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# Risk, Learning, and the Technology Content of FDI: A Dynamic Model

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# Risk, Learning, and the Technology Content of FDI: A Dynamic Model

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**Abstract**

This paper builds a dynamic model to examine the two-way interaction between FDI and the South's technology frontier. Inferior technology capacity in the South generates risk of production failure, which discourages inward FDI with high technology content. Only if the risk is not prohibitive does the first wave of FDI take place, which enables the South to learn from producing for multinationals and push forward its technology frontier. Consequently, the risk constraints are relaxed, which induces subsequent FDI with ever higher technology content. This reinforcing process implies an FDI agglomeration phenomenon and a magnified long-run policy impact.

*Key Words*: Foreign Direct Investment; Technology; Risk; Learning by Doing; Dynamic

*JEL Classification:* F21; F23; O24; O33

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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). Modern FDI theories with firm heterogeneity, however, consider predominately the tradeoff between fixed and variable costs of FDI; analyses on how risk affects firms' FDI decisions are generally absent. This paper aims to fill this gap.

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 more complicated their production processes and the higher the risk of quality control failure. In certain industries, such risk consideration may outweigh the conventional cost consideration and eliminate all FDI in a candidate Southern country. Economist (2004) documented examples where some high-tech Japanese firms chose to maintain their production at home; in other cases, they reverted their FDI decisions and forwent their overseas operations in place when the negative effect of quality control failure turned out to be detrimental. More anecdotal examples and supporting empirical findings are provided in Section 2.

We introduce the risk of quality control failure into the Melitz-model with firm heterogeneity, and further incorporate learning by doing in a dynamic setting. Building on the three pillars—risk, learning, and dynamics, our model modifies the predictions of standard FDI models on the sorting pattern of firms, rationalizes the underlining goals of important FDI policies, and proposes a theory on the two-way interaction between FDI and the South's development level.

Specifically, the incorporation of risk consideration implies an upper limit on the technology content of FDI, in addition to the lower cutoff predicted by the conventional model: given that the risk of FDI is not prohibitive, only firms of 'intermediate' production technology content 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 technology spectrum face minimal risks of quality control failure. The risk consideration, however, weighs in the determination of the upper bound when the quality control failure becomes a binding concern. While hosting multinational production is believed as an important channel for international technology spillover, which helps propel the South's march on its ladder of technology frontier, the aforementioned upper bound confines the base for learning and casts a limit on the technology frontier that the South can achieve 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, are many government FDI policies and interventions created. See for example, the industrial parks for IT in China[1] and for biotechnology in Singapore.[2] The model's dynamic process of learning by doing then implies a reinforcing interaction between FDI and the improvement of the South's technology frontier, with the endogenous evolution of FDI risk fueling the interaction. This result suggests a long-run magnified policy impact, which would be overlooked in a static framework.

We elaborate on the three model elements below. First, borrowing from the idea of the O-ring theory of Kremer (1993), we assume that the risk of quality control failure by producing in the South increases with the technology gap between the South's technology capacity and the level demanded by the firm from the North. Although a firm with a more advanced technology 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. Risk consideration thus creates an upper limit on the technology content of FDI. It also implies that the South's technology frontier must meet a minimum threshold to induce positive amounts of FDI inflow, as all firms may be discouraged by such a negative risk effect if the technology capacity in a Southern country is too low.

Second, we model the learning process in the spirit of Matsuyama (2002). Specifically, the South improves its technology capacity through accumulated experience in producing for multinational firms. The more the accumulated experience, the further the South will push ahead its technology frontier. However, the extent of technology spillover is bounded by the host country's absorptive capacity, which may hinge on the South's human capital, R&D intensity, IPR standard and enforcement, and its cultural and geographical distance to the North. This helps explain why the gains in technology transfer from the presence of FDI may vary across South.

Third, the dynamic interaction between FDI inflows and the improvement of the South's technology frontier leads to an agglomeration phenomenon of FDI as follows. Given the South's initial technology frontier exceeds the minimum threshold, the first wave of FDI inflow takes place. This first wave helps the South build up production experience and kicks off the momentum to push forward its technology frontier. As the frontier moves out, the probability of FDI success rises and this in turn relaxes the constraint facing firms previously keeping their production in the North. Consequently, it triggers a second wave of FDI led by technologically more advanced firms. The larger production mass then pushes the South's technology frontier out further, relaxes the risk constraint, and triggers another wave of FDI

[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

bringing with it even more advanced levels of technology. This dynamic process continues until it converges to a steady state.

It is interesting to note that the set of steady states is a lattice, and the momentum propelling the South's technology frontier stops at the least element of the lattice. That is, if there are multiple steady states, the South is trapped into the lowest steady state with a relatively low level of technology frontier. This result offers two valuable policy implications. First, being the first mover in opening up to FDI guarantees only an earlier start of the learning process but not a higher level of development in the long-run; it is the South's initial technology capacity that determines the path of technology progress and the eventual development level. Second, an FDI policy by the South could actually pull the South out of the development trap toward one of the higher steady-state development levels.

We work out the effects of several important parameters on the values of the technology frontier in the South, the FDI stock, and the bounds for the technology content of inward FDI at the steady state. These encompass infrastructure parameters (the South's initial technology frontier and its absorptive capacity), cost parameters (the wage in the South and the fixed setup cost of FDI), and industry-specific technology parameters (the degree of risk sensitivity and the degree of input substitution). These exercises clarify the mechanisms through which many FDI policies operate and highlight the potential persistent impact of one-time industrial policies on development as their initial effects are reinforced through the endogenous dynamic process.

Our paper contributes additional insights to the literature on the timing of FDI. Antràs (2005) applies incomplete contract theory and shows that FDI occurs in the later period of the product life cycle, as the holdup problem is less a concern when production becomes more standardized. McDonald and Siegel (1986), and the subsequent studies surveyed by Dixit and Pindyck (1994), develop the option-theory approach to study the relationship between the timing of irreversible FDI and uncertainty. Most of the analyses study the timing decision of a single firm. By assumption, new information on market conditions reveals as time goes by. As a direct result, higher uncertainty over the potential FDI profitability leads to a greater option value, and waiting is therefore more valuable. Our model considers a continuum of firms with heterogeneous production technologies. The risk of FDI failure facing each firm remains at the same level over time unless the host country's technology frontier improves, which is a result of positive externality generated by the firms already operating in the South; moreover, the risk prevails unless the South's technology frontier exceeds the level required by the production technology. Thus, there is a non-zero measure of firms that are deterred from undertaking FDI at the steady state.

Our paper modifies the predictions of Findlay (1978) on the relationship between the gap of the North-South development levels and the dynamics of FDI inflows. Findlay (1978) hypothesizes that the South catches up faster, the more backward its development level is relative to the North and the more exposed it is to FDI; moreover, the further behind the South's development level is, the more unexploited opportunity there exists and the more FDI inflows it will attract. Although we support the argument that inward FDI is an important channel through which the less developed countries acquire the advanced technology developed abroad, by explicitly taking into account the FDI risk, our paper changes two of his main predictions. First, we show that the development gap between the South and the North has a negative effect on the amount of FDI inflows, as a larger gap renders quality control more risky and FDI less profitable. Second, similar to Parente and Prescott (1994) and Stokey (2009), we differentiate between the growth *potential* indicated by the existing development gap and the *realized* growth that depends positively on the South's learning capacity. In our model, the South's learning capacity depends on parameters of human capital as well as experience in production for multinational firms. As a more backward South attracts less FDI inflows, which in turn generates a slower buildup of learning capacity, the initial technology backwardness of the South in our model has a negative and magnified long-run effect on the South's development.

