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Risk, Firm Heterogeneity, and Dynamics of FDI Entry

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Abstract

We study the dynamics of FDI entry under a setting with firm heterogeneity and FDI uncertainty. The risk of FDI failure depends positively on the complexity of production technology, negatively on the quality of infrastructure in the host country, and evolves over time with the extent of knowledge diffusion. The incorporation of FDI uncertainty leads to a non-monotonic relationship between technology complexity and the timing of FDI entry: firms with intermediate technology levels lead the first wave of FDI, which helps lower the investment uncertainty facing subsequent investors and induces a wider range of FDI entry in the second period. We prove the existence of a stable steady state for this self-reinforcing process and identify how the extensive margin of FDI at the steady state varies with the host and home country characteristics. Supporting empirical observations are also provided.

Keywords: foreign direct investment; uncertainty; knowledge diffusion; dynamics; magnet effect

JEL classification: F21; F23

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1. INTRODUCTION

Risk assessments play an important role in practice when firms decide on the location and timing of foreign direct investment (FDI). Factors that could influence the success probability of FDI include the quality of infrastructure in the host country, the difficulty of product quality control, and the reliability of supply chains at the investment location. According to A.T.Kearney (2004), these risk factors are among the most critical considerations of the CEO's of the world's largest 1000 companies when making FDI decisions. See Figure 1 for more information.

The literature on FDI decisions considers, however, predominantly the tradeoff between fixed and variable costs, regardless of whether the research focus is on horizontal or vertical FDI. See, for example, the survey by Helpman (2006). Analyses on how risk affects firms' FDI decisions are generally absent. Although the studies based on cost considerations offer explanations for the question as to why some firms undertake FDI but others do not, they leave issues related to FDI timing unaddressed. In particular, the timing of FDI entry is commonly observed to vary across firms and depend on the development levels of the host countries. For example, for a given host-source country pair, while some firms in an industry would forge ahead to exploit FDI opportunities, others would take a wait-and-see attitude. Furthermore, countries with different development levels tend to receive FDI in a given industry in a hierarchical manner. See, for example, the flying-geese pattern documented by Feenstra and Rose (2000). Since the factors determining investment risk are usually related to product and country characteristics and the relevance of these risk factors evolves over time, we believe that taking into account these risk factors in firms' FDI decisions will help to explain the dynamics of FDI entry and enhance the prediction power of the existing models.

We build upon the recent literature on FDI entry decisions with firm heterogeneity by Antràs and Helpman (2004) and Helpman et al. (2004). Under the market structure of monopolistic competition, the setup enables one to analyze the equilibrium sorting of heterogeneous firms into different market-entry modes and organizational forms. As to be elaborated shortly, the risk factors considered in our paper generally apply to horizontal as well as vertical FDI. We study only the latter case and adopt a framework similar to Antràs and Helpman (2004). We deviate from their focus of incomplete contract, however, and concentrate instead on different aspects of FDI risk and the effects of these risk factors on the timing of FDI entry made by heterogeneous firms.

Specifically, we develop a dynamic North-South trade model, in which production of final goods requires a successful matching between headquarter services and intermediate inputs. Headquarter services are always produced in the North by final-good producers (in short, firms, hereafter). Intermediate inputs, however, can be produced either in the North or in the South by plant operators. Firms in the North decide whether to engage an intermediate-input plant operator in the North via domestic vertical integration or to engage one in the South via FDI.

It is assumed that FDI is associated with a higher risk of matching failure than domestic vertical integration. In the event of unsuccessful matching between the headquarter service and the intermediate input, firms will not be able to sell the defective final product and have to suffer a loss as a result. This scenario is referred to as investment failure. Thus, in addition to the higher fixed cost associated with FDI, each firm seeking cheap labor in the South to produce the intermediate input also has to take into account the higher risk of investment failure.

We explicitly model three main factors determining the likelihood of investment failure. They are: (1) the quality of infrastructure in the host country, (2) the extent of knowledge diffusion, and (3) the sophisticatedness of production technology. The first factor is country-specific, the second industry-specific and time dependent, and the third firm-specific, as to be elaborated below.

First, as found in several empirical studies, the quality of infrastructure provision (such as power, water, roadway, and IT) and institutions in the host country are key factors explaining the destination of investment. See, for example, Fung et al. (2004), Wei (2000), and Cheng and Kwan (2000) among others. This is consistent with the findings of the survey conducted by A.T.Kearney (2004) shown in Figure 1, where government regulations, political and social disturbances, IT disruption, and absence of rule of law are considered by firms as some of the most critical risk factors of FDI. Given these empirical observations, we assume that the probability of investment failure decreases with a higher quality of infrastructure or institutions in the host country.

Second, as is well recognized in the literature, FDI is an important channel for international knowledge diffusion. See for example, Findlay (1978), Antràs (2005), Javorcik (2004), Veugelers and Cassiman (2004), and Blomström and Sjöholm (1999). See also surveys by Blomström and Kokko (1998) and Keller (2004). The evidence for positive knowledge spillover is in particular prominent in the case of vertical FDI in which multinationals transplant advanced know-how of intermediate input production to local suppliers in the host country. We argue that through demonstration effect, knowledge is diffused from these suppliers producing for multinationals to the local industry. As a result, the industry-wide technological level improves in the host country, which helps lower the risk of FDI failure. The extent of knowledge diffusion strengthens as the mass of multinationals present in the local industry increases, which changes the distribution of FDI uncertainty over time.

Third, quality control is noted by CEO's in the same survey (A.T.Kearney, 2004) as the most critical product-specific risk associated with overseas operations. Grossman et al. (2005) also point out that firms' decisions to undertake FDI depend on their abilities to secure efficient and reliable suppliers of intermediate inputs. We argue that the risk of quality control is especially threatening for firms producing sophisticated products and adopting advanced technologies, which involve complicated operation procedures and require intensive face-to-face communications throughout the entire designing, manufacturing, and marketing process. This argument of ours is in line with the O-ring theory of Kremer (1993) and similar to those found in the product-cycle literature of Vernon (1966), Antràs (2005), and Lu (2007), among others. We further link the sophisticatedness of firm production technology to firm productivity, based on the widespread agreement in the literature that differences in firm technology account for significant variations in firm productivity. See for example, empirical studies by Klette (1996), Griliches (1998), and Klette and Kortum (2004), and theoretical formalizations by Kremer (1993) and Acemoglu et al. (2006). By incorporating both strands of literatures, we assume that other things being equal, firms of more sophisticated production technologies are associated with not only higher productivity levels but also with higher probabilities of FDI failure.[1]

Incorporating the three factors discussed above into the risk function facing each firm, our model reaches three empirically relevant predictions. First, the risk presented by poor infrastructure in the host country can be prohibitive and thwart all potential FDI inflows. Accordingly, a minimum level of infrastructure in the South is necessary to make FDI viable at all. This is different from the conventional finding in the literature that with cost-saving considerations alone, sufficiently productive firms always find it profitable to undertake FDI.

[1] As argued above, in a given industry, firms employing more sophisticated technology are more productive; meanwhile, they also face higher challenge in transferring technology to a less developed South. The resulting reduced-form assumption of a positive association between productivity and FDI risk is a convenient one. We recognize the possibility that more productive firms are more capable of "solving" quality control problems, and thus a structural approach may be more desirable in modeling the relationship between productivity and FDI risk. The results of the paper will remain valid, however, without the above reduced-form assumption, if risk aversion is present in the model.

Second, the evolution of FDI risk following the diffusion of industry-specific knowledge leads to a dynamic pattern of FDI entry, where international production migration occurs in clusters and in orders. As shown in the paper, a first wave of FDI, if it takes place, channels production knowledge from the North to the South and generates positive externality for subsequent investors. As a result, industry-wide investment uncertainty decreases. The lower risk of FDI failure then stimulates a second wave of production migration, which in turn triggers a third wave of migration. We label this dynamic process of sequential FDI entry the "magnet effect" of FDI. The magnet effect of FDI postulated in this paper is related to the agglomeration effect or self-reinforcing effect documented in the empirical literature. 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 the FDI in China exhibits a strong self-reinforcing effect: existing FDI stock in a region attracts further FDI inflows.

Third, the firm-specific risk of product quality control takes a heavier toll on more productive firms which produce more sophisticated products. This argument, along with the fixed and variable cost tradeoff consideration, implies a non-monotonic relationship between firm productivity and FDI propensity: firms of intermediate productivity levels are more likely to undertake FDI than the least and the most productive firms. This prediction presents another departure from the common conception in the literature that more productive firms in a given industry are more likely to undertake FDI. The conventional prediction emerges as a special case in our framework when the risk factor is negligible.

In sum, our framework implies that firms of intermediate productivity levels will lead the first wave of FDI, if a minimum threshold level of infrastructure in the host country is met. The first wave of FDI then attracts a second wave of FDI entry by firms both less productive and more productive than the pioneering batch of firms. As the process continues, the extensive margin of firms undertaking FDI enlarges toward the lower and higher end of productivity spectrum. We prove the existence of a stable steady state for this self-reinforcing process of magnet effect and characterize the extensive margin of FDI at the steady state. We also derive theoretically the change in the compositions of firms undertaking FDI at the steady state as the host-home country characteristics change. Numerical simulations are then conducted to illustrate the equilibrium convergent path and the comparative-static analysis results.

Later in the paper, we provide some supporting evidence using Taiwanese firm-level data. Due to the special historical background between Taiwan and China, FDI flows from Taiwan to China were prohibited prior to 1990. The change of FDI policy in 1990 serves as a natural experiment and provides us an opportunity to observe the timing of FDI entry after the ban was lifted. The economic environment of China in the 1990s suggests that the three risk factors considered in the paper are highly relevant. We find that the FDI entry by Taiwanese firms in the electronics industry took place sequentially and was led by firms of intermediate productivity levels, exhibiting a pattern which resembles the magnet effect proposed in the paper.

Our study helps to shed some light on the issue of how globalization affects industrial restructuring in the source country. Our study implies that the aggregate industry productivity may increase after FDI liberalization since firms of intermediate productivity move out but those of high productivity continue to stay in the home country, especially in industries where investment uncertainty is highly sensitive to production technology. Our paper also suggests that subsidies offered by host countries to attract FDI have an amplifying effect due to the magnet effect discussed above. If the magnet effect is strong enough (say the host and home countries are close in terms of geographical or culture and language distance), small differences between host countries in exogenous factors (such as infrastructure levels or FDI subsidies) will lead to substantial differences in the quality and quantity of FDI inflows.

Several papers have also made important contributions toward the understanding of investment timing, entry, and exit under uncertainty. These include McDonald and Siegel (1986), Dixit (1989), Dixit and Pindyck (1994), Caballero and Pindyck (1996), and Rob and Vettas (2003) among others. Most of these papers consider a single firm's optimal entry decision while assuming the uncertainty to follow some deterministic stochastic processes. Lin and Saggi (2002), on the other hand, consider a duopoly model in which the first firm's entry into a foreign market creates positive externality for the later potential entrant by lowering the entry cost facing the second firm. They then explore conditions under which simultaneous or sequential entry of the two ex-ante identical firms into the foreign market will occur. Contrary to the above literature, we attempt to provide economic foundations for the force governing the underlying distribution of uncertainty, and allow the distribution of uncertainty to evolve over time with the endogenous knowledge diffusion. In a setting with a continuum of firms, we are able to address how the dynamics of FDI entry and the extensive margin of FDI vary with the host and source country characteristics. Due to the setup of market structure with monopolistic competition, however, strategic interactions among firms are not considered in our paper. We leave this interesting extension for future work.

The rest of the paper is organized as follows. In Section 2, we introduce our formulation of FDI uncertainty and its effect on firms' FDI decisions. In Section 3, we highlight the initial condition for non-zero measure of firms to undertake FDI before any knowledge diffusion occurs. We then formalize the magnet effect of FDI and prove the existence of a stable steady state for such a self-reinforcing process. We also derive theoretically the variation in the extensive margin of FDI at the steady state as key parameters of the model change. In Section 4, we provide simulation results illustrating the FDI dynamic path. Section 5 presents empirical evidence supporting our theoretical predictions. Section 6 concludes. Proofs of propositions and lemmas are shown in the appendix.

2. THE MODEL

The world has a unit measure of population with the following preference structure:

$$U = x_0 + \frac{1}{\alpha_j}\sum_{j=1}^{J} X_j^{\alpha_j}, \quad 0 < \alpha_j < 1$$

$$X_j = \left[\int x_j(i)^{\alpha_j} di\right]^{1/\alpha_j},$$

where x_0 is the numeraire, a homogeneous good produced both in the North and in the South. Labor is the only factor of production, and the production technology of x_0 exhibits constant returns to scale; thus the labor productivity of a country in producing the numeraire good determines its wage rate. The North is assumed to have an absolute advantage in producing the numeraire good, and therefore commands a higher wage: $w^N > w^S$. The non-numeraire good X_j represents the aggregate consumption of differentiated products $x_j(i)$ in sector j. The elasticity of substitution between any two varieties within a sector ($\sigma_j = \frac{1}{1-\alpha_j}$) is allowed to differ across sectors.

The derived inverse demand function for each variety i in sector j is:

$$p_j(i) = x_j(i)^{\alpha_j - 1} \tag{1}$$

Production of the final good $x_j(i)$ requires a successful matching between the headquarter service, $h_j(i)$, and the intermediate input, $m_j(i)$. The headquarter service is always produced in the North by final-good producers H; the intermediate input, however, can be produced either in the North or in the South by plant operators M. There is an infinitely elastic supply of such plant operators or suppliers in both locations. Final-good producers H in the North (in short, firms, hereafter) decide whether to engage an intermediate-input supplier in the North via domestic vertical integration or to engage one in the South via FDI. It is assumed that by integrating the production in the North (N), there is no risk of mismatch between the headquarter service and the intermediate input, and the output of variety i in sector j is determined by the production technology:

$$x_j^N(i) = \theta \left[\frac{h_j(i)}{\eta_j}\right]^{\eta_j} \left[\frac{m_j(i)}{1-\eta_j}\right]^{1-\eta_j} \tag{2}$$

The parameter η_j denotes the intensity of the headquarter service in the production of the final good in sector j that is common to all varieties. The higher η_j is, the more important is the headquarter service component. The parameter θ indicates the productivity level of H in producing a variety of the final good in sector j. As argued in the introduction, we will also use this parameter to indicate the sophisticatedness of production technology employed by H to produce the final good. The types of firms θ are distributed according to a cumulative distribution function $G(\theta)$.

