 1993; 3,099 (47) in 1994; 3,227 (57) in 1995; 3,544 (37) in 1996; 3,580 (39) in 1997; 3,388 (47) in 1998; 3,401 (33) in 1999; 3,324 (35) in 2000; 3,248 (17) in 2001; 3,083 (32) in 2002; 3,010 (21) in 2003; 2,939 (28) in 2004; 2,856 (33) in 2005; 2,779 (26) in 2006; 2,659 (31) in 2007; 2,518 (28) in 2008; 2,491 (21) in 2009; 1,563 (5) in 2010. Outliers with $|ROA| > 5$ are not included in the above diagrams to harmonize the scale. These observations are small in number (196), and all of them are observations without FDI entries; thus, this does not bias the presentation in any way in favor of our theory.

Figure 6: Incidence of FDI entries into China by Taiwanese firms in the manufacturing industries

Firm productivity (annual return on assets in the preceding four quarters)
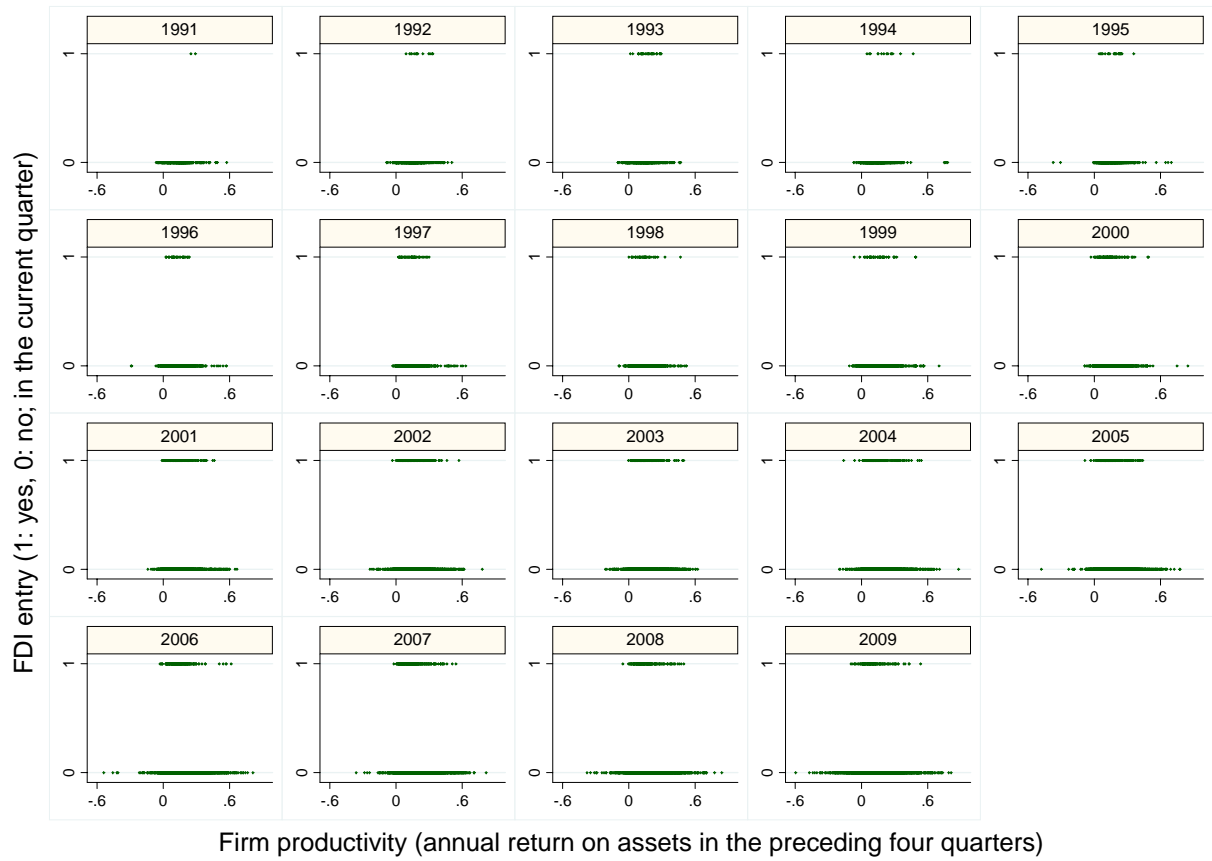
Note: Observations are quarterly, but they are grouped together by years in the above diagrams to conserve space. The pattern based on quarterly diagrams is similar. The numbers of observations (and FDI entries) in each year are: 430 (2) in 1991; 514 (14) in 1992; 565 (33) in 1993; 615 (14) in 1994; 686 (21) in 1995; 803 (35) in 1996; 962 (52) in 1997; 1,180 (41) in 1998; 1,497 (50) in 1999; 1,804 (107) in 2000; 2,136 (177) in 2001; 2,606 (247) in 2002; 2,916 (243) in 2003; 3,281 (224) in 2004; 3,504 (234) in 2005; 3,682 (219) in 2006; 3,921 (258) in 2007; 4,088 (202) in 2008; 4,192 (158) in 2009. The detailed numbers of observations and FDI entries for each quarter are available in Chang and Lu (2011). Outliers with $ROA > 0.9$ or $ROA < -0.6$ are not included in the above diagrams to harmonize the scale. These observations are small in number (11), and all of them are observations without FDI entries; thus, this does not bias the presentation in any way in favor of our theory.