Glass and Saggi (1998) have also studied the effect of the North-South technology gap on the technology level of FDI, in a quality-ladder product cycle model. In particular, successful imitation in the South helps close the North-South technology gap, and makes further FDI with higher technology feasible. However, the causal effect is one way in the sense that the presence of multinationals' production generates no feedback to either the speed or the extent of the catch up by the South, a mechanism highlighted in our paper. In Glass and Saggi (1998), the South progresses automatically with the North's innovation; thus, there is no sustained development trap as may arise and be intervened by FDI policies in our model.

# 2. EMPIRICAL RELEVANCE

This section previews the important implications of our model and their empirical relevance. In the model, we emphasize the higher risk that a firm with an advanced technology blueprint may encounter if the production is carried out in the backward South instead of in the North. In practice, anecdotal examples abound where a high-technology firm prefers to keep its production at home in spite of the wage disadvantage. For example, Economist (2004) reported that Kenwood of Japan shifted its production of mini-disc players from Malaysia back to Yamagata, Japan in 2002, and witnessed its product's defect rate to fall by 80%. Similarly, Canon of Japan, with a high-tech product line (ranging from precision photocopiers, to optical components for digital cameras, to expensive equipment for making semiconductors and flat-panel television screens) was observed to maintain a majority of its worldwide production at home, and Sharp of Japan to open a new "sixth-generation" plant to make flat panels for televisions in Mie prefecture, Japan in 2004, in the midst of rapid movement of manufacturing by other Japanese firms to South Korea, Taiwan and China.

The effect of such risk consideration on firms of different technology levels is also vivid in the examples cited in Makino et al. (2004). They found that among the Japanese electronic consumer goods companies, Canon had the highest R&D rates and was the lowest of all in its number of overseas subsidiaries in less developed countries relative to those in developed countries. In contrast, Hitachi had half the R&D rate as Canon and a very high proportion of overseas subsidiaries in less developed countries. Overall, parent firms investing in developed countries had a higher average R&D rate than those investing in less developed countries. In another study of Japanese manufacturing firms, Head and Ries (2003) also found that lower-productivity firms tend to invest in lower-income host countries while higher-productivity firms in higher-income host countries.

Our model suggests that inward FDI in an industry takes place only if the South's technology frontier achieves a certain minimum threshold. Empirical studies of the determinants of FDI location often lend support to this prediction of a threshold effect. See for example, Kellenberg (2007), Fung et al. (2004), Globerman and Shapiro (2003), Wei (2000), Cheng and Kwan (2000) among others. The model further shows that the required threshold level of the South's technology frontier is higher in industries with higher risk sensitivity. This implication fits well with the empirical finding of a product-cycle (flying-geese) FDI pattern. As documented in Feenstra and Rose (2000), more sophisticated industries often start production in the more advanced countries before transferring to the less developed countries.

The model further implies that the flows of inward FDI in a newly opened South tend to occur gradually, rather than in a "big-bang" fashion, through a learning-by-doing process during which the uncertainty of producing in the host country is reduced and that triggers subsequent inflows of FDI. This mechanism is a plausible cause for the dynamic agglomeration phenomenon observed by many 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.

Our model also suggests that the extent of the learning-by-doing effect is positively related to the leaning speed of the FDI host country. Empirical studies, such as Borensztein et al. (1998), Alfaro et al. (2004), Balasubramanyam et al. (1996), and Durham (2004), have used different proxies for the learning speed and found that conditional on the amount of FDI inflows, international technology transfer is more significant in host countries with better absorptive capacity.

# 3. MODEL

## 3.1 Production Technology and Risk

Consider a world with two countries, the North and the South. Consumer preferences are identical in the two countries and imply an isoelastic demand for a variety (good) $i$ of an industry $j$ as

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

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

The production function for each variety in each industry is similar to that of the O-ring theory (Kremer, 1993). In particular, production of a variety requires a continuum of steps $s \in [0, \theta]$, where $\theta$ is the measure of intermediate steps to be performed. The magnitude of $\theta$ thus reflects the complexity of the production technology. All steps must be performed successfully for there to be valuable output and positive revenues; otherwise, the final good is of no market value. That is,

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

where $\lambda(s)$ denotes the intensity of effort used to carry out step $s$; $0 < \rho < 1$, and $\frac{1}{1-\rho}$ corresponds to the elasticity of substitution between different steps, which can be different across industries. The blueprints of all production technologies are developed and owned by firms, who are located in the North. Each firm is associated with one type of production technology $\theta$, which is distributed according to a cumulative distribution function $G(\theta)$ with $\theta \geq 1$.

It is assumed that labor is the only factor of production and that the wage rate in the North $w^N$ is higher than the wage rate in the South $w^S$. One unit of labor is required for each unit intensity used to carry out a step regardless of the production location. Thus, depending on the production location $l$, $l \in \{N, S\}$, a firm with a production technology $\theta$

chooses the intensity of intermediate steps to minimize its production cost as follows:

$$\min_{\{\lambda(s),\ s\in[0,\theta]\}} \int_0^\theta w^l \lambda(s) ds,$$
$$\text{s.t.} \ \left[\int_0^\theta \lambda(s)^\rho ds\right]^{\frac{1}{\rho}} \geq x.$$

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:

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

where $\frac{\partial c^l(\theta)}{\partial w^l} > 0$, $\frac{\partial c^l(\theta)}{\partial \theta} < 0$, and $\frac{\partial c^l(\theta)}{\partial \rho} > 0$. Thus, the unit cost of production is lower if the cost of labor input $w^l$ is lower, which explains the location advantage of producing in the South. The unit cost is also lower if a firm uses more intermediate steps $\theta$ to produce a good. Thus, the more sophisticated production technology a firm has, the more productive it is. Finally, the unit cost is higher, if the tasks performed in different steps are more substitutable, as it would require more intensive input $\lambda$ in each step to produce a given amount of output.

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 the final good is produced. The probability $\gamma^l(\theta)$ of completing all intermediate steps successfully for a given production technology $\theta$ in a given 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 the parameter $z$ ($z \geq 0$) the degree of risk sensitivity to the technology gap between the required production technology $\theta$ and the South's technology frontier $T^S$ (as measured by the reverse of $\frac{T^S}{\theta}$). Note that both $T^S$ and $z$ are industry-specific.

We assume that there is no risk of failure by producing in the North, for all blueprints are developed in the North, and that there is no risk of failure by producing in the South if the technology frontier of the South is ahead of the required level of the production blueprint

$(\theta \leq T^S)$. In contrast, the risk of failure by producing in the South is present if the required technology level of a firm is beyond the South's technology frontier. The larger the technology gap, the smaller the success probability of FDI production.

The above formulation embodies the general idea that the longer the production chain $\theta$ and the more sophisticated the production technology, the more risky it is to produce abroad. The argument for the positive correlation between the complexity of the blueprint and the risk level of FDI is that carrying out the production abroad is more difficult if completing the tasks requires intense and tacit communication. In our setup, if the blueprint is more complicated and takes more steps to execute, the chance of misunderstanding during information exchange and making mistakes in the production process increases with FDI production.

The risk sensitivity $z$ reflects the elasticity of the success probability to the technology gap; the higher the degree of risk sensitivity $z$, the greater the negative effect of a given technology gap on the success probability of FDI production. Particularly, the success probability approaches zero as $z$ tends to infinity, and it approaches one as $z$ reduces to zero. The difference in the degrees of risk sensitivity across industries may be illustrated by the contrast between the textile industry and the wafer fabrication industry, for example: an accidental power failure will have much smaller impacts on the yields of a textile firm than of a wafer fabrication firm.