If the intermediate input is instead produced in the South (S), H faces a potential risk that the intermediate input produced abroad may fail to match the exact specification designed by the North. In this case, the output is zero. The production technology in this case is:

$$x_j^S(i) = \begin{cases} \theta \left[\frac{h_j(i)}{\eta_j}\right]^{\eta_j} \left[\frac{m_j(i)}{1-\eta_j}\right]^{1-\eta_j}, & \text{in case of FDI success;} \\ 0, & \text{in case of FDI failure.} \end{cases} \tag{3}$$

Firms are assumed to be risk-neutral. In the following, we focus on one sector and suppress the sector index to simplify the notation. By (1), (2), and (3), the revenue function for variety i given the amounts of inputs is:

$$R^l(i) = \gamma^l \theta^\alpha \left[\frac{h(i)}{\eta}\right]^{\alpha\eta} \left[\frac{m(i)}{1-\eta}\right]^{\alpha(1-\eta)}, \quad l = \{N, S\} \tag{4}$$

where $\gamma^N = 1$, and $0 < \gamma^S < 1$ is the probability of successful matching between the headquarter service and the intermediate input when the latter is produced in the South.

It is assumed that the fixed organizational cost (in Northern labor units) for H to coordinate the integration of the headquarter service and the intermediate input is higher in the case of FDI than in the case of domestic vertical integration:

$$f^S > f^N. \tag{5}$$

The production of either the headquarter service or the intermediate input is assumed to have a unit labor requirement of one. Following AH's assumption of incomplete contracts, H and M negotiate the division of revenues after the inputs have been produced. The division depends on the relative negotiating powers of the two parties and their outside options. If the negotiation fails, H can potentially seize the intermediate input, but at the cost of a fraction $(1-\delta)$ of the final output, regardless of whether M is located in the North or in the South. Suppose in addition that H is able to extract a fraction β_0 of the surplus from the contract with M at the *ex post* negotiation. Then, the division of revenues for H is: $\beta = \delta^\alpha + \beta_0[1-\delta^\alpha]$. Given the expected division of *ex post* revenues, H and M choose the optimal production level of headquarter service and intermediate input that maximizes their respective operating profits. This leads to a joint operating profit for H and M, which depends on the location of M:

$$\pi^l(\theta, \eta) = \gamma^{l\frac{1}{1-\alpha}} \theta^{\frac{\alpha}{1-\alpha}} \psi^l(\eta) - w^N f^l, \quad l = \{N, S\}, \tag{6}$$

where

$$\psi^l(\eta) = \frac{1 - \alpha[\beta\eta + (1-\beta)(1-\eta)]}{\{(1/\alpha)\,(w^N/\beta)^\eta\,[w^l/(1-\beta)]^{1-\eta}\}^{\alpha/(1-\alpha)}}. \tag{7}$$

Under the assumption that there is an infinitely elastic supply of potential M agents in either location, the final-good producer H, by charging an optimal amount of up-front fee for engaging any of the intermediate-good supplier M, can capture the entire amount of the joint operating profit in (6). Thus, H chooses the organizational form (between domestic vertical integration and FDI) that will yield higher joint operating profit.

Given that $w^S < w^N$, it follows that $\psi^S(\eta) > \psi^N(\eta)$. Thus, a firm H by undertaking FDI in the South reaps a larger variable profit margin if the FDI venture is a success. However, the higher variable profit margin is discounted by the potential risk of mismatch and investment failure. We assume that the success probability of FDI takes the following form:

$$\gamma^S(\theta) \quad = \quad \left(\frac{b}{\theta}\right)^{\alpha z}, \quad 0 < b \leq \theta, \quad 0 < z, \tag{8}$$

where the parameter b indicates the minimum level of firm productivity and technology sophistication in an industry, and the parameter z characterizes the industry-specific elasticity of FDI success probability to technology sophistication. For example, given the same θ, some industries (such as the electronics or automobile industry) may be more sensitive to risk than others (such as the apparel or furniture industry). Within the same industry, z may also change over time as the 'general' technology of the industry becomes more standardized at the FDI destination. For a given z, the FDI success probability decreases with the sophisticatedness of production technology. The larger z is, the more negatively affected is the FDI success probability by a higher level of technology sophistication. By normalization, the success probability equals one for the least sophisticated variety and approaches zero as the technology sophistication level approaches infinity.

Define $\tilde{\theta} = \theta^{\frac{\alpha}{1-\alpha}}$, and $\tilde{b} = b^{\frac{\alpha}{1-\alpha}}$. It follows that

$$\pi^S(\tilde{\theta}, z) = \psi^S \tilde{b}^z \tilde{\theta}^{1-z} - w^N f^S, \tag{9}$$

$$\pi^N(\tilde{\theta}) = \psi^N \tilde{\theta} - w^N f^N. \tag{10}$$

Equation (9) implies that the expected profit of undertaking FDI is increasing and concave in $\tilde{\theta}$ for $0 < z < 1$ and (weakly) decreasing in $\tilde{\theta}$ for $z \geq 1$. In the latter case, as firm productivity increases, the positive effect of a larger market share on variable profits is more than offset by the negative effect of a higher risk of investment failure. This formulation includes the framework of Antràs and Helpman (2004) as a special case when the risk of FDI failure approaches zero. To see this, note that $\lim_{z\to 0}\gamma^S = 1$ and $\lim_{z\to 0}\pi^S(\tilde{\theta}, z) \to \tilde{\pi}^S(\tilde{\theta}) \equiv \psi^S\tilde{\theta} - w^N f^S$.

Assumption 1 The parameters satisfy the conditions that (i) $\tilde{b} < \frac{w^N f^N}{\psi^N}$; (ii) $\frac{f^N}{\psi^N} < \frac{f^S}{\psi^S}$.

Define $\tilde{\theta}_N \equiv \frac{w^N f^N}{\psi^N}$, $\tilde{\theta}_S \equiv \frac{w^N f^S}{\psi^S}$, and $\tilde{\theta}_{NS} \equiv \frac{w^N(f^S - f^N)}{\psi^S - \psi^N}$. They correspond respectively to the productivity level with which a firm will break even by engaging a plant operator in the North, by engaging one in the South, and be indifferent between the two, under the scenario without FDI risk. Assumption 1 implies $\tilde{\theta}_N < \tilde{\theta}_{NS}$. Thus, without FDI uncertainty, firms are partitioned according to their productivity levels into the least productive ones who do not produce, the less productive ones who engage plant operators in the North, and the most productive ones who engage plant operators in the South. Thus, by making Assumption 1, we assume that the production of intermediate components in the North is not competed away by the South, even in the scenario that is most favorable to FDI.

Lemma 1 *Under Assumption 1, there exists a unique $z^* \in (0, 1)$ such that the curve π^S is tangent to π^N, and*

(i) for all $z \in (0, z^*)$, $\exists\ \{\tilde{\theta}_0, \tilde{\theta}_1\} = \{\tilde{\theta} | \pi^S(\tilde{\theta}, z) - \pi^N(\tilde{\theta}) = 0\}$, where $\tilde{\theta}_{NS} < \tilde{\theta}_0 < \tilde{\theta}_1$, such that $\pi^S(\tilde{\theta}, z) > \pi^N(\tilde{\theta}) > 0$ for all $\tilde{\theta} \in (\tilde{\theta}_0, \tilde{\theta}_1)$, and $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ for all $\tilde{\theta} \in [\tilde{b}, \tilde{\theta}_0) \cup (\tilde{\theta}_1, \infty)$;

(ii) for all $z \in (z^*, \infty)$, $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ for all $\tilde{\theta} \in [\tilde{b}, \infty)$.

Proof of Lemma 1. The proof is shown in the appendix. ■

Lemma 1 indicates that the expected profit of undertaking FDI can be severely affected by the risk of FDI failure such that no firms stand to gain from FDI. The value z^* defines the critical threshold of risk elasticity. The risk elasticity must be sufficiently small ($z < z^*$) for FDI to take place. The sketch of the proof of Lemma 1 is illustrated in Figure 2. In the figure, productivity levels $\tilde{\theta}$ are indicated on the horizontal axis and expected profits on the vertical axis. A typical $\pi^S(\tilde{\theta}, z)$ curve starts at the vertical intercept $\pi^S = -w^N f^S$ and passes through Point "A" in the figure where $\tilde{\theta} = \tilde{b}$. As z approaches zero, the curve $\pi^S(\tilde{\theta}, z)$ approaches the schedule $\tilde{\pi}^S(\tilde{\theta}) = \psi^S\tilde{\theta} - w^N f^S$, which lies above the schedule $\pi^N(\tilde{\theta}) = \psi^N\tilde{\theta} - w^N f^N$ for all $\tilde{\theta} \geq \tilde{\theta}_{NS}$. Define $\pi_z^S(\tilde{\theta}, z) \equiv \frac{\partial \pi^S(\tilde{\theta}, z)}{\partial z}$ to obtain

$$\pi_z^S(\tilde{\theta}, z) = \psi^S \tilde{b}^z \tilde{\theta}^{1-z} \ln(\frac{\tilde{b}}{\tilde{\theta}}). \tag{11}$$

Observe that $\pi_z^S(\tilde{\theta}, z) \lesseqqgtr 0$ for $\tilde{\theta} \gtreqqless \tilde{b}$. Thus, as z increases from zero, the curve $\pi^S(\tilde{\theta}, z)$ rotates clockwise around Point "A". As $z \to 1$, the curve $\pi^S(\tilde{\theta}, z)$ approaches a step function with $\pi^S = -w^N f^S$ for $\tilde{\theta} = 0$ and $\pi^S = \psi^S \tilde{b} - w^N f^S$ for all $\tilde{\theta} > 0$. This function falls below the schedule $\pi^N(\tilde{\theta})$ completely for all $\tilde{\theta} \geq \tilde{b}$ by Assumption 1. It follows from the above derivations that there exists a unique $z^* \in (0, 1)$ such that the curve $\pi^S(\tilde{\theta}, z)$ is tangent to the schedule $\pi^N(\tilde{\theta})$. For $z \in (0, z^*)$, the curve $\pi^S(\tilde{\theta}, z)$ intersects with the schedule $\pi^N(\tilde{\theta})$ twice, at $\tilde{\theta}_0$ and $\tilde{\theta}_1$, with both of them necessarily larger than $\tilde{\theta}_{NS}$. By the concavity of the curve $\pi^S(\tilde{\theta}, z)$, it follows that $\pi^S(\tilde{\theta}, z) > \pi^N(\tilde{\theta}) > \pi^N(\tilde{\theta}_{NS}) > 0$ for all $\tilde{\theta} \in (\tilde{\theta}_0, \tilde{\theta}_1)$, and that $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ otherwise. For $z \in (z^*, \infty)$, the curve $\pi^S(\tilde{\theta}, z)$ falls completely below the schedule $\pi^N(\tilde{\theta})$ for all $\tilde{\theta} \geq \tilde{b}$; thus, $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$, for all $\tilde{\theta} \in [\tilde{b}, \infty)$.

Proposition 2 *For $z \in (0, z^*)$, firms are partitioned according to their productivity levels as follows:*

(i) firms with $\tilde{\theta} \in [\tilde{b}, \tilde{\theta}_N]$ exit the market;

(ii) firms with $\tilde{\theta} \in [\tilde{\theta}_N, \tilde{\theta}_0] \cup [\tilde{\theta}_1, \infty)$ undertake domestic vertical integration in the North;

(iii) firms with $\tilde{\theta} \in [\tilde{\theta}_0, \tilde{\theta}_1]$ undertake FDI in the South.

On the other hand, for $z \in (z^*, \infty)$, FDI is not viable:

(i) firms with $\tilde{\theta} \in [\tilde{b}, \tilde{\theta}_N]$ exit the market;

(ii) firms with $\tilde{\theta} \in [\tilde{\theta}_N, \infty)$ undertake domestic vertical integration in the North.

Proof of Proposition 2. The results follow immediately from Lemma 1 and the definition of $\tilde{\theta}_N$. ■

Proposition 2 indicates that as the risk elasticity becomes sufficiently low and falls below the threshold level ($z < z^*$), firms of intermediate productivity levels relocate the production of intermediate inputs to the South, while the least and the most productive firms remain to have them produced in the North. This implies a non-monotonic relationship between firm productivity and FDI propensity. This is contrary to the AH prediction, where the most productive firms are most likely to undertake FDI. The reason for the least productive firms to keep the production line in the North is similar to the argument under the AH setting: firms with smaller market shares find the variable profit gain from lower wages in the South not sufficient to offset the higher fixed organizational cost associated with FDI. In the current model, the incentive to locate the production line in the

South is further weakened by the possibility of FDI failure; thus, the set of lower productive firms to keep the production line in the North is larger ($\tilde{\theta}_{NS} < \tilde{\theta}_0$). On the other hand, the risk of FDI failure accounts for the prediction that the most productive firms also refrain from relocating the production line to the South. As these firms with larger market shares are also engaged in varieties of more sophisticated technology, they face higher possibilities of FDI failure associated with their products. The wage advantage offered by the South is more than offset by the expected loss of FDI failure when the sophistication level of the engaged technology is sufficiently high ($\tilde{\theta} > \tilde{\theta}_1$).

Proposition 3 *For $z \in (0, z^*)$,*

(i) the lower bound of the range of firms undertaking FDI, $\tilde{\theta}_0$, increases with z,

(ii) the upper bound of the range of firms undertaking FDI, $\tilde{\theta}_1$, decreases with z, and

(iii) the range of firms undertaking FDI, $(\tilde{\theta}_1 - \tilde{\theta}_0)$, decreases with z; in particular, as $z \to 0$, $(\tilde{\theta}_1 - \tilde{\theta}_0) \to \infty$ and as $z \to z^*$, $(\tilde{\theta}_1 - \tilde{\theta}_0) \to 0$.