In addition to unit production cost, firms of all technology levels also have to incur the same fixed setup cost (in Northern labor units) to start the production. It is assumed that the fixed setup cost is higher in the case of FDI, when the production is carried out in the remote South, than in the firm's home country North:

$$f^N < f^S.$$

It is also assumed that firms are risk neutral. Given the production location $l$, $l \in \{N, S\}$ and its production technology, a firm chooses the optimal output level that maximizes its expected profit, taking into account the risk of production:

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

The optimal output level is $x^l(\theta) = \left(\frac{\alpha\gamma^l(\theta)}{c^l(\theta)}\right)^{\frac{1}{1-\alpha}}$, which decreases in the unit cost and increases in the success rate of production. Note that both the unit cost (3) and the success rate of production, (4) and (5), are location and technology dependent. The optimal output level can be further expressed as:

$$
\begin{aligned}
x^N(\theta) &= \Omega^N \theta^\nu, && \forall\ \theta,\ \text{where } 1 \leq \theta, && (7)\\
x^S(\theta) &= \begin{cases} \Omega^S \theta^\nu, & \text{if } 1 \leq \theta \leq T^S, \\ \Omega^S \left(\frac{T^S}{\theta}\right)^{\frac{z}{1-\alpha}} \theta^\nu, & \text{if } T^S < \theta, \end{cases} && && (8)
\end{aligned}
$$

where $\nu \equiv \left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{1-\alpha}\right) > 0$, and $\Omega^l \equiv \left(\frac{\alpha}{w^l}\right)^{\frac{1}{1-\alpha}}$. Note that $\Omega^N < \Omega^S$. If there is no FDI uncertainty, either due to $z = 0$ or $\theta \leq T^S$, a firm with a more advanced blueprint will command a larger market share, and FDI always induces production expansion. In face of FDI risk, however, firms will cut back their outputs if producing in the South; this offsetting effect is the larger, the more advanced a firm's production technology is. The optimal expected profit for firms with a blueprint $\theta$ producing in location $l$, $l \in \{N, S\}$, is equal to:

$$
\begin{aligned}
\pi^N(\theta) &= \psi^N \theta^{\nu\alpha} - w^N f^N, && \forall\ \theta,\ \text{where } 1 \leq \theta, && (9)\\
\pi^S(\theta; T^S, z) &= \begin{cases} \psi^S \theta^{\nu\alpha} - w^N f^S, & \text{if } 1 \leq \theta \leq T^S, \\ \psi^S \left(\frac{T^S}{\theta}\right)^{\frac{z}{1-\alpha}} \theta^{\nu\alpha} - w^N f^S, & \text{if } T^S < \theta, \end{cases} && && (10)
\end{aligned}
$$

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

## 3.2 FDI Decision: To Stay or To Go?

A firm decides whether or not to undertake FDI by comparing $\pi^N(\theta)$ and $\pi^S(\theta; T^S, z)$. The decision is made by weighing the advantage of lower unit cost by producing in the South against its disadvantage of higher fixed cost and higher risk of production failure. Such a comparison is illustrated in Figure 1. For illustrative purposes, we have converted the scale of production technology, where $\tilde{\theta} = \theta^{\nu\alpha}$ 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 between $\theta$ and $\tilde{\theta}$ (or that between $T^S$ and $\tilde{T}^S$) is a one-to-one, monotonic transformation; thus, we will often discuss results in the original scale of production technology even as we refer to the figure. It is immediately clear that $\tilde{\pi}^N$ is a liner function and increasing 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 $T^S$, as shown by panels (a)-(d) in Figure 1 with different combinations of risk sensitivity and technology frontier in the South. We discuss each case in turn.

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 and implies that the profit function of producing in the South $\tilde{\pi}^S$ is a linear schedule, as shown in panel (a) of Figure 1. We will refer to this scenario as the risk-free case. To ensure that even in the risk-free case, some firms will still produce in the North in face of FDI opportunity, the literature typically assumes:

**Assumption 1** $\theta_N < \theta_{NS}$, where $\theta_N \equiv \left(\frac{w^N f^N}{\psi^N}\right)^{\frac{1}{\nu\alpha}}$, and $\theta_{NS} \equiv \left(\frac{w^N (f^S - f^N)}{\psi^S - \psi^N}\right)^{\frac{1}{\nu\alpha}}$.

Note that $\theta_N$ corresponds to the technology level where a firm will break even by producing in the North, and $\theta_{NS}$ the technology level where a firm will be indifferent between producing in the North and in the South under the risk-free case. It follows that firms are partitioned 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 cannot afford the higher fixed cost of FDI and 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 of the risk-free case between the profit functions of producing in the North and in the South 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 more FDI by 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. This critique in general applies to both vertical and horizontal FDIs, as long as the FDI risk is not negligible.

More realistic and richer implications are obtained once FDI uncertainty is incorporated into the standard model. The possible scenarios are illustrated in panels (b), (c), and (d) of Figure 1. As suggested by (10), for a firm with a sufficiently low level of technology ($1 \leq \theta \leq T^S$) such that it incurs no risk of production failure in the South, its expected profit from FDI is increasing in its technology level; these firms face the same tradeoff of fixed versus unit costs as in the risk-free case. For a firm with a relatively high level of production technology ($T^S < \theta$), however, the saving in unit cost is further offset by the higher risk of FDI production. The larger the technology gap, the larger is the offset in its expected market size and profit of producing in the South relative to the risk-free case. Other things being equal, the greater the risk sensitivity, the larger is also the offset in expected market size and profit of producing in the South relative to the risk-free case for all firms subject to the risk. Thus, the expected profit from FDI, $\tilde{\pi}^S$, is linear and increasing in $\tilde{\theta}$ before $\tilde{T}^S$, coinciding with the risk-free case. It tilts down and becomes a concave function after $\tilde{T}^S$, with the downward shift being larger for a higher level of risk sensitivity. 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 will be shown formally in Proposition 1, FDI may not take place in the case where the South's technology frontier is relatively low, $1 \leq T^S \leq \theta_{NS}$. For given $T^S$ in this range, there exists a unique degree of risk sensitivity $z^*$ as a function of $T^S$ such that FDI occurs if and only if the risk sensitivity is smaller than $z^*$. As shown in Figure 1(b), for $z < z^*$ where the risk perception is relatively mild, positive amounts of FDI occur. The expected profit function of FDI, $\tilde{\pi}^S$, crosses the profit function of producing in the North $\tilde{\pi}^N$ twice, first from below at $\theta_0$ and then from above at $\theta_1$. Firms are partitioned according to their technology levels into those of the lowest technology levels, with $\theta \in [1, \theta_N]$, who exit the market, those 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.

Given firms that enter the market, 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 profit by shifting production to the South to pay off the higher fixed setup cost of FDI. 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 frontier that the higher likelihoods of FDI failure more than offset the wage saving. Thus, it is the firms of intermediate technology levels that may find FDI profitable.

In Figure 1(c) with $z^* \leq z$ and $1 \leq T^S \leq \theta_{NS}$, the risk sensitivity perceived by firms is so high that the wage advantage of producing in the South is more than offset by the expected loss of production failure for all firms. The expected profit function of FDI, $\tilde{\pi}^S$, lies everywhere below the profit function of producing in the North $\tilde{\pi}^N$, and as a result, no firms find it profitable to relocate production to the South.

In the case where the South's technology frontier is relatively high $\theta_{NS} < T^S$ as shown in Figure 1(d), the expected profit function of FDI crosses the profit function of producing in the North from below at $\theta_{NS}$ as in the risk-free case; it then crosses the profit function of producing in the North again from above at a technology level $\theta_1$ greater than $T^S$. In this case, the measure of inward FDI is necessarily positive.

The above discussion suggests an interplay between the South's technology frontier and the degree of risk sensitivity in determining the profitability of FDI in an industry. This is characterized in the following proposition.

**Proposition 1** *For any given level of initial technology frontier $T^S \in [1, \theta_{NS}]$ 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 $T^S \in (\theta_{NS}, \infty)$, FDI occurs regardless of $z$. Alternatively, for any given degree of risk sensitivity $z$, there exists a unique threshold $T^{S*}(z)$ for the initial technology frontier in the South, such that positive amounts of FDI take place if and only if $T^{S*}(z) < T^S$ and that $dT^{S*}(z)/dz \geq 0$.*

*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 $(z, T^S)$ parameter space into two areas — the upper-left area that implies a non-zero measure of FDI, and the lower-right area that implies a zero measure of FDI. When the degree of risk sensitivity is very small such that $z \in [0, z^*(1))$, FDI takes place regardless of the level of technology frontier in the South: thus, $T^{S*}(z) = 1$. When the degree of risk sensitivity is very large such that $z \geq z^*(\theta_{NS})$, the advantage of having a more advanced blueprint becomes a "curse" when the blueprint is executed in the remote, backward South, as in this case, the net gain of FDI is strictly decreasing in the firm's technology level $\theta$ for $\theta > T^S$. This property implies that if the firms with $\theta = T^S$ find FDI not profitable, all firms exposed to FDI risk will find FDI not profitable either. Therefore, no firm will find FDI desirable if $T^S \leq \theta_{NS}$, where recall that $\theta_{NS}$ is the cutoff type in the risk-free case. Thus, to ensure a non-zero measure of FDI in this case, it must hold that $T^S > \theta_{NS}$: i.e., $T^{S*}(z) = \theta_{NS}$.

Note that the mapping from $z \in [z^*(1), z^*(\theta_{NS}))$ to $T^{S*}(z)$ outlined by the strictly increasing 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 some firms. Intuitively speaking, if the industry is more risk-sensitive, the higher is the required minimum level of $T^S$ for a non-zero measure of FDI to occur.

### 3.3 Extensive and Intensive Margins of FDI

If FDI takes place, let $\Theta^S \equiv [\theta_0, \theta_1]$ denote the technology content of inward FDI. The upper and lower bound of the technology content $\Theta^S$ can be defined formally as follows:

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

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

where $\pi^l_\theta \equiv \partial \pi^l / \partial \theta$ for $l \in \{N, S\}$. Note that the expected profit function of producing in the South crosses the profit function of producing in the North from below at $\theta_0$ and from above at $\theta_1$, as indicated by Figure 1(b) and Figure 1(d), which gives rise to the signs claimed in (11) and (12).

Recall that if the technology frontier in the South is sufficiently low such that it is lower than the risk-free cutoff type $\theta_{NS}$, the lower bound $\theta_0$ of the technology content of inward FDI in the case with the risk factor will necessarily be higher than $\theta_{NS}$, as the expected profit of producing in the South is strictly lower than in the risk-free case. On the other hand, when the technology frontier is sufficiently high and surpasses the risk-free cutoff type $\theta_{NS}$, the risk factor is no longer a constraint for firms with technology levels in between $\theta_{NS}$ and $T^S$, and all firms within this range behave as in the risk-free case and hence will produce in the South; thus, in this case, the lower bound $\theta_0$ of the technology content of inward FDI with the risk factor coincides with the risk-free cutoff type $\theta_{NS}$.

**Lemma 2** *The upper bound $\theta_1$ of the technology content $\Theta^S$ of inward FDI increases, while the lower bound $\theta_0$ of the technology content $\Theta^S$ of inward FDI decreases weakly, with the South's technology frontier $T^S$:*

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

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

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

*Proof of Lemma 2.* Note that $\pi_\theta^N(\theta_1) - \pi_\theta^S(\theta_1) > 0$, $\pi_\theta^N(\theta_0) - \pi_\theta^S(\theta_0) < 0$, and $\pi_{T^S}^S > 0$. The first two signs thus follow. Next, note that $\theta_0 = \theta_{NS}$ regardless of $T^S$ if $\theta_{NS} \leq T^S$. The last equality therefore follows. ■

Let $X^S \equiv \chi(\theta_0, \theta_1, T^S)$ denote the aggregate scale of production of the South for multinational firms in a given industry during a given period. Then,

$$\chi(\theta_0, \theta_1, T^S) = \int_{\theta_0}^{\theta_1} x^S(\theta) dG(\theta). \tag{15}$$

Given (8), the aggregate scale of production of the South for multinational firms in a given industry is

$$\chi(\theta_0, \theta_1, T^S) = \begin{cases} \displaystyle\int_{\theta_0}^{\theta_1} \Omega^S \left(T^S\right)^{\frac{z}{1-\alpha}} (\theta)^{\nu - \frac{z}{1-\alpha}} dG(\theta), & \text{if } 1 \leq T^S < \theta_{NS}, \\ \displaystyle\int_{\theta_0}^{T^S} \Omega^S \theta^\nu dG(\theta) + \int_{T^S}^{\theta_1} \Omega^S \left(T^S\right)^{\frac{z}{1-\alpha}} (\theta)^{\nu - \frac{z}{1-\alpha}} dG(\theta), & \text{if } \theta_{NS} \leq T^S. \end{cases} \tag{16}$$

We choose a Pareto distribution with shape $k$ for the cumulative distribution function $G(\theta)$ such that $G(\theta) = 1-(1/\theta)^k$ for $\theta \geq 1$ with $k > \nu$. The last restriction on the shape parameter $k$ ensures that the aggregate output of all firms in any given period is finite regardless of their production location even in the risk-free case. Given this, we have

$$\chi(\theta_0, \theta_1, T^S) = \begin{cases} \frac{\Omega^S k}{a} \left(T^S\right)^{\frac{z}{1-\alpha}} \left[(\theta_0)^{-a} - (\theta_1)^{-a}\right], & \text{if } 1 \leq T^S < \theta_{NS}, \\ \\ \frac{\Omega^S k}{(k-\nu)} \left[(\theta_0)^{-(k-\nu)} - \left(T^S\right)^{-(k-\nu)}\right] & \\ \qquad + \frac{\Omega^S k}{a} \left(T^S\right)^{\frac{z}{1-\alpha}} \left[\left(T^S\right)^{-a} - (\theta_1)^{-a}\right], & \text{if } \theta_{NS} \leq T^S, \end{cases} \tag{17}$$

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

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

$$\frac{dX^S}{dT^S} = \left(\frac{\partial \chi}{\partial \theta_0}\frac{\partial \theta_0}{\partial T^S} + \frac{\partial \chi}{\partial \theta_1}\frac{\partial \theta_1}{\partial T^S} + \frac{\partial \chi}{\partial T^S}\right) \equiv \Lambda > 0. \tag{18}$$

*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. ■

Note that the production $X^S$ for multinational firms increases with the South's technology frontier $T^S$ at the rate $\Lambda$. This amount includes the increase in production for the existing multinational firms because of the improved risk condition and expected profit $\frac{\partial \chi}{\partial T^S}$ (an intensive margin), as well as the increase in production due to new 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 scale of production of the South for multinational firms with an improved technology frontier in the South $T^S$.