Proof of Proposition 3. The proof is shown in the appendix. ■

The results are quite intuitive. As the risk elasticity z decreases, the FDI success probability increases for all firms. The marginal firms which were indifferent between FDI and domestic vertical integration, now find it profitable to relocate the production line to the South as FDI now offers higher expected variable profits. The range of firms undertaking FDI enlarges and approaches the scenario of AH ($\tilde{\theta}_0 \to \tilde{\theta}_{NS}$ and $\tilde{\theta}_1 \to \infty$) as FDI risk vanishes.

3. THE DYNAMICS OF FDI

In this section, we extend the static model introduced above to a dynamic setting with multiple time periods to identify the timing of FDI entry by heterogeneous firms and to formalize the magnet effect of FDI. Variables introduced previously are now indexed by time subscripts to indicate their values at the applicable time period. The dynamics arise from the endogenous diffusion of knowledge from the multinational to the local industry in the host country: the presence of some initial FDI in an industry generates industry-specific knowledge diffusion from the North to the South and lowers the industry's risk elasticity for a subsequent period. Specifically, the risk elasticity z_t is assumed to evolve according to the following dynamics:

$$z_t = \frac{1}{K + T_{t-1}}, \quad K \geq 0, \quad t = 1, 2, \ldots \tag{12}$$

where the parameter K indicates the level of infrastructure in the South, which is shared by all industries. The variable T_{t-1} represents the accumulated level of industry-specific knowledge diffused from the North to the South in period $t-1$. The level of infrastructure encompasses various aspects of a nation's capacity to support general production activities. This includes physical infrastructure, social capital, human capital, and governance infrastructure. Equation (12) implies that the higher the level of infrastructure in the South, the lower the risk elasticity for all industries to undertake FDI in the South. The risk elasticity for an industry is further lowered if the presence of FDI undertaken by firms in the same industry in previous periods leads to knowledge diffusion from the North to the South and improves the production capacity of the intermediate-input suppliers in the South. Equation (12) implies that the larger the amount of industry-specific knowledge diffused from the North to the South, the lower the risk elasticity of the industry. In particular, the accumulated level of industry-specific knowledge diffused from the North to the South in period t is defined as:

$$T_t = \frac{\tilde{G}(\tilde{\theta}_{1,t}) - \tilde{G}(\tilde{\theta}_{0,t})}{d}, \quad d > 0, \tag{13}$$

where $\tilde{\theta}_{0,t}$ and $\tilde{\theta}_{1,t}$ indicate the lower and upper bound of the range of firms undertaking FDI in period t, and $\tilde{G}(\tilde{\theta})$ is the transformed cumulative distribution function expressed in terms of the scaled productivity level $\tilde{\theta}$. In (13), the magnitude $\tilde{G}(\tilde{\theta}_{1,t}) - \tilde{G}(\tilde{\theta}_{0,t})$ represents the absolute mass of firms with intermediate-input production located in the South in period t. It is scaled by the economic distance, d, between the host and home country of FDI. The economic distance, d, summarizes the barriers to knowledge diffusion arising from physical distance, and cultural, language, and institutional differences. For a given absolute mass of firms with FDI in the South, the effective mass and the extent of knowledge diffusion it creates is larger, the closer the two countries are in terms of their economic distance.

Begin with an initial period ($t = 0$) when FDI is not present in the South ($T_0 = 0$). In this case, the level of infrastructure in the South is the only determinant of the risk elasticity z, and of the viability of FDI, in the industry.

Corollary 4

(i) The minimum level of infrastructure required of the South to trigger the first wave of FDI is $K^* = 1/z^*$.

(ii) For $K > K^*$, *the range of the first wave of FDI,* $(\tilde{\theta}_{1,1} - \tilde{\theta}_{0,1})$, *is larger, the higher is the level of infrastructure,* K, *in the South; in particular,* $\mathrm{d}\tilde{\theta}_{1,1}/\mathrm{d}K > 0$ *and* $\mathrm{d}\tilde{\theta}_{0,1}/\mathrm{d}K < 0$.

Proof of Corollary 4. The result in (i) follows from Lemma 1 and the fact that $T_0 = 0$. The result in (ii) follows from Proposition 3 and the fact that $z_1 = 1/K$. ■

The importance of the recipient country's infrastructure in attracting FDI inflows has been documented by various empirical studies. For example, Wei (2000) examined the depressing effect of corruption on inward FDI. Globerman and Shapiro (2002) estimated the minimum threshold of infrastructure that a recipient country must achieve to attract positive flows of FDI from the United States.

If the South meets the minimum threshold of infrastructure ($K > K^*$), Corollary 4 applies and firms with $\tilde{\theta} \in (\tilde{\theta}_{0,1},\, \tilde{\theta}_{1,1})$ undertake FDI in period 1. By (12) and (13), the knowledge diffusion created by these firms helps lower the risk elasticity in period 2 ($z_2 < z_1$, as $T_1 > T_0 = 0$). Thus, earlier FDI creates positive externality for subsequent FDI. This is illustrated in Figure 3, where the curve $\pi^S(\tilde{\theta}; K, T_{t-1})$ tilts upward at $t = 2$. Firms with productivity levels in the range of $(\tilde{\theta}_{0,1} - \epsilon,\, \tilde{\theta}_{0,1})$ or $(\tilde{\theta}_{1,1},\, \tilde{\theta}_{1,1} + \epsilon)$, who find it not profitable to undertake FDI in period 1, now prefer moving the production process to the South, since the risk associated with FDI is lower than before. As a result, the first wave of production migration induces a second wave of production migration, $(\tilde{\theta}_{0,1},\, \tilde{\theta}_{1,1}) \subset (\tilde{\theta}_{0,2},\, \tilde{\theta}_{1,2})$, the effective mass of FDI firms is enlarged, and the resulting knowledge diffusion strengthened, $T_2 > T_1 > T_0 = 0$. The larger mass of FDI firms further reduces the FDI uncertainty and triggers another wave of FDI. We label this phenomenon the "magnet effect" of FDI. This dynamic process can be summarized by the sequence $\left\{(\tilde{\theta}_{1,t},\, \tilde{\theta}_{0,t},\, z_t)\right\}_{t=1}^{\infty}$ which satisfies the following system of equations:

$$\begin{aligned}
\pi^S(\tilde{\theta}_{1,t}, z_t) - \pi^N(\tilde{\theta}_{1,t}) &= 0 \qquad t = 1, 2, \ldots &(14)\\
\pi^S(\tilde{\theta}_{0,t}, z_t) - \pi^N(\tilde{\theta}_{0,t}) &= 0 \qquad t = 1, 2, \ldots &(15)\\
z_t - \frac{1}{K + d^{-1}\tilde{G}(\tilde{\theta}_{1,t-1}) - d^{-1}\tilde{G}(\tilde{\theta}_{0,t-1})} &= 0 \qquad t = 2, 3, \ldots &(16)
\end{aligned}$$

with the initial condition that $z_1 = 1/K < z^*$.

Proposition 5 *There exists a stable steady-state solution* $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$ *to the system (14)–(16).*

Proof of Proposition 5. As we focus on the steady state, the time subscript will be omitted in the following proof. Let $\tilde{\theta}_1(z)$ and $\tilde{\theta}_0(z)$ indicate the solutions to (14) and (15) as functions of z. Thus, (13) can be re-expressed as:

$$T(z) = \frac{\tilde{G}(\tilde{\theta}_1(z)) - \tilde{G}(\tilde{\theta}_0(z))}{d} \tag{17}$$

On the other hand, at the steady state, (16) reduces to:

$$z(T) = \frac{1}{K + T} \tag{18}$$

These two functions are illustrated in Diagram (a) of Figure 4. Define $\underline{z} \equiv \frac{1}{K + d^{-1}\left(1 - \tilde{G}(\tilde{\theta}_{NS})\right)}$. Note that $z(0) = 1/K$, where $1/K < z^*$ by default such that a first wave of FDI occurs and (14)–(15) apply. Next, note that $z(\frac{1 - \tilde{G}(\tilde{\theta}_{NS})}{d}) = \underline{z}$, which is the minimum value that z can possibly take and which occurs if $\tilde{\theta}_1 \to \infty$ and $\tilde{\theta}_0 \to \tilde{\theta}_{NS}$. Finally, note that $z(T)$ is a decreasing convex function of T.

On the other hand, note that $T(z^*) = 0$ and $T(\underline{z}) < \frac{1 - \tilde{G}(\tilde{\theta}_{NS})}{d}$. The former result follows from Proposition 3 (*iii*). The latter result follows from the fact that at $\underline{z} > 0$, the curve $\pi^S(\tilde{\theta}, z)$ is still concave and will hence intersect with $\pi^N(\tilde{\theta})$ at finite $\tilde{\theta}_1$ and at $\tilde{\theta}_0 > \tilde{\theta}_{NS}$, leading to $\tilde{G}(\tilde{\theta}_1(\underline{z})) < 1$ and $\tilde{G}(\tilde{\theta}_0(\underline{z})) > \tilde{G}(\tilde{\theta}_{NS})$. Recall that $\mathrm{d}\tilde{\theta}_0/\mathrm{d}z > 0$ and $\mathrm{d}\tilde{\theta}_1/\mathrm{d}z < 0$ by Proposition 3(*i*) and 3(*ii*). This implies that $\mathrm{d}T/\mathrm{d}z < 0$. Thus, $T(z)$ is a monotonically decreasing function of z.

The above characterizations of $T(z)$ and $z(T)$ are captured in Diagram (a) of Figure 4, where z is expressed along the horizontal axis and T the vertical axis. We note that the curve $T(z)$ crosses the curve $z(T)$ from below. The intersection of the two curves defines the steady-state level z^c, which implies the corresponding steady-state level of $(\tilde{\theta}_1^c, \tilde{\theta}_0^c)$. If there is a deviation from the steady state, for example, at Point "B" in Diagram (a), the system converges back to the steady-state level z^c. Thus, the steady state is also stable.

In Diagram (b), a more general scenario is illustrated, where the curve $T(z)$ is still monotonically decreasing in z but intersects with the curve $z(T)$ more than once. In this case, we note that there must be an odd number of steady-state solutions and more than one of them are stable. In fact, if the system starts from $z = 1/K$ as is the case in our dynamic setting, the stable steady state closer to $z = 1/K$ is the realized steady state, which is represented by Point "I" in Diagram (b). To conclude, there always exists a stable steady-state triplet $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$ which solves the system (14)–(16). ■

The above proposition indicates that the "magnet effect" in attracting new waves of FDI will die out eventually, instead of strengthening indefinitely, so that the dynamic process converges to a stable steady state. At the steady state, a finite range of firms engage in FDI, and the relocation of production from the North to the South ceases.

Lemma 6 *At a stable steady state $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$ of the system (14)–(16), the following holds:*

$$\begin{aligned} \lambda^c &\equiv (z^c)^2 d^{-1} \tilde{G}'(\tilde{\theta}_1^c) \left[\pi_\theta^S(\tilde{\theta}_1^c, z^c) - \psi^N\right]^{-1} \pi_z^S(\tilde{\theta}_1^c, z^c) \\ &- (z^c)^2 d^{-1} \tilde{G}'(\tilde{\theta}_0^c) \left[\pi_\theta^S(\tilde{\theta}_0^c, z^c) - \psi^N\right]^{-1} \pi_z^S(\tilde{\theta}_0^c, z^c) < 1. \end{aligned} \tag{19}$$

where $\pi_\theta^S \equiv \frac{\partial \pi^S(\tilde{\theta}, z)}{\partial \tilde{\theta}}$.

Proof of Lemma 6. The proof is shown in the appendix. ■

Note that $\pi_\theta^S(\tilde{\theta}_1, z) - \psi^N < 0$ and that $\pi_\theta^S(\tilde{\theta}_0, z) - \psi^N > 0$, which follow from the fact that the curve $\pi^S(\tilde{\theta}, z)$ crosses the schedule $\pi^N(\tilde{\theta})$ from below at $\tilde{\theta}_0$ and from above at $\tilde{\theta}_1$. Recall as well that $\pi_z^S(\tilde{\theta}, z) < 0$ for all $\tilde{\theta} > \tilde{b}$. Thus, λ defined at any given $(\tilde{\theta}_1, \tilde{\theta}_0, z)$ is a positive number. In particular, λ represents the secondary change to the risk elasticity z following a prior change in z. To see this, note that in (19), $\left|[\pi_\theta^S(\tilde{\theta}_1, z) - \psi^N]^{-1} \pi_z^S(\tilde{\theta}_1, z)\right|$ and $\left|[\pi_\theta^S(\tilde{\theta}_0, z) - \psi^N]^{-1} \pi_z^S(\tilde{\theta}_0, z)\right|$ measure respectively the increase in $\tilde{\theta}_1$ and the decrease in $\tilde{\theta}_0$ following a decrease in z. The terms preceding them, $z^2 d^{-1} \tilde{G}'(\tilde{\theta}_1)$ and $z^2 d^{-1} \tilde{G}'(\tilde{\theta}_0)$, then measure respectively how the increase in $\tilde{\theta}_1$

and the decrease in $\tilde{\theta}_0$ strengthen the knowledge diffusion T and further reduce the risk elasticity z. In other words, λ is the magnet power in terms of z in each wave of FDI. Lemma 6 indicates that for a steady state to be stable, a small shock to z must not magnify itself ($\lambda^c < 1$), so that the accumulated magnet effect (on z) given any shock to the system is finite (at $(1 - \lambda^c)^{-1}$).