### 3.4 Learning by Doing

We model the catch up process of the South to improve its technology frontier in a similar way in which Matsuyama (2002) models the learning process of an industry to upgrade its productivity. That is, through accumulated productions specific to an industry, the South gains experiences and its technology frontier in the industry improves. However, such experiences do depreciate and the experiences of the more recent periods play a more important role. Specifically, let $Q_t^S$ denote the stock of effective production experiences of the South in a given industry at period $t$:

$$Q_t^S = \sum_{\tau=0}^{t} \left(\frac{1}{1+\delta_D}\right)^{t-\tau} \delta_L X_\tau^S, \tag{19}$$

where $\delta_D > 0$, $\delta_L > 0$, and the periods start when the South just opens up to inward FDI so that $X_0^S = 0$. Note that the parameter $\delta_L$ corresponds to the learning speed of the South in transforming the current production into production experiences. This learning speed likely depends on the human capital of the labor force in the South or the intellectual property rights (IPR) protection in the South. A more educated work force in the South is more likely to better absorb the production technique and practice handed down from the firms from the North and transform them into the South's own stock of production know-how and knowledge. A weaker IPR protection may also imply a faster rate of technology spillover from the multinational firms to the local industry, which may explain to some extent the South's reluctance to tighten their IPR protection policies (Grossman and Lai, 2004). The parameter $\delta_D$, on the other hand, can be interpreted as the depreciation rate of the South's learning experiences. Workers move, retire, and die over time, and some learning experiences are lost from one period to the next period. A larger $\delta_D$ corresponds to a smaller fraction ($\frac{1}{1+\delta_D}$) of learning experiences preserved from one period to the next period. The higher the value of $\delta_L$, the smaller the value of $\delta_D$, the larger the stock of effective production experiences. These experiences $Q_t^S$ translate into the technology frontier of the South $T_t^S$ through a learning function $\Gamma(\cdot)$. That is,

$$T_t^S \equiv T_0^S + \Gamma(Q_t^S), \tag{20}$$

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 learning function implies that the South's technology frontier in a given period will remain at its initial level $T_0^S$, if the initial level falls short of the minimum threshold stipulated in Proposition 1 and as a result, inward FDI and the subsequent learning by the South do not take place. Otherwise, the South's technology frontier improves with the South's accumulated production experiences and approaches infinity if the stock of effective production experiences tends to infinity.

## 3.5 The Dynamics of FDI

In any given period $t = 1, 2, 3, \ldots$, firms face two state variables $(Q_{t-1}^S, T_{t-1}^S)$ and make FDI decisions determining the values of three choice variables $(\theta_{0,t}, \theta_{1,t}, X_t^S)$. Given $T_{t-1}^S$ at the beginning of the period, if FDI takes place, the technology content of FDI, $\Theta_t^S = [\theta_{0,t}, \theta_{1,t}]$, is determined by (11) and (12) with $T^S = T_{t-1}^S$. The aggregate production for multinational firms is then determined according to (17) with $X_t^S = \chi(\theta_{0,t}, \theta_{1,t}, T_{t-1}^S)$. Given (19), note that the stock of effective production experiences iterates according to:

$$Q_t^S = \frac{1}{1+\delta_D} Q_{t-1}^S + \delta_L X_t^S. \tag{21}$$

The larger stock of effective production experiences at the end of period in turn implies a higher level of technology frontier in the South $T_t^S$ by (20).

Thus, start from period $t = 1$, with zero amounts of prior FDI, $Q_{t-1}^S = 0$, and with the South's initial technology frontier at $T_0^S \in [1, \theta_{NS}]$, the first wave $\Theta_1^S$ of FDI takes place if the risk sensitivity $z$ is smaller than the ceiling $z^*(T_0^S)$ as shown in Proposition 1. This implies a current production of $X_1^S = \chi(\theta_{0,1}, \theta_{1,1}, T_0^S)$, a stock of effective production experiences of $Q_1^S = \delta_L X_1^S$, and a new higher level of technology frontier in the South $T_1^S$.

In period $t = 2$, given the higher level of technology frontier in the South, the expected profit of producing in the South increases for all firms $\theta \in [T_0^S, \infty)$ previously constrained by the risk factor. This triggers a second wave of FDI undertaken by a wider range of firms $\Theta_2^S \supset \Theta_1^S$ involving firms of both more and less sophisticated production technologies, as indicated by Lemma 2. This dynamic process of FDI is illustrated in Figure 3. In the case where $T_0^S > \theta_{NS}$, the dynamic process of FDI is similar except that the lower bound of the technology content of inward FDI hits the risk-free cutoff level $\theta_{NS}$ immediately in the first period and the expansion of the technology content of FDI is via the upper bound $\theta_1$ only.

Thus, the first wave of FDI by exposing the South to the more advanced production technologies from the North helps the South to upgrade its technology frontier through learning by doing and creates a less risky environment for subsequent FDI. The improved condition in the South attracts a second wave of FDI and results in an enlarged production base in the South, which in turn leads to a higher technology frontier in the South and a new wave of FDI.

### 3.6 Steady State

We show that the above dynamic process of FDI is stationary and there exists at least one stable steady state. We first specify the conditions that characterize a steady state. In particular, in a given industry, the lower and upper bounds of the technology content of FDI ($\theta_0$ and $\theta_1$), the aggregate scale of production of the South for multinational firms ($X^S$), the stock of effective production experiences ($Q^S$), and the South's technology frontier ($T^S$) are constants at a steady state. Note that given (21), the stock of effective production experiences at a steady state can be solved as

$$Q^S = \delta X^S, \quad \text{where } \delta = (1 + 1/\delta_D)\, \delta_L. \tag{22}$$

We then substitute the above equation into (20) and the solutions implied by (11) and (12) into (17). The steady state conditions can be summarized by the following two simultaneous equations:

$$\begin{aligned} T^S &= T_0^S + \Gamma\left(\delta X^S\right), && (23)\\ X^S &= \chi(\theta_0(T^S), \theta_1(T^S), T^S). && (24) \end{aligned}$$

In the trivial case where FDI never takes off, the steady state is simply the status quo. Thus, our discussion below focuses on the nontrivial case where $z$ is sufficiently small such that $z < z^*(T_0^S)$. As a result, at a steady state, the South lifts its technology frontier up to a higher stable level and secures a non-zero measure of FDI production.

**Proposition 4** *Suppose $z < z^*(T_0^S)$. The dynamic process of FDI as described in Section 3.5 is stationary, and there exists at least one stable steady state.*

We first characterize (24). If at a steady state, the South's technology frontier $T^S$ were at its initial level $T_0^S$, then

$$X^S = \underline{X}^S \equiv \chi(\theta_0(T_0^S), \theta_1(T_0^S), T_0^S) > 0. \tag{25}$$

Alternatively, if at a steady state, the South's technology frontier $T^S$ were to approach infinity, the aggregate scale of production of the South for multinational firms in an industry would be equivalent to that in the risk-free case,

$$X^S = \bar{X}^S \equiv \int_{\theta_{NS}}^{\infty} \Omega^S \theta^\nu dG(\theta) = \frac{\Omega^S k}{(k-\nu)} \left(\theta_{NS}\right)^{-(k-\nu)}. \tag{26}$$

Furthermore, recall that $X^S$ increases in $T^S$ at a rate of $\Lambda > 0$ by Proposition 3. Thus, the aggregate scale of production $X^S$ as a function of $T^S$ has a positive lower bound $\underline{X}^S$ if $T^S = T_0^S$. It increases in $T^S$ and approaches $\bar{X}^S$ from below as $T^S$ tends to infinity. This relationship is illustrated in Figure 4(a) by the $PP$ schedule, where $PP$ stands for production.

Next, we characterize (23). Note that the level of technology frontier in the South $T^S$ would stay at its initial level $T_0^S$ if zero FDI production took place ($X^S = 0$); it increases monotonically in $X^S$ at a rate of $\delta\Gamma_Q$, and would reach an upper bound $\bar{T}^S \equiv T_0^S + \Gamma(\delta\bar{X}^S)$

in the most optimistic scenario if all firms above the cutoff level $\theta_{NS}$ were to undertake FDI as in the risk-free case. This relationship is illustrated in Figure 4(a) by the $LL$ schedule, where $LL$ stands for learning.

As the $LL$ curve starts below the $PP$ curve and ends up above it, the two curves must cross at least once. In other words, there exists at least a steady-state equilibrium. If there is only one steady state as illustrated in Figure 4(a), the steady state is also stable, because if one starts from any alternative state, the two variables will adjust and converge toward the crossover point $I$.

In general, there could be multiple steady states as illustrated in Figure 4(b), as we do not specify a particular functional form for the learning function $\Gamma()$. The set of steady states is a lattice. If we relabel the horizontal axis as $T^S_{t-1}$ and the vertical axis as $X^S_t$, we could readily use Figure 4(b) to illustrate the dynamic process of FDI. Starting with the initial technology frontier $T^S_0$, the South's production for multinational firms and the South's technology frontier grow (following the arrows) until they converge to the least element of the lattice. That is, if there are multiple steady states, the South is trapped into the lowest steady state with a relatively low level of inward FDI and a relatively low level of technology frontier, instead of achieving the higher stable steady state(s). This has important policy implications as we will discuss in Section 3.7.

**Lemma 5** *At a stable steady state, the following property holds,*

$$\delta\Gamma_Q\Lambda < 1. \tag{27}$$

*Proof of Lemma 5.* At a stable steady state, the $PP$ curve crosses the $LL$ curve from above. This is equivalent to state that $\frac{d\chi}{dT^S} < \left[\frac{d\Gamma}{dX^S}\right]^{-1}$ or $\frac{d\Gamma}{dX^S}\frac{d\chi}{dT^S} < 1$. Note that $\frac{d\Gamma}{dX^S} = \delta\Gamma_Q$ and that $\frac{d\chi}{dT^S} = \Lambda$. The result in (27) therefore follows. ■

Note that starting from a steady state, a unit positive disturbance to the technology frontier in the South $T^S$ will lead to an increase in the production $X^S$ for multinational firms by an amount $\Lambda$. For each unit increase in production for multinational firms, it has in turn an effect on the technology frontier by an amount of $\delta\Gamma_Q$. Thus, the multiplier of the technology frontier due to a unit shock equals $\delta\Gamma_Q\Lambda$. Lemma 5 says that at a stable steady state, the multiplier must be smaller than one, so that the economy will gyrate back toward its initial state following a small disturbance to the endogenous variables. A multiplier smaller than one also implies that the effect following a disturbance to the exogenous variables will be finite. Given these qualities, we focus on stable steady states below.

### 3.7 Comparative Static Analyses and Policy Implications

In this section, we work out the effect of changes to the model's parameters on the steady-state values of the endogenous variables. This part of analysis will serve as the basis for our discussions of FDI policies that could be adopted by the South to influence the long-run level of their development and the technology content of their inward FDI.

The analysis starts with the two equations (23) and (24) that characterize a steady state. Let $q$ denote one of the exogenous parameters $(T_0^S, \delta_D, \delta_L, w^S, f^S, f^N, z, \rho)$. First, take total differentiation of (24) with respect to $X^S$, $T^S$ and $q$; we have:

$$\frac{dX^S}{dq} = \Xi + \Lambda \frac{dT^S}{dq}, \tag{28}$$

where $\Xi \equiv \left( \frac{\partial \chi}{\partial \theta_0} \frac{\partial \theta_0}{\partial q} + \frac{\partial \chi}{\partial \theta_1} \frac{\partial \theta_1}{\partial q} + \frac{\partial \chi}{\partial q} \right)$ has the similar interpretation as $\Lambda$: the first two terms indicate the extensive effect and the third term the intensive effect on the aggregate production for multinational firms because of a change in the exogenous parameter $q$. The change in the parameter $q$ also affects the aggregate production for multinational firms indirectly through its effect on the technology frontier, which in turn has its own intensive and extensive effects on the aggregate production for multinational firms as summarized by $\Lambda$. Next, take total differentiation of (23) with respect to $X^S$, $T^S$ and $q$, and substitute $\frac{dX^S}{dq}$ with the expression in (28); we get

$$\frac{dT^S}{dq} = \Sigma^{-1} \delta \Gamma_Q \Xi + \Sigma^{-1} X^S \Gamma_Q \frac{\partial \delta}{\partial q} + \Sigma^{-1} \frac{\partial T_0^S}{\partial q}, \tag{29}$$

where $\Sigma \equiv 1 - \delta \Gamma_Q \Lambda$. To see (29), note that following a shock to the exogenous parameter $q$, the effects on the technology frontier could be threefold. First, a change in $q$ has a direct effect $\Xi$ on the aggregate production for multinational firms, which in turn affects the technology frontier by a rate $\delta \Gamma_Q$, and through the positive reinforcing feature of the dynamic process, generates a multiple $\Sigma^{-1}$ of the initial effect on the technology frontier. Second, if the parameter $q$ has a direct bearing on the stock of effective production experiences $Q^S$ through $\delta$, it will affect the technology frontier by a rate $X^S \Gamma_Q$ and generate another layer of multiplier effect on the technology frontier. Finally, the technology frontier can also be altered through the initial technology frontier $T_0^S$. Not all three channels are operating at any one time. For parameters $(w^S, f^S, f^N, z, \rho)$, only the first channel is working; for $(\delta_D, \delta_L)$, only the second channel is working, and for $T_0^S$, only the third channel is working.

We could further characterize the changes in the steady-state technology content of inward FDI, by taking total differentiation of (11) and (12) to obtain

$$\frac{d\theta_1}{dq} = \frac{\partial\theta_1}{\partial q} + \frac{\partial\theta_1}{\partial T^S}\frac{dT^S}{dq}, \tag{30}$$

$$\frac{d\theta_0}{dq} = \begin{cases} \frac{\partial\theta_0}{\partial q} + \frac{\partial\theta_0}{\partial T^S}\frac{dT^S}{dq}, & \text{if } 1 \leq T^S < \theta_{NS}, \\ \frac{\partial\theta_0}{\partial q}, & \text{if } \theta_{NS} \leq T^S. \end{cases} \tag{31}$$

The upper and lower bounds for the technology content of inward FDI can be directly affected by the exogenous parameter $q$ if it appears in the profit functions; in addition, they will also be indirectly affected through the change in the equilibrium technology frontier following a change in $q$. In the case that the lower bound $\theta_0$ has already hit its lower limit $\theta_{NS}$, the indirect effect will cease to operate, as is implied by Lemma 2. Finally, it is also possible to characterize the changes to the steady-state value of $Q^S$ following a change in $q$, by taking total differentiation of (22):

$$\frac{dQ^S}{dq} = \delta\frac{dX^S}{dq} + X^S\frac{\partial\delta}{\partial q}, \tag{32}$$

where the changes to the steady-state stock of effective production experiences occur mainly through the changes to the equilibrium current production $X^S$ following a change in $q$, and in addition, through a direct effect on $Q^S$ for given $X^S$ if the parameter under study happens to be $\delta_D$ or $\delta_L$. In particular, it is straightforward to see that $\frac{\partial\delta}{\partial\delta_D} < 0$, $\frac{\partial\delta}{\partial\delta_L} > 0$, and $\frac{\partial\delta}{\partial q} = 0$ otherwise.