Proposition 7 *The stable steady-state value of* $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$ *varies with the underlying parameters* (K, d, f^S, f^N, w^S) *in the following definite directions:*
(i) $\mathrm{d}\tilde{\theta}_1^c / \mathrm{d}K > 0$, $\mathrm{d}\tilde{\theta}_0^c / \mathrm{d}K < 0$, $\mathrm{d}z^c / \mathrm{d}K < 0$;
(ii) $\mathrm{d}\tilde{\theta}_1^c / \mathrm{d}d < 0$, $\mathrm{d}\tilde{\theta}_0^c / \mathrm{d}d > 0$, $\mathrm{d}z^c / \mathrm{d}d > 0$;
(iii) $\mathrm{d}\tilde{\theta}_1^c / \mathrm{d}f^S < 0$, $\mathrm{d}\tilde{\theta}_0^c / \mathrm{d}f^S > 0$, $\mathrm{d}z^c / \mathrm{d}f^S > 0$;
(iv) $\mathrm{d}\tilde{\theta}_1^c / \mathrm{d}f^N > 0$, $\mathrm{d}\tilde{\theta}_0^c / \mathrm{d}f^N < 0$, $\mathrm{d}z^c / \mathrm{d}f^N < 0$;
(v) $\mathrm{d}\tilde{\theta}_1^c / \mathrm{d}w^S < 0$, $\mathrm{d}\tilde{\theta}_0^c / \mathrm{d}w^S > 0$, $\mathrm{d}z^c / \mathrm{d}w^S > 0$.

Proof of Proposition 7. The proof is shown in the appendix. ■

The stated effects of the listed parameters in Proposition 7 are as expected. A better infrastructure in the South (larger K) and a lower barrier to knowledge diffusion (smaller d) decrease the FDI risk elasticity and increase the FDI success probability for all firms. This leads to a larger range of firms undertaking FDI at the steady state, and as a result, a lower level of FDI risk elasticity at the steady state. On the other hand, as the fixed organizational cost associated with FDI (domestic vertical integration) decreases (increases), or as the wage rate in the South falls, the balance tilts toward FDI and a larger range of firms find it more profitable to locate the production line in the South. With the larger presence of FDI in the South at the steady state, the FDI risk elasticity is also lower.

4. SIMULATION

In this section, we conduct simulations to illustrate the equilibrium convergent path and the magnet effect of FDI introduced above. By varying the parameter values, we will also illustrate the effects of such changes on the steady-state level $(\tilde{\theta}_1^c, \tilde{\theta}_0^c)$ as proposed in Proposition 7. We choose a Pareto distribution with shape k for the cumulative distribution function $G(\theta)$, i.e., $G(\theta) = 1-(b/\theta)^k$. This corresponds to a transformed cumulative distribution function $\tilde{G}(\tilde{\theta}) = 1 - \left(\tilde{b}/\tilde{\theta}\right)^{\tilde{k}}$, with $\tilde{k} \equiv \frac{1-\alpha}{\alpha} k$.

We choose the following parameter values for our benchmark case: $w^N = 4,\ w^S = 1,\ f^N = 1,\ f^S = 2,\ \alpha = 0.5,\ \delta = 0.64,\ \beta_0 = 0.5,\ \eta = 0.6,\ b = 100,\ K = 5,\ k = 1$, and $d = 1$. Substituting them into (7), one can derive ψ^N and ψ^S and verify that Assumption 1 holds. Given the parameter values, the time path of $\{(\theta_{0,t},\ \theta_{1,t})\}_{t=1}^{\infty}$ can be derived by iteration according to the system (14)–(16). The result for the benchmark case is shown in the middle panels of Figures 5–9.

We perturb the values of the following parameters $q \in \{K, d, f^S, f^N, w^S\}$ with respect to the benchmark case and derive the corresponding time path of $(\theta_{0,t},\ \theta_{1,t})$. For each parameter, two alternative values are tried to illustrate the effect of an increase and a decrease in the corresponding parameter value. We discuss the results for each of the parameters in turn.

Figure 5 illustrates the effect of the level of infrastructure in the South on the transition dynamics and the steady-state level of FDI. The parameter K is perturbed as follows: $K = \{5.25,\ 5,\ 4.75\}$. The results indicate that a better infrastructure in the South attracts a wider range of intermediate firms in the first wave of international production migration, which in turn creates larger externality and leads to a bigger second wave of international production migration. At the steady state, a wider range of intermediate firms undertake FDI in the South that has a higher level of infrastructure. It is straightforward to see that if the level of infrastructure in the South falls significantly below $K = 4.75$, the first wave of FDI will not start at all.

The next case demonstrates the effect of the economic distance between the host and the home country of FDI. We vary the parameter d according to: $d = \{10,\ 1,\ 0.5\}$. The results are shown in Figure 6. Conditional on the same level of infrastructure in the South, K, the same range of firms undertake FDI in the first wave of international production migration. However, given the same absolute mass of firms with production plants in the South in the first period, a shorter distance between the host and the home country facilitates greater knowledge diffusion and leads to a larger subsequent wave of international production migration. At the steady state, a wider range of intermediate firms undertake FDI in the South that is closer to the North.

The next two experiments look at how the extent of FDI is affected by the relative fixed cost of different organizational forms. The experiments are $f^S = \{2.05,\ 2,\ 1.95\}$ and $f^N = \{1.08,\ 1,\ 0.92\}$, respectively. The results in Figure 7 demonstrate that the required fixed organizational cost to have the intermediate input produced in the South is negatively correlated with the extent of FDI. As f^S increases, a smaller range of intermediate firms undertake FDI in the first wave of migration.

The effect then propagates to the subsequent waves of migration. At the steady state, a smaller range of intermediate firms undertake FDI in the South that requires a higher fixed organizational cost. Figure 8 shows that the fixed organizational cost of having the intermediate input produced in the North has exactly the opposite effect. As f^N increases, a larger range of intermediate firms relocate the production of intermediate inputs to the South in the first wave of migration. The trend continues until the steady state is reached.

Figure 9 illustrates the effect of wages in the South, w^S, on the extent of FDI. The variation for this parameter is: $w^S = \{1.02,\ 1,\ 0.9\}$. As shown by the figure, the higher the wage in the South is, the smaller is the range of intermediate firms undertaking FDI in the first period. The intuition is straightforward: as w^S increases, the expected profit for all firms by locating production in the South decreases, which in turn reduces the FDI incentive. Via the magnet effect, a smaller range of firms undertake FDI at the steady state.

5. EMPIRICAL OBSERVATIONS

The non-monotonic relationship between firm productivity and FDI propensity is observed in a sample of Taiwanese firms over a period of 15 years since 1991 when the Taiwanese government lifted the ban on westward FDI in mainland China. The details are shown in Figure 10. In the figure, the timing of the first-time FDI undertaken by a Taiwanese firm, measured as the number of quarters elapsed since 1991, is indicated along the vertical axis, and the (standardized) productivity level of a firm along the horizontal axis. A total number of 492 firms in the electronics industry are sampled.

The firms in the sample are firms listed on either the Taiwan Stock Exchange Corporation or the Over the Counter market. We compile the information on the timing of FDI for each firm based on the Foreign Direct Investment Database published by Taiwan Economic Journal Data Bank (TEJ) and the Yearly Report published by the Investment Commissions, Ministry of Economic Affairs, Taiwan. Our data do not allow us to distinguish between vertical and horizontal FDI. The productivity of a firm is measured by the ratio of Return on Assets (ROA). We take the average of the ratios for a firm between 1991 and 1993, as an indication of a firm's initial productivity level. The ROA data are taken from the TEJ Financial Statement Database.

As shown in the figure, the firms with intermediate productivity levels tend to undertake FDI earlier than the most and the least productive firms. This finding contradicts the conventional perception that higher-productivity firms have a higher tendency to undertake FDI than lower-productivity firms. The figure also suggests that the range of intermediate firms who undertake FDI expands over time, resembling a 'tornado cloud'. This dynamic feature echoes our simulation results.

6. CONCLUSION

This paper contributes to the literature on the dynamics of FDI entry. In a setting with heterogeneous firms, we investigate the role of uncertainty in firms' FDI decision and economic factors that determine the distribution of FDI uncertainty. It is hypothesized that FDI uncertainty depends on the level of infrastructure in the host country, the technology sophisticatedness of the transplanted product, and the mass of pre-existing firms with FDI experience.

The paper reaches the following predictions on the timing of FDI entry. First, FDI entry is not automatic and will occur only with a sufficiently high level of infrastructure in the host country. Second, a non-monotonic correlation is identified between the technology sophisticatedness of the product that a firm produces and the firm's optimal timing of FDI entry. Third, the presence of pioneering firms with FDI experience will help lower the overall investment uncertainty, by channeling industry-specific knowledge from the North to the South, and trigger consecutive waves of FDI entry. The strength of knowledge diffusion depends on cultural or language barriers and geographical distance. This implies that the self-reinforcing effect of FDI entry will vary across home-host country pairs. These predictions generated by the model are plausibly testable.

We conclude with some policy implications of our analysis: first, FDI liberalization may lead to an increase in the average industry productivity of the home country, since firms of intermediate productivity move out but those of high productivity continue to stay, especially in industries where investment uncertainty is highly sensitive to the sophisticatedness of production technology; second, the self-reinforcing effect may help explain why some small differences in the characteristics of host countries (such as infrastructure or FDI subsidies) can lead to substantial differences in the quality and quantity of FDI inflows; finally, the analysis in the paper suggests that the required provision of incentives (such as subsidies or tax exemptions) by host countries to attract FDI is non-linear in the technological level of firms and varies over time as the knowledge diffusion takes place.

APPENDIX: PROOFS OF PROPOSITIONS AND LEMMAS

Proof of Lemma 1. Define $\tilde{\theta}^+$ such that $\frac{\partial \pi^S}{\partial \tilde{\theta}}|_{\tilde{\theta}=\tilde{\theta}^+} = \frac{\partial \pi^N}{\partial \tilde{\theta}}|_{\tilde{\theta}=\tilde{\theta}^+}$; that is, $\tilde{\theta}^+$ is the productivity level where the two curves π^S and π^N have the same slope. It is straightforward to verify that

$$\tilde{\theta}^+ = \tilde{b}\left[(1-z)\frac{\psi^S}{\psi^N}\right]^{1/z} \quad \text{for } z < 1.$$

Thus, $\tilde{\theta}^+ \geq \tilde{b}$ if and only if $z \leq 1 - \frac{\psi^N}{\psi^S} \equiv \bar{z}$.

(i) For $0 < z < \bar{z}$, the difference between the two curves at $\tilde{\theta}^+$ is

$$\pi^S(\tilde{\theta}^+, z) - \pi^N(\tilde{\theta}^+) = \frac{z}{1-z}\tilde{\theta}^+\psi^N - w^N(f^S - f^N).$$

Define $\phi(z) \equiv \frac{z}{1-z}\tilde{\theta}^+$ and $g(z) \equiv \frac{1-z}{z}$. It is straightforward to show that

$$\begin{aligned}\frac{\partial \tilde{\theta}^+}{\partial z} &= \frac{\partial ln\tilde{\theta}^+}{\partial z}\,\tilde{\theta}^+ \\ &= \left\{-\frac{1}{z^2}ln\left[(1-z)\frac{\psi^S}{\psi^N}\right] - \frac{1}{z(1-z)}\right\}\tilde{\theta}^+ < 0,\end{aligned}$$

where the last inequality follows from the fact that $(1-z)\frac{\psi^S}{\psi^N} > 1$ for $0 < z < \bar{z}$. Because $\lim_{z\to 0}\tilde{\theta}^+ \to \infty$ and $\lim_{z\to 0} g(z) \to \infty$, by L'Hôpital rule,

$$\begin{aligned}\lim_{z\to 0}\phi(z) &= \lim_{z\to 0}\frac{\partial\tilde{\theta}^+/\partial z}{\partial g(z)/\partial z} \\ &= \lim_{z\to 0}\left\{ln\left[(1-z)\frac{\psi^S}{\psi^N}\right] + \frac{z}{1-z}\right\}\tilde{\theta}^+ \to \infty.\end{aligned}$$

Thus,

$$\lim_{z\to 0}\pi^S(\tilde{\theta}^+, z) - \pi^N(\tilde{\theta}^+) \to \infty.$$

On the other hand, it is straightforward to show that $\lim_{z\to\bar{z}} \phi(z) = \frac{\bar{z}}{1-\bar{z}}\ \tilde{b} = \frac{\psi^S - \psi^N}{\psi^N}\ \tilde{b}$. Therefore,

$$\lim_{z\to\bar{z}} \pi^S(\tilde{\theta}^+, z) - \pi^N(\tilde{\theta}^+) = \tilde{b}(\psi^S - \psi^N) - w^N(f^S - f^N) < 0,$$

where the last inequality follows by Assumption 1. Finally, observe that for $0 < z < \bar{z}$,

$$\begin{aligned}
\frac{\partial \phi(z)}{\partial z} &= \left[\frac{\partial ln\tilde{\theta}^+}{\partial z} - \frac{\partial ln\ g(z)}{\partial z}\right]\phi(z) \\
&= \left\{-\frac{1}{z^2} ln\left[(1-z)\frac{\psi^S}{\psi^N}\right] - \frac{1}{z(1-z)} + \frac{1}{z(1-z)}\right\}\phi(z) \\
&= \left\{-\frac{1}{z^2} ln\left[(1-z)\frac{\psi^S}{\psi^N}\right]\right\}\phi(z) < 0.
\end{aligned}$$

Therefore,

$$\partial\left[\pi^S(\tilde{\theta}^+, z) - \pi^N(\tilde{\theta}^+)\right]/\partial z < 0.$$

In summary, as $z \to 0$, $\pi^S(\tilde{\theta}, z)$ becomes linear, and $\tilde{\theta}^+ \to \infty$. The difference between $\pi^S(\tilde{\theta}, z)$ and $\pi^N(\tilde{\theta})$ at $\tilde{\theta} = \tilde{\theta}^+$ approaches infinity. As z increases, $\tilde{\theta}^+$ decreases and the difference between $\pi^S(\tilde{\theta}^+, z)$ and $\pi^N(\tilde{\theta}^+)$ also decreases monotonically. At $z = \bar{z}$, $\tilde{\theta}^+ = \tilde{b}$ and the difference between $\pi^S(\tilde{\theta}^+, z)$ and $\pi^N(\tilde{\theta}^+)$ becomes negative. Therefore, there must exist a unique $z^* \in (0, \bar{z})$ such that $\pi^S(\tilde{\theta}^+, z^*) - \pi^N(\tilde{\theta}^+) = 0$. In other words, the curve $\pi^S(\tilde{\theta}, z)$ is tangent to $\pi^N(\tilde{\theta})$ at $z = z^*$.

For $z \in (0, z^*)$, $\pi^S(\tilde{\theta}^+, z) - \pi^N(\tilde{\theta}^+) > 0$. Thus, the curve $\pi^S(\tilde{\theta}, z)$ must have intersected with the line $\pi^N(\tilde{\theta})$ twice. Label the corresponding productivity levels $\tilde{\theta}_0$ and $\tilde{\theta}_1$ with $\tilde{\theta}_0 < \tilde{\theta}_1$, such that $\pi^S(\tilde{\theta}, z) - \pi^N(\tilde{\theta}) = 0$ at $\tilde{\theta} = \{\tilde{\theta}_0, \tilde{\theta}_1\}$. Then it follows from the concavity of $\pi^S(\tilde{\theta}, z)$ that $\pi^S(\tilde{\theta}, z) - \pi^N(\tilde{\theta}) > 0$ for all $\tilde{\theta} \in (\tilde{\theta}_0, \tilde{\theta}_1)$. Next, note that for $z > 0$, the curve $\pi^S(\tilde{\theta}, z)$ falls below the line $\tilde{\pi}^S(\tilde{\theta}) = \psi^S\tilde{\theta} - w^N f^S$, which intersects with the line $\pi^N(\tilde{\theta})$ at $\tilde{\theta}_{NS}$. Thus, it must be the case that $\tilde{\theta}_0 > \tilde{\theta}_{NS}$ for $z > 0$. Moreover, because $\tilde{\theta}_0 > \tilde{\theta}_N$, it follows that $\pi^N(\tilde{\theta}) > 0$ for $\tilde{\theta} \in (\tilde{\theta}_0, \tilde{\theta}_1)$. Therefore, $\pi^S(\tilde{\theta}, z) > \pi^N(\tilde{\theta}) > 0$ for all $\tilde{\theta} \in (\tilde{\theta}_0, \tilde{\theta}_1)$, where $\tilde{\theta}_{NS} < \tilde{\theta}_0 < \tilde{\theta}_1$. It also follows from the concavity of $\pi^S(\tilde{\theta}, z)$ that $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ for all $\tilde{\theta} \in [\tilde{b}, \tilde{\theta}_0) \cup (\tilde{\theta}_1, \infty)$.

(ii) For $z^* < z < \bar{z}$, the curve $\pi^S(\tilde{\theta}, z)$ falls completely below the line $\pi^N(\tilde{\theta})$ for all $\tilde{\theta} \in [\tilde{b}, \infty)$. Thus, $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ for all $\tilde{\theta} \in [\tilde{b}, \infty)$.

For $\bar{z} \leq z < 1$, $\tilde{\theta}^+ \leq \tilde{b}$, and because $\frac{\partial \pi^S}{\partial \tilde{\theta}}$ is decreasing in $\tilde{\theta}$, it follows that $\frac{\partial \pi^S}{\partial \tilde{\theta}} < \frac{\partial \pi^N}{\partial \tilde{\theta}}$, for all $\tilde{\theta} > \tilde{b}$. In addition, $\pi^S(\tilde{b}, z) < \pi^N(\tilde{b})$ by Assumption 1. It follows that $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ for all

$\tilde{\theta} \in [\tilde{b}, \infty)$.

For $z \geq 1$, the curve $\pi^S(\tilde{\theta}, z)$ is (weakly) decreasing in $\tilde{\theta}$. Given that $\pi^S(\tilde{b}, z) < \pi^N(\tilde{b})$ by Assumption 1, it follows that $\pi^S(\tilde{\theta}, z) < \pi^N(\tilde{\theta})$ for all $\tilde{\theta} \in [\tilde{b}, \infty)$.

The desired result in (*ii*) therefore follows. ∎

Proof of Proposition 3. Recall that by definition,

$$\pi^S(\tilde{\theta}_1, z) - \pi^N(\tilde{\theta}_1) = 0 \tag{20}$$

$$\pi^S(\tilde{\theta}_0, z) - \pi^N(\tilde{\theta}_0) = 0 \tag{21}$$

with $\tilde{\theta}_0 < \tilde{\theta}_1$. Take total derivatives of (20) and (21) with respect to $\tilde{\theta}_1$, $\tilde{\theta}_0$ and z and define $\pi^S_\theta \equiv \frac{\partial \pi^S(\tilde{\theta}, z)}{\partial \tilde{\theta}}$. We obtain

$$\mathrm{d}\tilde{\theta}_1/\mathrm{d}z = -\left[\pi^S_\theta(\tilde{\theta}_1, z) - \psi^N\right]^{-1} \pi^S_z(\tilde{\theta}_1, z) < 0 \tag{22}$$

$$\mathrm{d}\tilde{\theta}_0/\mathrm{d}z = -\left[\pi^S_\theta(\tilde{\theta}_0, z) - \psi^N\right]^{-1} \pi^S_z(\tilde{\theta}_0, z) > 0 \tag{23}$$

where the inequalities follow from the fact that $(\pi^S_\theta(\tilde{\theta}_1, z) - \psi^N) < 0$, $(\pi^S_\theta(\tilde{\theta}_0, z) - \psi^N) > 0$ and that $\pi^S_z(\tilde{\theta}, z) < 0$ for all $\tilde{\theta} > \tilde{b}$. The results (22) and (23) imply that $\mathrm{d}(\tilde{\theta}_1 - \tilde{\theta}_0)/\mathrm{d}z < 0$. As $z \to 0$, $\pi^S(\tilde{\theta}, z) \to \tilde{\pi}^S(\tilde{\theta}) = \psi^S \tilde{\theta} - w^N f^S$; thus $\tilde{\theta}_0 \to \tilde{\theta}_{NS}$ and $\tilde{\theta}_1 \to \infty$. On the other hand, as $z \to z^*$, the curve $\pi^S(\tilde{\theta}, z)$ becomes tangent to the line $\pi^N(\tilde{\theta})$; thus, $\tilde{\theta}_0 \to \tilde{\theta}_1$. ∎

Proof of Lemma 6. Refer to Figure 4. Note that at a stable steady state, the curve $T(z)$ crosses the curve $z(T)$ from below. Thus, at a stable steady state, the slope of $T(z)$ in absolute value is smaller than the slope of $z^{-1}(T)$ in absolute value, where $z^{-1}(T)$ denotes the inverse function of $z(T)$. It is straightforward to see that $z^{-1}(T)$ is $T = 1/z - K$. It follows that at a stable steady state $(\tilde{\theta}^c_1, \tilde{\theta}^c_0, z^c)$,

$$\begin{aligned}
&\left|\text{slope of } T(z)\right| < \left|\text{slope of } z^{-1}(T)\right| \\
\Rightarrow\ & \left|d^{-1}\tilde{G}'(\tilde{\theta}^c_1)\ (\mathrm{d}\tilde{\theta}^c_1/\mathrm{d}z) - d^{-1}\tilde{G}'(\tilde{\theta}^c_0)\ (\mathrm{d}\tilde{\theta}^c_0/\mathrm{d}z)\right| < \left|-1/(z^c)^2\right| \\
\Rightarrow\ & -d^{-1}\tilde{G}'(\tilde{\theta}^c_1)\ (\mathrm{d}\tilde{\theta}^c_1/\mathrm{d}z) + d^{-1}\tilde{G}'(\tilde{\theta}^c_0)\ (\mathrm{d}\tilde{\theta}^c_0/\mathrm{d}z) < 1/(z^c)^2 \\
\Rightarrow\ & -(z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}^c_1)\ (\mathrm{d}\tilde{\theta}^c_1/\mathrm{d}z) + (z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}^c_0)\ (\mathrm{d}\tilde{\theta}^c_0/\mathrm{d}z) < 1.
\end{aligned}$$

Substitute $\mathrm{d}\tilde{\theta}_1^c/\mathrm{d}z$ and $\mathrm{d}\tilde{\theta}_0^c/\mathrm{d}z$ with the expressions from (22) and (23), and evaluate them at the steady-state value $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$. The desired result (19) follows. ■

Proof of Proposition 7. At the steady state, the system (14)–(16) becomes

$$\begin{aligned} \pi^S(\tilde{\theta}_1^c, z^c) - \pi^N(\tilde{\theta}_1^c) &= 0 \quad (24) \\ \pi^S(\tilde{\theta}_0^c, z^c) - \pi^N(\tilde{\theta}_0^c) &= 0 \quad (25) \\ z^c - \frac{1}{K + d^{-1}\tilde{G}(\tilde{\theta}_1^c) - d^{-1}\tilde{G}(\tilde{\theta}_0^c)} &= 0 \quad (26) \end{aligned}$$

(i) and (ii): Let $q \in \{K, d\}$ represent the parameter of interest. Taking total derivatives of the system (24)–(26) with respect to $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$ and q, we obtain:

$$\begin{bmatrix} \pi_\theta^S(\tilde{\theta}_1^c, z^c) - \psi^N & 0 & \pi_z^S(\tilde{\theta}_1^c, z^c) \\ 0 & \pi_\theta^S(\tilde{\theta}_0^c, z^c) - \psi^N & \pi_z^S(\tilde{\theta}_0^c, z^c) \\ (z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}_1^c) & -(z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}_0^c) & 1 \end{bmatrix} \begin{bmatrix} \mathrm{d}\tilde{\theta}_1^c \\ \mathrm{d}\tilde{\theta}_0^c \\ \mathrm{d}z^c \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ (\partial z^c/\partial q)\mathrm{d}q \end{bmatrix}. \quad (27)$$

Express $\mathrm{d}\tilde{\theta}_1^c$ and $\mathrm{d}\tilde{\theta}_0^c$ in terms of $\mathrm{d}z^c$ using the first two rows of (27) and substitute them into the third row. We obtain,

$$(1 - \lambda^c)\,\mathrm{d}z^c = (\partial z^c/\partial q)\mathrm{d}q. \quad (28)$$

Given that $\partial z^c/\partial K = -(z^c)^2 < 0$, it follows that

$$\begin{aligned} \mathrm{d}z^c/\mathrm{d}K &= (1 - \lambda^c)^{-1}(\partial z^c/\partial K) < 0, \quad (29) \\ \mathrm{d}\tilde{\theta}_1^c/\mathrm{d}K &= (\mathrm{d}\tilde{\theta}_1^c/\mathrm{d}z^c)(\mathrm{d}z^c/\mathrm{d}K) > 0, \quad (30) \\ \mathrm{d}\tilde{\theta}_0^c/\mathrm{d}K &= (\mathrm{d}\tilde{\theta}_0^c/\mathrm{d}z^c)(\mathrm{d}z^c/\mathrm{d}K) < 0, \quad (31) \end{aligned}$$

where we have used Lemma 6 and Equations (22) and (23). Similarly, given that $\partial z^c/\partial d = (z^c)^2 d^{-2}[\tilde{G}(\tilde{\theta}_1^c) - \tilde{G}(\tilde{\theta}_0^c)] > 0$, it follows that

$$\begin{aligned} \mathrm{d}z^c/\mathrm{d}d &= (1 - \lambda^c)^{-1}(\partial z^c/\partial d) > 0, \quad (32) \\ \mathrm{d}\tilde{\theta}_1^c/\mathrm{d}d &= (\mathrm{d}\tilde{\theta}_1^c/\mathrm{d}z^c)(\mathrm{d}z^c/\mathrm{d}d) < 0, \quad (33) \\ \mathrm{d}\tilde{\theta}_0^c/\mathrm{d}d &= (\mathrm{d}\tilde{\theta}_0^c/\mathrm{d}z^c)(\mathrm{d}z^c/\mathrm{d}d) > 0, \quad (34) \end{aligned}$$

by Lemma 6 and Equations (22) and (23).

(iii)–*(v)*: Let $q \in \{f^S, f^N, w^S\}$ represent the parameter of interest. Taking total derivatives of the system (24)–(26) with respect to $(\tilde{\theta}_1^c, \tilde{\theta}_0^c, z^c)$ and q, we obtain:

$$\begin{bmatrix} \pi_\theta^S(\tilde{\theta}_1^c, z^c) - \psi^N & 0 & \pi_z^S(\tilde{\theta}_1^c, z^c) \\ 0 & \pi_\theta^S(\tilde{\theta}_0^c, z^c) - \psi^N & \pi_z^S(\tilde{\theta}_0^c, z^c) \\ (z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}_1^c) & -(z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}_0^c) & 1 \end{bmatrix} \begin{bmatrix} \mathrm{d}\tilde{\theta}_1^c \\ \mathrm{d}\tilde{\theta}_0^c \\ \mathrm{d}z^c \end{bmatrix} = \begin{bmatrix} -\left[\pi_q^S(\tilde{\theta}_1^c, z^c) - \pi_q^N(\tilde{\theta}_1^c)\right]\mathrm{d}q \\ -\left[\pi_q^S(\tilde{\theta}_0^c, z^c) - \pi_q^N(\tilde{\theta}_0^c)\right]\mathrm{d}q \\ 0 \end{bmatrix} \quad (35)$$

Express $\mathrm{d}\tilde{\theta}_1^c$ and $\mathrm{d}\tilde{\theta}_0^c$ in terms of $\mathrm{d}z^c$ and $\mathrm{d}q$ using the first two rows of (35) and substitute them into the third row. We obtain

$$\begin{aligned} (1-\lambda^c)\,\mathrm{d}z^c &= (z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}_1^c)\left[\pi_\theta^S(\tilde{\theta}_1^c, z^c) - \psi^N\right]^{-1}\left[\pi_q^S(\tilde{\theta}_1^c, z^c) - \pi_q^N(\tilde{\theta}_1^c)\right]\mathrm{d}q \\ &- (z^c)^2 d^{-1}\tilde{G}'(\tilde{\theta}_0^c)\left[\pi_\theta^S(\tilde{\theta}_0^c, z^c) - \psi^N\right]^{-1}\left[\pi_q^S(\tilde{\theta}_0^c, z^c) - \pi_q^N(\tilde{\theta}_0^c)\right]\mathrm{d}q \\ &\equiv \Omega_q^c \mathrm{d}q \end{aligned}$$