**Proposition 6** *The following country characteristics of the South can be altered in a proper direction to raise the equilibrium level of technology frontier in the South and the technology content of inward FDI:*

$$\begin{array}{ll} (i) & \frac{dT^S}{dT_0^S} > 0, \frac{dX^S}{dT_0^S} > 0, \frac{dQ^S}{dT_0^S} > 0, \frac{d\theta_1}{dT_0^S} > 0, \frac{d\theta_0}{dT_0^S} \leq 0 \textit{ with equality when } \theta_{NS} \leq T^S; \\ (ii) & \frac{dT^S}{d\delta_D} < 0, \frac{dX^S}{d\delta_D} < 0, \frac{dQ^S}{d\delta_D} < 0, \frac{d\theta_1}{d\delta_D} < 0, \frac{d\theta_0}{d\delta_D} \geq 0 \textit{ with equality when } \theta_{NS} \leq T^S; \\ (iii) & \frac{dT^S}{d\delta_L} > 0, \frac{dX^S}{d\delta_L} > 0, \frac{dQ^S}{d\delta_L} > 0, \frac{d\theta_1}{d\delta_L} > 0, \frac{d\theta_0}{d\delta_L} \leq 0 \textit{ with equality when } \theta_{NS} \leq T^S; \\ (iv) & \frac{dT^S}{dw^S} < 0, \frac{dX^S}{dw^S} < 0, \frac{dQ^S}{dw^S} < 0, \frac{d\theta_1}{dw^S} < 0, \frac{d\theta_0}{dw^S} > 0; \\ (v) & \frac{dT^S}{df^S} < 0, \frac{dX^S}{df^S} < 0, \frac{dQ^S}{df^S} < 0, \frac{d\theta_1}{df^S} < 0, \frac{d\theta_0}{df^S} > 0. \end{array}$$

*Proof of Proposition 6.* Proof is provided in the appendix. ■

We discuss the policy implications of Proposition 6. As shown, the upper bound of the technology content of FDI ($\theta_1$), the aggregate production for multinational firms ($X^S$), the stock of effective production experiences ($Q^S$), and the South's technology frontier ($T^S$) at the steady state are positively correlated, while the lower bound ($\theta_0$) of the technology content at the steady state moves in the oppositive direction if it is not already at its lowest level $\theta_{NS}$. This suggests that the South's FDI policies could target different aspects of the FDI dynamic mechanisms, (11), (12), (17), (20), and (21), and achieve similar effects of enhancing the technology content of inward FDI.

The Southern government could aim at raising the South's initial technology frontier $T_0^S$. As suggested by Proposition 1, a higher initial technology frontier in the South will make FDI in the country more likely to take off in the first place. Furthermore, if a first wave of FDI occurs, a higher initial technology frontier in the South will attract a wider range of firms from the North, as indicated by Lemma 2, and hence a larger initial mass of production for multinational firms. The larger initial mass of production generates a bigger step forward by the South on the technology frontier and a steeper decline in the perceived risk of FDI failure for all firms previously constrained by the technology frontier in the South, and attracts a new wave of inward FDI. In every period, the stock of effective production experiences is strictly higher in a Southern country with a higher initial technology frontier than in one with a lower initial technology frontier, and hence, the learning effect of the former is strictly higher than the latter. Coupled with its initial advantage, this implies that the former country will have a higher steady state technology frontier than the latter. Thus, a Southern country's initial advantage in its technology frontier is persistent and is amplified through the self-reinforcing dynamic process of FDI. The effect of $T_0^S$ on the steady-state technology frontier in the South and the aggregate production for multinational firms is illustrated in Figure 5(a).

Alternatively, the South may target improving the rate $\delta$ at which the South retains knowledge from producing for inward FDI. As implied by the model, the higher the learning speed $\delta_L$ and the lower the depreciation rate $\delta_D$, the more effective is the Southern work force in acquiring and preserving FDI production experience that is the driving force of improving its own technology frontier. This policy target in reality could be implemented by education policies that improve the general human capital of the work force and its absorptive capacity. As discussed earlier, if there are multiple steady states, the South is trapped into the lowest steady state with a relatively low level of technology frontier. A FDI policy by the South thus could affect its steady-state technology frontier in an industry by working around the neighborhood of the lowest steady state, or more importantly, it could actually pull the South out of the lowest steady state toward one of the higher steady state(s). This possibility of a quantum leap in development by the South because of adjustment in key economic parameters is illustrated in Figure 5(b) for either an increase in $\delta_L$ or a decrease in $\delta_D$, where by heightening the speed of knowledge accumulation and of technology improvement, the South could actually escape the potential development trap and grows until it reaches the region of the highest steady state.

Last but not least, policies to reduce the marginal labor cost $w^S$ or the fixed setup cost $f^S$ of conducting FDI have often been used in practice by the South. The lower marginal labor cost or fixed setup cost of producing in the South will in the first instance increase the upper bound and lower the lower bound of the FDI technology content, and hence increase the amount of inward FDI. In addition to attracting a wider range of firms from the North (an extensive effect), a reduction in $w^S$ also stimulates more production by all existing FDI (an intensive effect; see (8)) and induces an even larger increase in the aggregate production for multinational firms than a mere reduction in $f^S$. The stimulus to the FDI production has often been cited as the rationale for such FDI subsidy policies. The new insights gained from the current model are that the increased amount of inward FDI will in turn increase the exposure of the South to a larger amount of advanced production technologies from the North, bring forward more learning and technology spillover from the North, and improve the South's technology frontier. The latter will in turn lower the FDI uncertainty and attract further flows of inward FDI. The effects of such policies on the South's development are illustrated in Figure 5(c) for a decrease in $w^S$ and Figure 5(d) for a decrease in $f^S$. It is arguable that $f^S$ is determined to a large extent by industry characteristics and vary across industries. In this view, the proposition implies that an industry that has a lower setup cost to produce also tends to be more footloose and its production technology more readily spread from the North to the South.

**Proposition 7** *The North may adopt defensive policies regarding $f^N$ to prevent its high-technology firms from relocating their production facilities to the South:*[3]

$$(i) \quad \frac{dT^S}{df^N} > 0, \frac{dX^S}{df^N} > 0, \frac{dQ^S}{df^N} > 0, \frac{d\theta_1}{df^N} > 0, \frac{d\theta_0}{df^N} < 0.$$

*Proof of Proposition 7.* Proof is provided in the appendix. ■

As argued earlier, the fixed setup cost can have both industry and country-specific contents, with the latter amenable to potential policy interventions. In the case of $f^N$, the North may subsidize firms to lower their fixed operation cost in the North $f^N$. The effects would be to weaken firms' incentives to produce in the South and to mitigate the dynamic reinforcing

[3]The effects of the Northern wage $w^N$ on the endogenous variables do not have definite signs, in contrast with $w^S$, as $w^N$ affects not only the variable profits of operating in the North but also the fixed setup costs in both locations in the current setup. In general, a Northern government may devise schemes to subsidize only the variable costs of operating in the North, countering the FDI incentive created by the lower wage in the South.

process of production migration. At the steady state, more higher-technology firms remain in the North and the South achieves a smaller technology progress in the industry affected. The results are exactly opposite to what is illustrated in Figure 5(d).