In the case of the parameter f^S, given that $\left[\pi_{f^S}^S(\tilde{\theta}, z) - \pi_{f^S}^N(\tilde{\theta})\right] = -w^N < 0$, it follows that $\Omega_{f^S}^c > 0$. Furthermore, using Lemma 6 and the system (35), we have

$$\mathrm{d}z^c/\mathrm{d}f^S = (1-\lambda^c)^{-1}\Omega_{f^S}^c > 0 \quad (36)$$

$$\begin{aligned} \mathrm{d}\tilde{\theta}_1^c/\mathrm{d}f^S = &- \left[\pi_\theta^S(\tilde{\theta}_1^c, z^c) - \psi^N\right]^{-1}\pi_z^S(\tilde{\theta}_1^c, z^c)\,\mathrm{d}z^c/\mathrm{d}f^S \\ &- \left[\pi_\theta^S(\tilde{\theta}_1^c, z^c) - \psi^N\right]^{-1}\left[\pi_{f^S}^S(\tilde{\theta}_1^c, z^c) - \pi_{f^S}^N(\tilde{\theta}_1^c)\right] < 0 \end{aligned} \quad (37)$$

$$\begin{aligned} \mathrm{d}\tilde{\theta}_0^c/\mathrm{d}f^S = &- \left[\pi_\theta^S(\tilde{\theta}_0^c, z^c) - \psi^N\right]^{-1}\pi_z^S(\tilde{\theta}_0^c, z^c)\,\mathrm{d}z^c/\mathrm{d}f^S \\ &- \left[\pi_\theta^S(\tilde{\theta}_0^c, z^c) - \psi^N\right]^{-1}\left[\pi_{f^S}^S(\tilde{\theta}_0^c, z^c) - \pi_{f^S}^N(\tilde{\theta}_0^c)\right] > 0. \end{aligned} \quad (38)$$

In the case of the parameter f^N, given that $\left[\pi_{f^N}^S(\tilde{\theta}, z) - \pi_{f^N}^N(\tilde{\theta})\right] = w^N > 0$, it follows that

$\Omega^c_{f^N} < 0$. Similarly, by using Lemma 6 and the system (35), we obtain:

$$
\begin{aligned}
\mathrm{d}z^c/\mathrm{d}f^N = & \quad (1-\lambda^c)^{-1}\Omega^c_{f^N} < 0 && (39)\\
\mathrm{d}\tilde{\theta}^c_1/\mathrm{d}f^N = & -\left[\pi^S_\theta(\tilde{\theta}^c_1, z^c) - \psi^N\right]^{-1} \pi^S_z(\tilde{\theta}^c_1, z^c)\ \mathrm{d}z^c/\mathrm{d}f^N \\
& -\left[\pi^S_\theta(\tilde{\theta}^c_1, z^c) - \psi^N\right]^{-1} \left[\pi^S_{f^N}(\tilde{\theta}^c_1, z^c) - \pi^N_{f^N}(\tilde{\theta}^c_1)\right] > 0 && (40)\\
\mathrm{d}\tilde{\theta}^c_0/\mathrm{d}f^N = & -\left[\pi^S_\theta(\tilde{\theta}^c_0, z^c) - \psi^N\right]^{-1} \pi^S_z(\tilde{\theta}^c_0, z^c)\ \mathrm{d}z^c/\mathrm{d}f^N \\
& -\left[\pi^S_\theta(\tilde{\theta}^c_0, z^c) - \psi^N\right]^{-1} \left[\pi^S_{f^N}(\tilde{\theta}^c_0, z^c) - \pi^N_{f^N}(\tilde{\theta}^c_0)\right] < 0. && (41)
\end{aligned}
$$

In the case of the parameter w^S, given that $\left[\pi^S_{w^S}(\tilde{\theta}, z) - \pi^N_{w^S}(\tilde{\theta})\right] = -\frac{(1-\eta)\alpha}{w^S(1-\alpha)}\psi^S\tilde{b}^z\tilde{\theta}^{1-z} < 0$, it follows that $\Omega^c_{w^S} > 0$. Using Lemma 6 and the system (35) again, we have:

$$
\begin{aligned}
\mathrm{d}z^c/\mathrm{d}w^S = & \quad (1-\lambda^c)^{-1}\Omega^c_{w^S} > 0 && (42)\\
\mathrm{d}\tilde{\theta}^c_1/\mathrm{d}w^S = & -\left[\pi^S_\theta(\tilde{\theta}^c_1, z^c) - \psi^N\right]^{-1} \pi^S_z(\tilde{\theta}^c_1, z^c)\ \mathrm{d}z^c/\mathrm{d}w^S \\
& -\left[\pi^S_\theta(\tilde{\theta}^c_1, z^c) - \psi^N\right]^{-1} \left[\pi^S_{w^S}(\tilde{\theta}^c_1, z^c) - \pi^N_{w^S}(\tilde{\theta}^c_1)\right] < 0 && (43)\\
\mathrm{d}\tilde{\theta}^c_0/\mathrm{d}w^S = & -\left[\pi^S_\theta(\tilde{\theta}^c_0, z^c) - \psi^N\right]^{-1} \pi^S_z(\tilde{\theta}^c_0, z^c)\ \mathrm{d}z^c/\mathrm{d}w^S \\
& -\left[\pi^S_\theta(\tilde{\theta}^c_0, z^c) - \psi^N\right]^{-1} \left[\pi^S_{w^S}(\tilde{\theta}^c_0, z^c) - \pi^N_{w^S}(\tilde{\theta}^c_0)\right] > 0. && (44)
\end{aligned}
$$

It is straightforward to verify that $\partial z^c/\partial q$ in (27) is indefinite for $q \in \{k\}$ and that $\pi^S_q(\tilde{\theta}, z) - \pi^N_q(\tilde{\theta})$ in (35) is indefinite for $q \in \{w^N, \eta, \delta, \beta_0, \alpha\}$. Thus, their effects on $(\tilde{\theta}^c_1, \tilde{\theta}^c_0, z^c)$ are indefinite. ■

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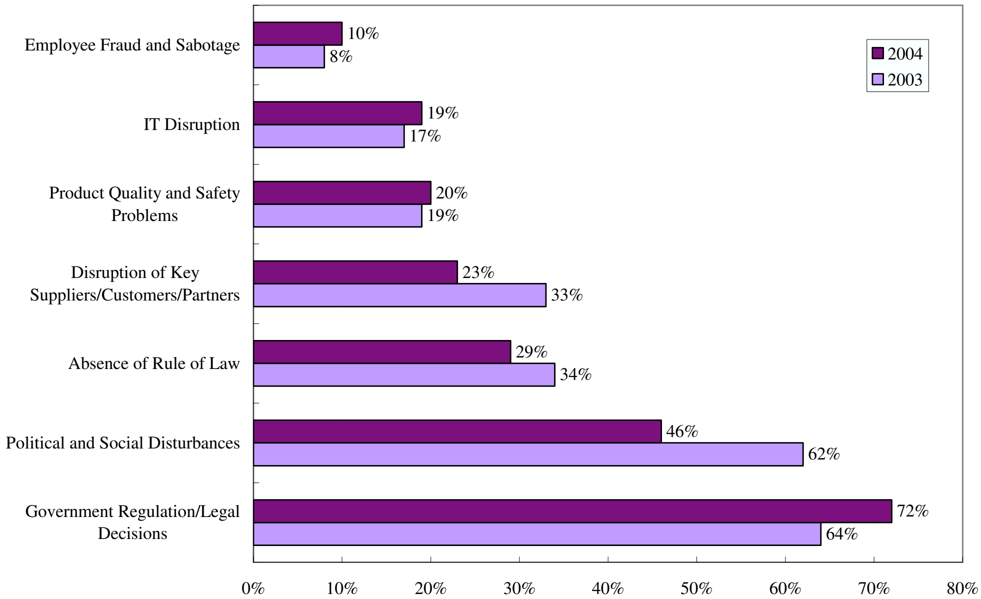
Figure 1: The Most Critical Risks to Global Operation: Year 2003/2004



Note:
1. The survey was conducted by the A.T.Kearney, Inc. (A.T.Kearney, 2004, Figure 7).
2. The respondents are 1000 CEO's or top managers from the world's largest 1000 companies.
3. The numbers in the chart indicate the percentages of the total number of respondents who consider the cited risk factor as important in their decisions to undertake global operation.

Figure 2: $\pi^S(\tilde{\theta}, z)$ as z varies

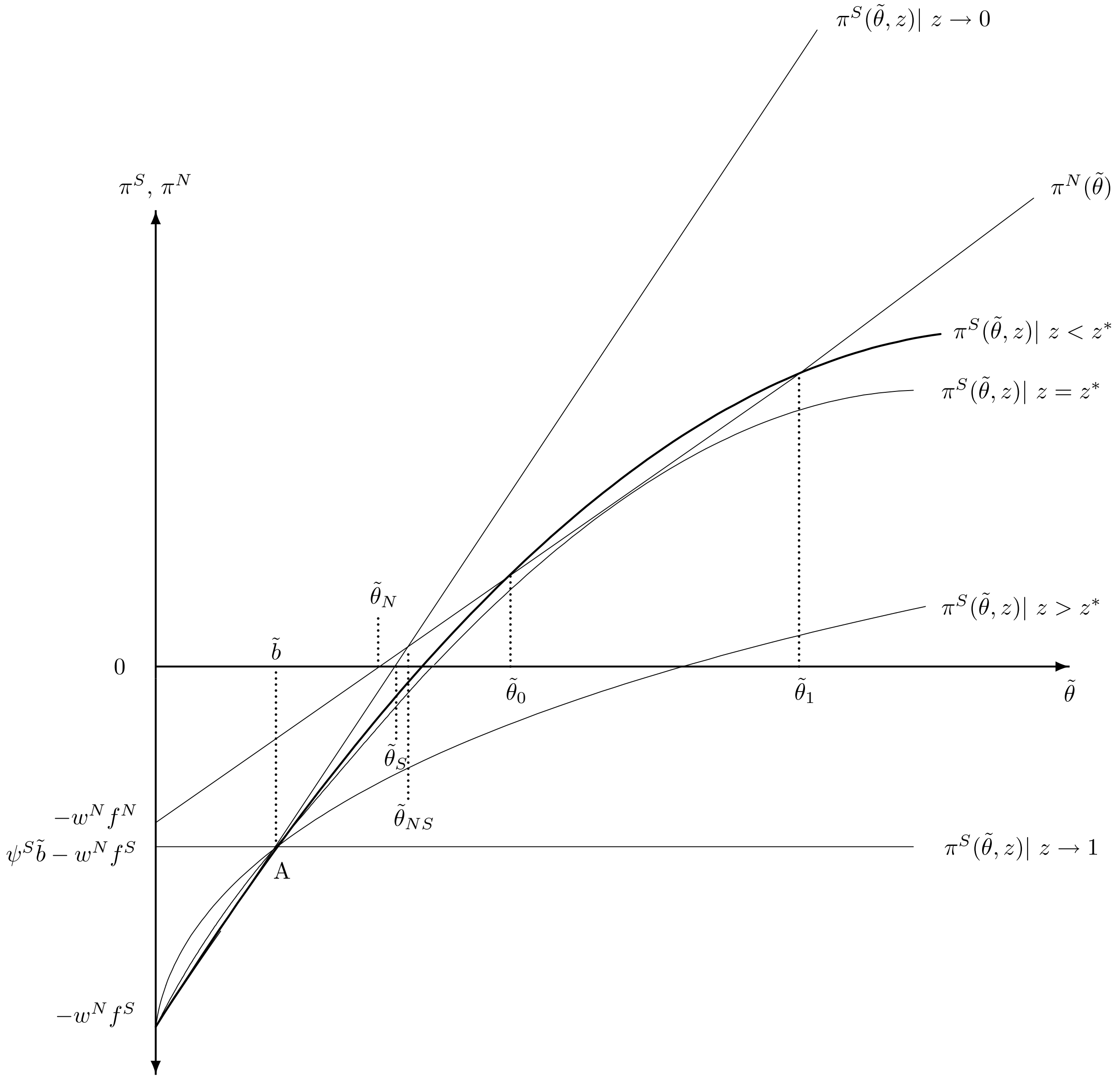


Figure 3: Magnet Effect of FDI

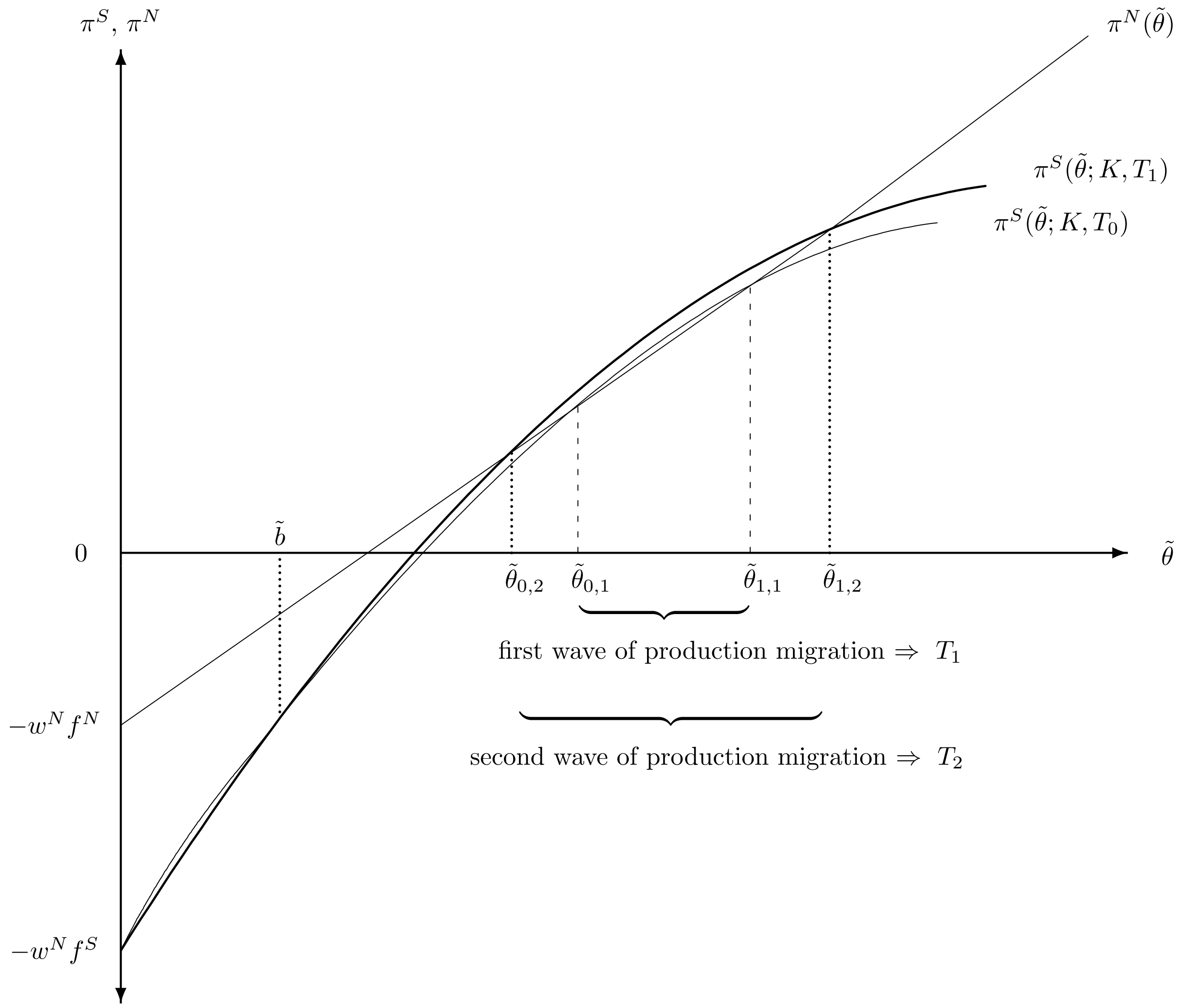
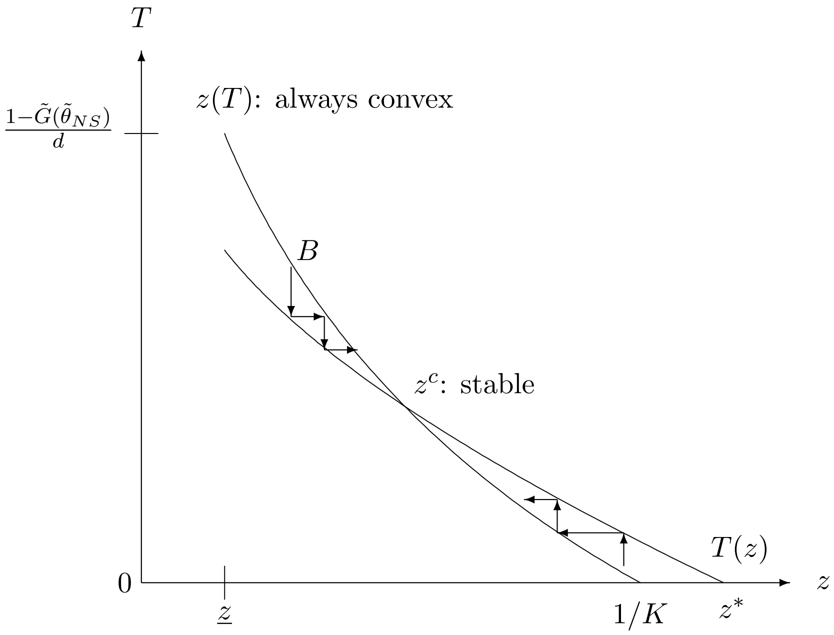


Figure 4: Existence and Stability of Steady State

(**a**)



(**b**)

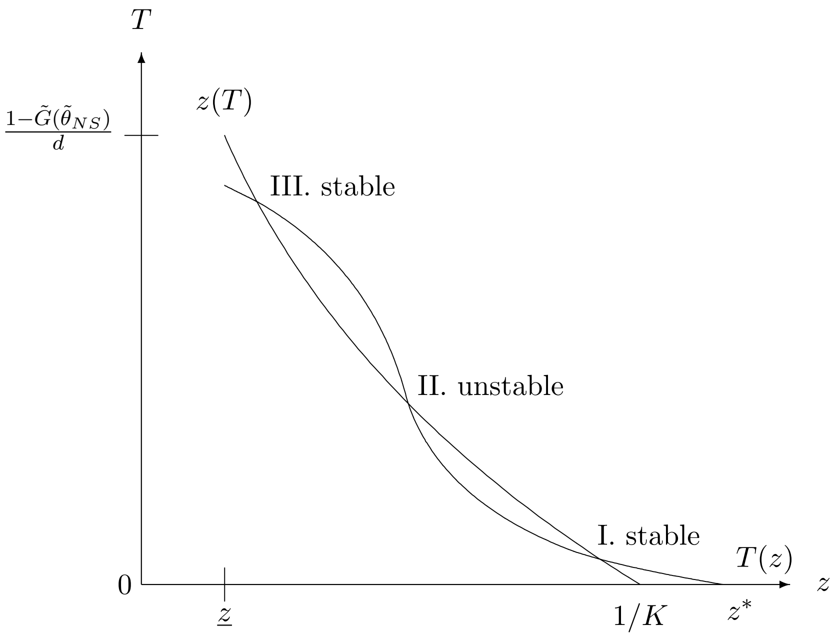


Figure 5: Effects of K on the Dynamics of FDI

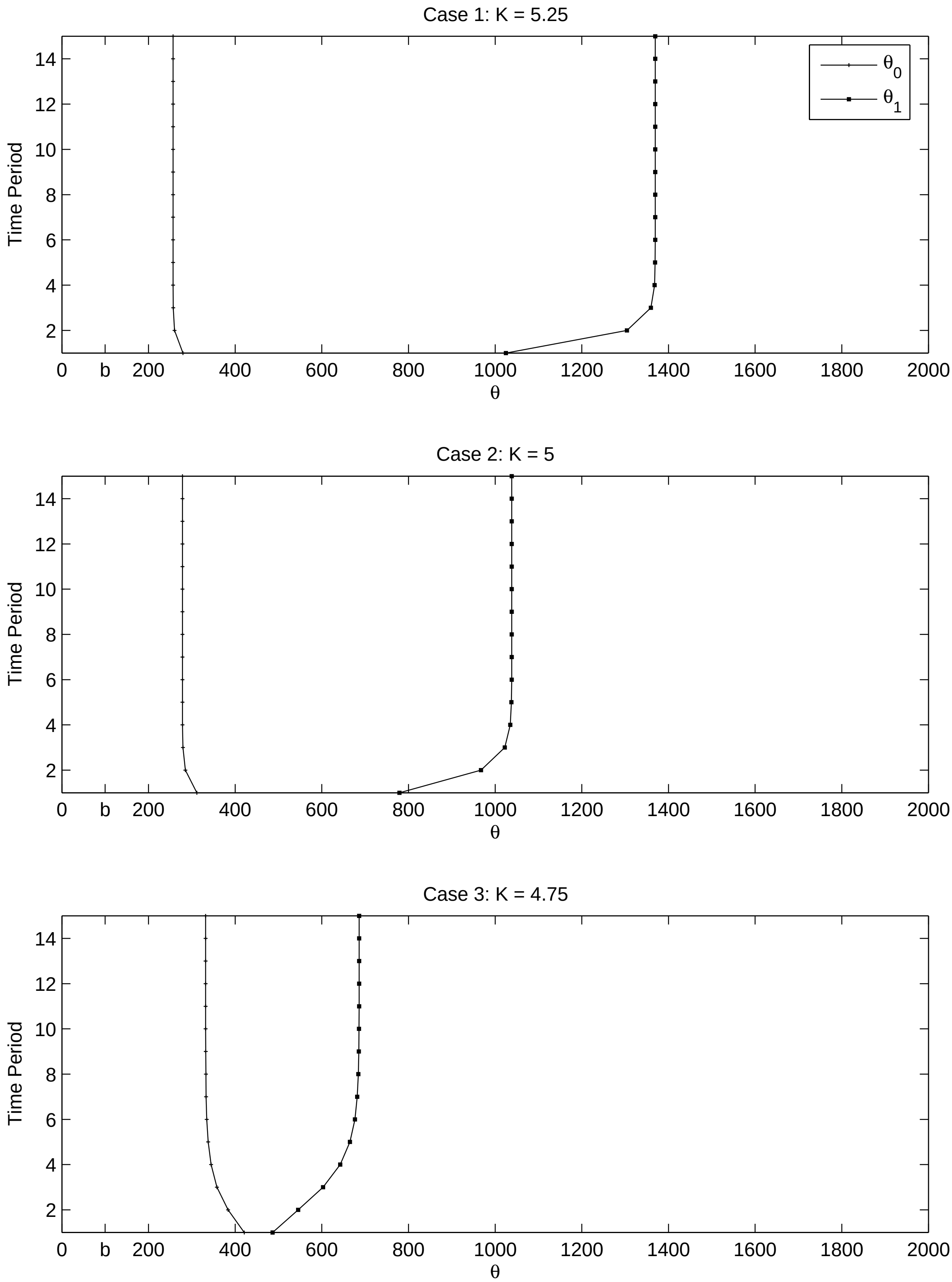


Figure 6: Effects of d on the Dynamics of FDI

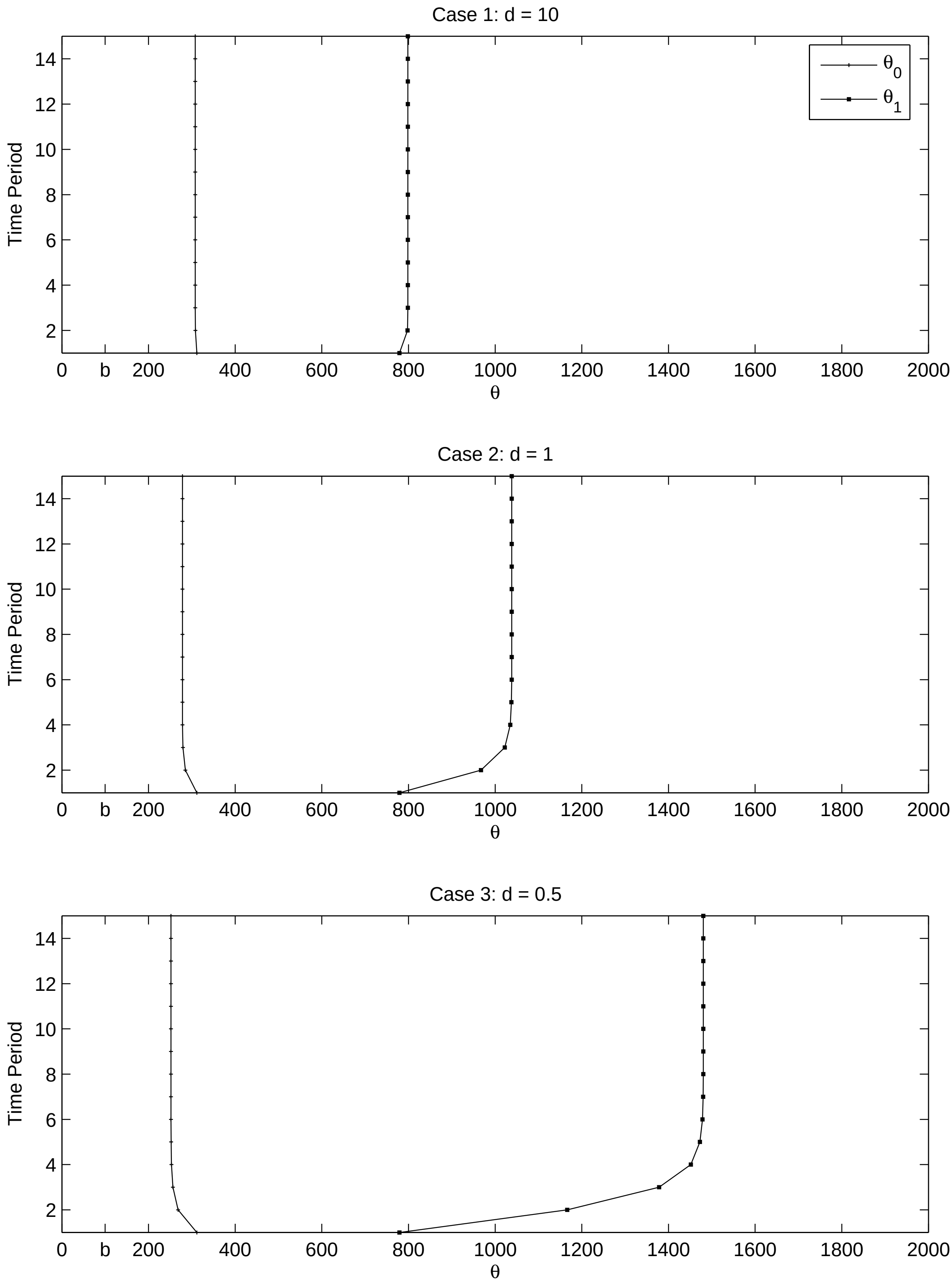


Figure 7: Effects of f^S on the Dynamics of FDI

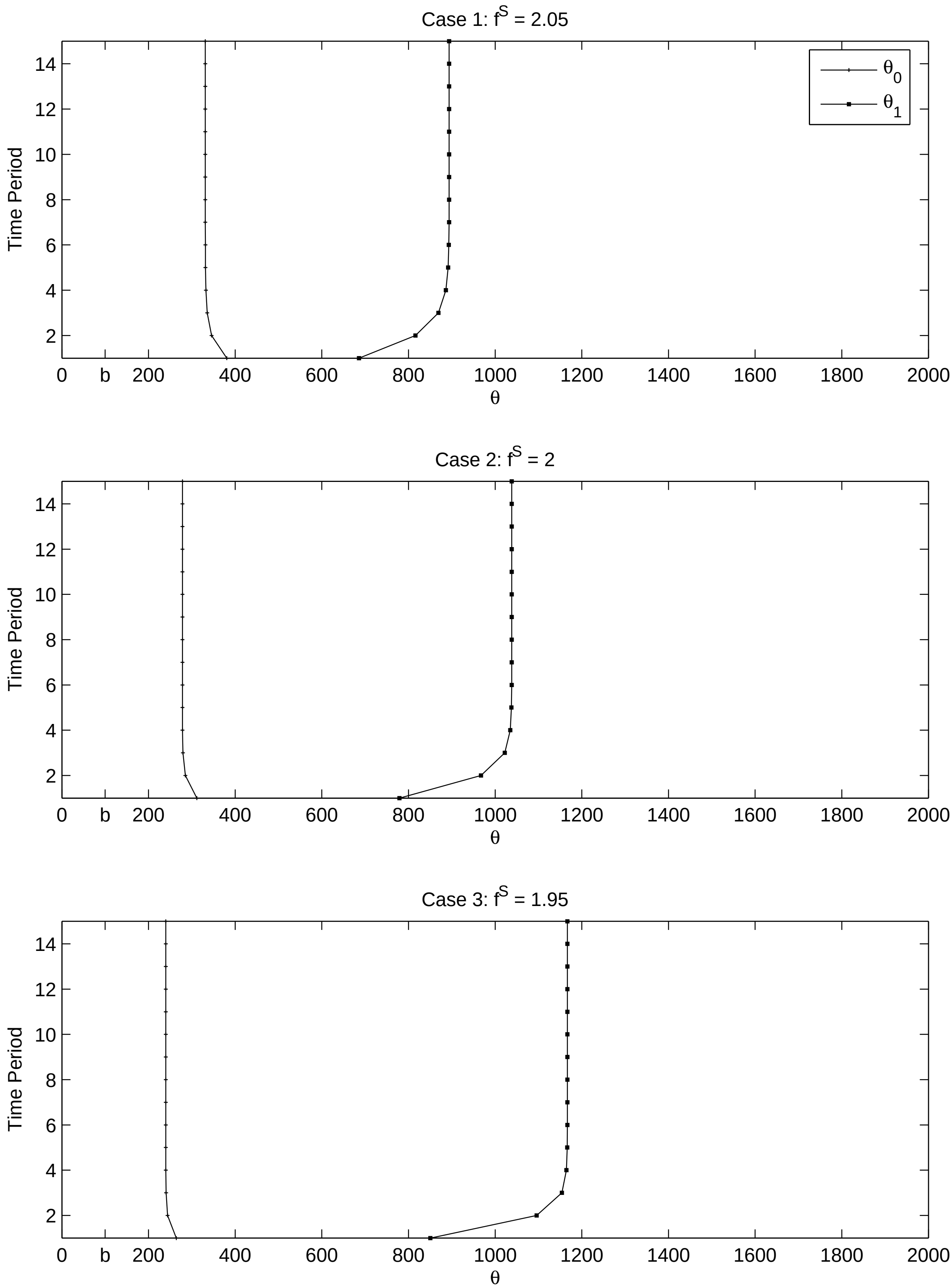


Figure 8: Effects of f^N on the Dynamics of FDI

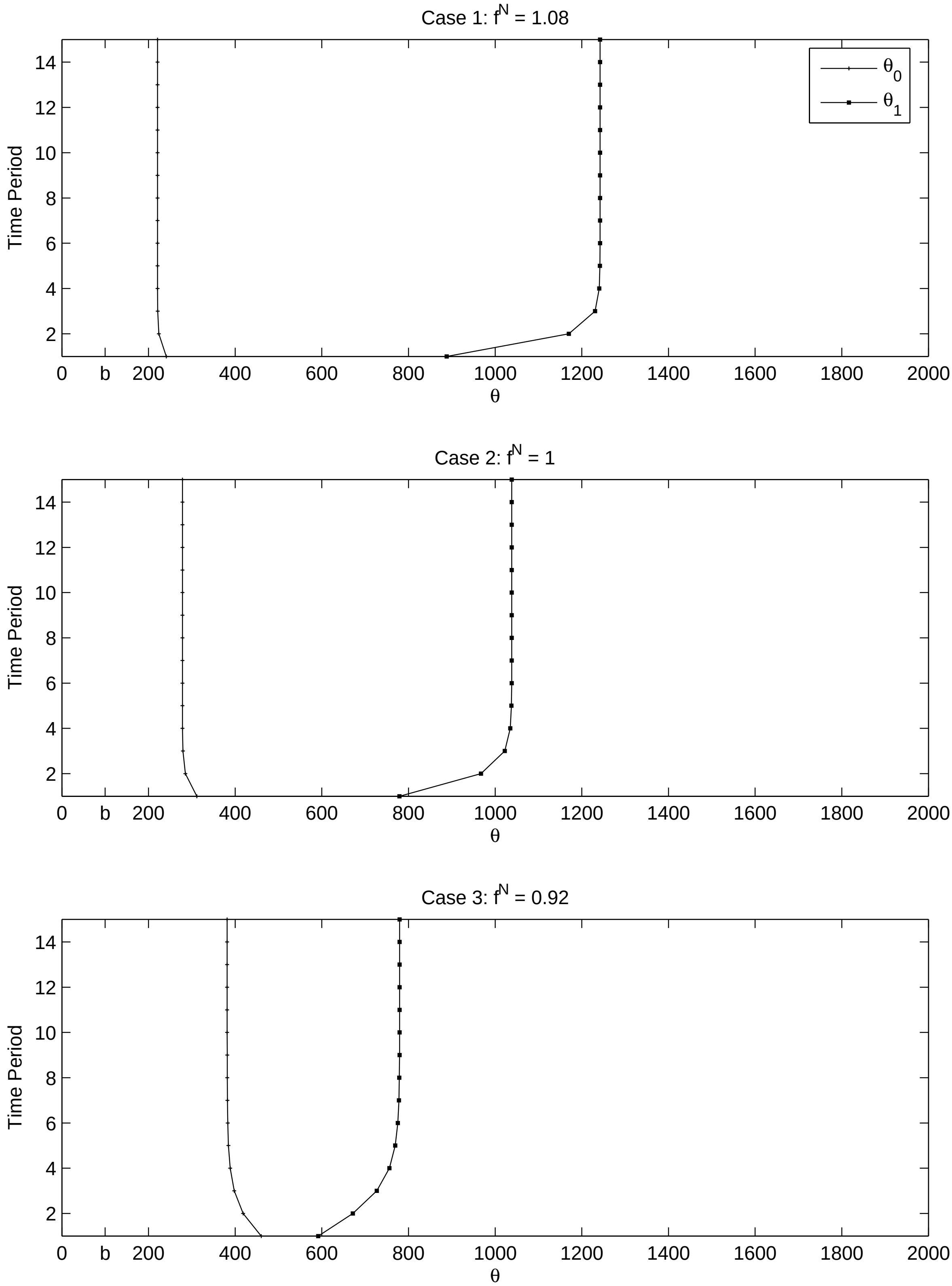


Figure 9: Effects of w^S on the Dynamics of FDI

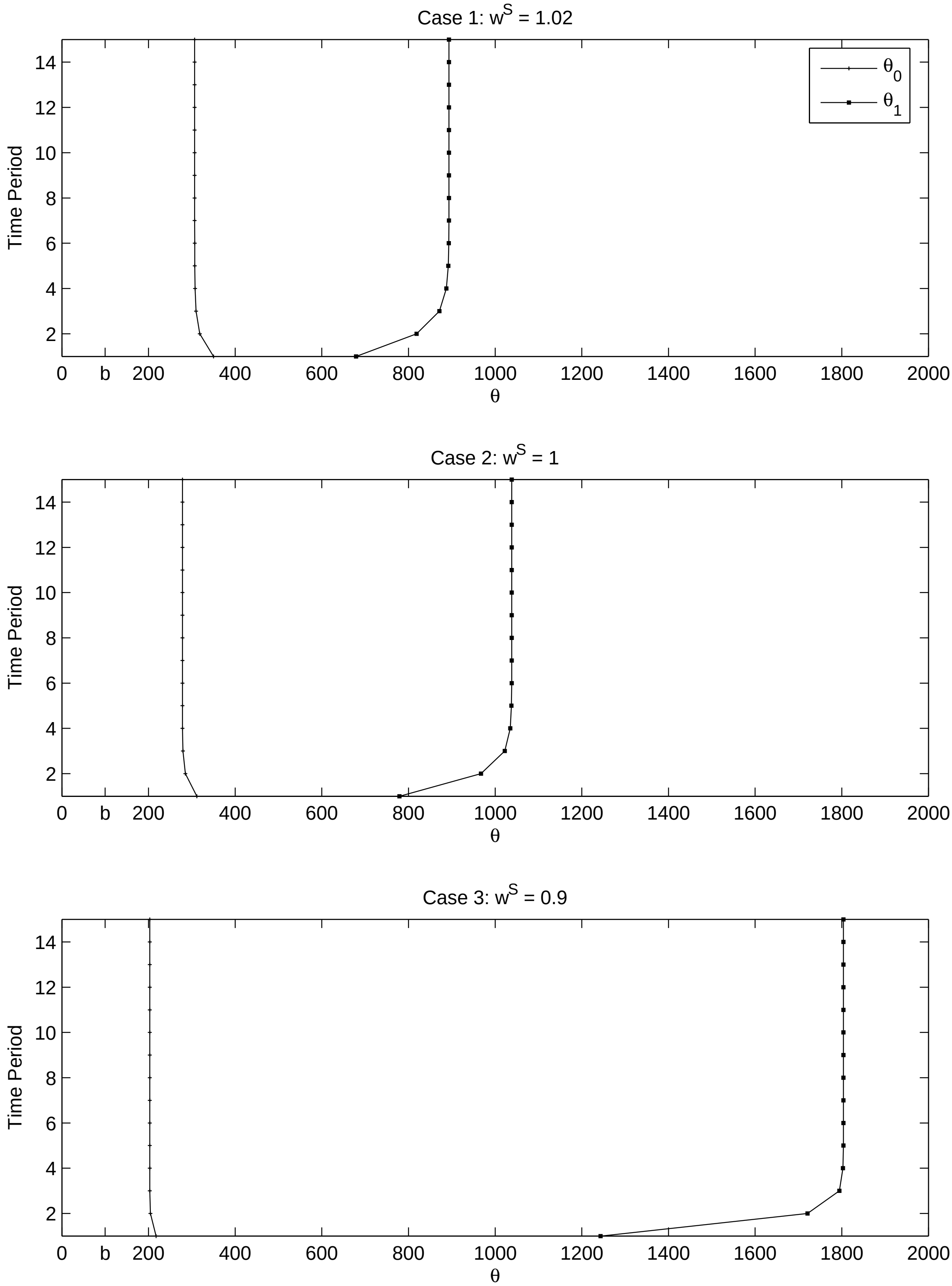
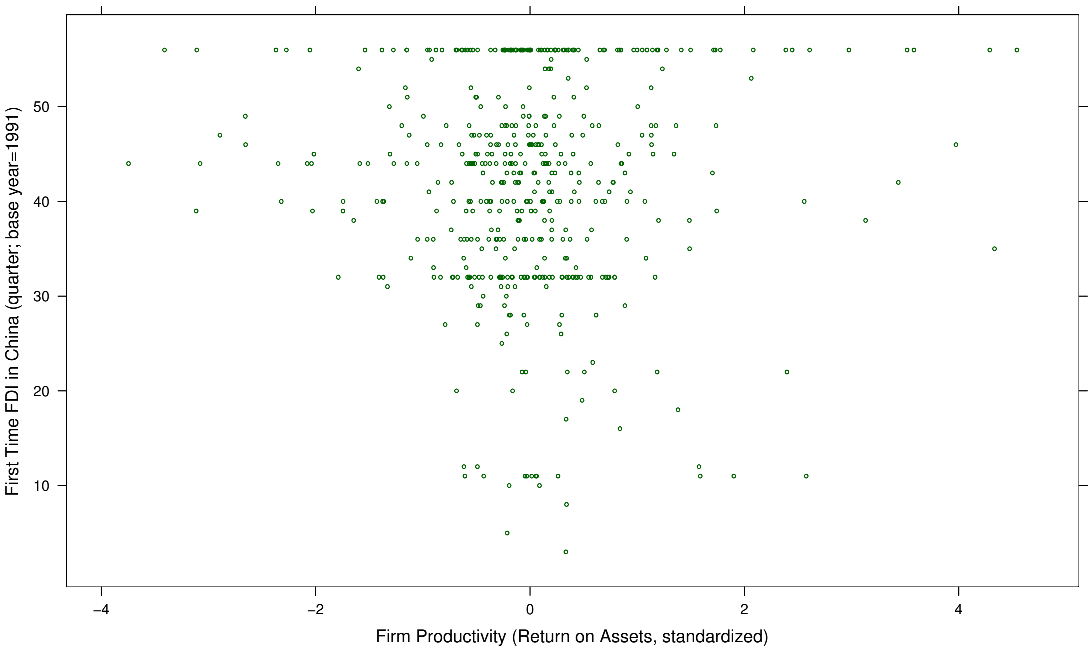


Figure 10: Firm Productivity and FDI Timing: FDI in China by Taiwanese Electronics Firms



Note:
1. The figure plots the timing of first time FDI undertaken by a Taiwanese firm in mainland China against the firm's productivity level. The data source is described in the text.
2. The productivity level of a firm is measured by the ratio of Return on Assets. The average of the ratios from 1991 to 1993 is used.
3. The productivity levels of all firms are standardized by the sample's mean and standard error.
4. The timing of a firm's initial FDI in mainland China is measured by the number of quarters elapsed since 1991 following the Taiwanese government's lift of its ban on outward FDI to mainland China.