**Proposition 8** *The FDI patterns and technology contents across industries depend on the following industry characteristics as follows:*

$$(i) \quad \frac{dT^S}{dz} < 0, \frac{dX^S}{dz} < 0, \frac{dQ^S}{dz} < 0, \frac{d\theta_1}{dz} < 0, \frac{d\theta_0}{dz} \geq 0 \text{ with equality when } \theta_{NS} \leq T^S;$$
$$(ii) \quad \frac{dT^S}{d\rho} < 0, \frac{dX^S}{d\rho} < 0, \frac{dQ^S}{d\rho} < 0, \frac{d\theta_1}{d\rho} < 0, \frac{d\theta_0}{d\rho} > 0.$$

*Proof of Proposition 8.* Proof is provided in the appendix.[4] ■

Although not within the South's control to a large extent, the above technology parameters or industry characteristics, $z$ and $\rho$, have important effects on the South's industry-specific development. A lower degree of risk sensitivity $z$ to technology gap, by raising the success rate of FDI, raises the expected profit of producing in the South for all firms constrained by the South's technology frontier, increases the upper bound of the technology content of inward FDI and lowers the lower bound if it is not already at its lower limit $\theta_{NS}$. This corresponds to a larger amount of inward FDI (an extensive effect). A lower degree of risk sensitivity $z$, by raising the success rate of FDI, also induces a larger amount of production by all existing FDI (an intensive effect; see (8)). Both effects lead to a bigger production of the South for multinational firms in the industry. This, in turn, leads to a larger stock of effective production experiences and a higher level of technology frontier in the industry of the South. The positive effect of a lower degree of risk sensitivity $z$ on the steady-state technology frontier in the industry of the South is illustrated in Figure 5(c).

The technology parameter $\rho$ specifying the elasticity of substitution $\frac{1}{1-\rho}$ between intermediate steps of production affects negatively the unit cost of production (3), the profit-maximizing output level, and hence the profit level. In particular, if the different intermediate steps of production are more substitutable, it takes more intensive labor input in each step to produce a given amount of output; this leads to a higher level of unit cost and a lower level of output and profit *ceteris paribus*. The negative impact is larger if the initial production scale is larger. For firms that have chosen to produce in the South, their output levels will be affected more negatively by an increase in $\rho$ than if they produced in the North, as these firms produce more in the South than they would in the North (firms that choose to produce in the South must have a higher level of variable profit and hence output producing

[4] It is also shown in the appendix that the effects of the demand elasticity $\alpha$ and the inverse dispersion measure of firms' technology levels $k$ do not have definite signs.

in the South than they would in the North, so as to offset, at least, the higher setup cost of FDI). Thus, an increase in $\rho$ and the elasticity of substitution between intermediate steps will discourage marginal firms from producing in the South, lowering the upper bound and increasing the lower bound of FDI technology content, and reduce the amount of inward FDI. On top of this negative extensive effect, all existing FDI's output also decreases (a negative intensive effect) in response to a higher $\rho$. Thus, overall, the aggregate production of the South for multinational firms in the industry is lower, which eventually leads to a lower level of technology frontier in the industry of the South. Figure 5(c) illustrates the opposite scenario of a decrease in $\rho$.

# 4. CONCLUSION

This paper addresses the risk of quality control failure and the stronger negative incentives it implies for higher-technology firms to undertake FDI in a relative backward South. This leads to a non-monotonic relationship between firms' performance measures and their propensity to carry out FDI, which is a departure from the literature, and an upper bound on the technology content of FDI, which provides a better description of the reality and more reasonable policy implications. The same risk consideration also implies an endogenous threshold on a Southern country's technology frontier that must be met before it will attract any inward FDI.

We further model the South's endogenous upgrading of its technology frontier through learning by producing for multinational firms. We show how the risk condition facing potential FDI entrants from the North improves endogenously as the host country's technology capacity strengthens. This implies a self-reinforcing FDI dynamic process, where the effects of the South's initial condition on the FDI stock, the technology content of FDI, and the South's technology frontier tend to be magnified at the steady state. The aforementioned threshold effect and agglomeration phenomenon have often been documented in empirics for FDI flows in specific industries or regions. However, to the best of our knowledge, they are first formalized in our paper.

The analytical framework presented thus suggests many relevant mechanisms which a Southern country may target to raise its long-run development level via exposure to FDI. These include improving its learning speed or absorptive capacity in transforming the technology content of FDI to its own knowledge stock for given amounts of FDI inflows, creating stronger cost incentives to increase the amount of FDI inflows in given industries, and addressing heterogeneities across industries in terms of risk sensitivity or input substitution. Many of these mechanisms have been explored in empirical studies or analyzed separately in different theoretical models. We present an overarching theory that encompasses these important aspects and clarifies the specific theoretical channels through which each potentially policy-dependent variable works to affect the incentives of FDI. Such structural dynamic frameworks were often lacking in previous empirical studies. The analysis of the risk factor in relation to production technology and its impact on the technology content of FDI in our framework also opens up a new area of research that has not received much attention by past empirical studies.

# 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 show 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

$$\tilde{\theta}^\dagger(\tilde{T}^S, z) = \left[\left(1 - \frac{z}{\nu\alpha(1-\alpha)}\right)\frac{\psi^S}{\psi^N}\right]^{\frac{\nu\alpha(1-\alpha)}{z}} \tilde{T}^S. \tag{33}$$

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:

$$\phi(\tilde{T}^S, z) \;\; = \;\; \psi^N \tilde{\theta}^\dagger(\tilde{T}^S, z)/g(z) - w^N(f^S - f^N), \tag{34}$$

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

$$\frac{\partial\phi(\tilde{T}^S, z)}{\partial z} < 0, \;\; \lim_{z\to 0}\phi(\tilde{T}^S, z) \to \infty, \;\; \lim_{z\to\bar{z}}\phi(\tilde{T}^S, z) = \tilde{T}^S\left(\psi^S - \psi^N\right) - w^N(f^S - f^N) < 0, \tag{35}$$

where the first limit follows by applying the 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 theory, it follows that there exists a unique $z^* \in (0, \bar{z})$, such that

$$\phi(\tilde{T}^S, z^*) = 0, \tag{36}$$

and that $\tilde{\pi}^S$ is tangent to $\tilde{\pi}^N$. For $z < z^*$, it follows that $\phi(\tilde{T}^S, z) > 0$ and as a result, positive amounts of FDI take place. For $T^S = \theta_{NS}$, the South profit function will lie everywhere below the North profit function with overlapping only at $\theta_{NS}$, 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 then 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, i.e. $T^S = 1$. For $z$ below the cap $z^*(1)$, FDI takes place necessarily, which is equivalent to say that $T^{S*}(z) = 1$ for $z \in [0, z^*(1)]$. For sufficiently large degrees of risk sensitivity such that $\bar{z} \leq z$, 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 $\theta_{NS}$, so $T^{S*}(z) = \theta_{NS}$ for $\bar{z} \leq z$. For $z \in (z^*(1), \bar{z})$, to show the existence of a unique $T^{S*}(z)$ is again equivalent to show 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, that

$$\phi(\tilde{T}^{S*}, z) = 0. \tag{37}$$

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

$$\frac{\partial \phi(\tilde{T}^S, z)}{\partial \tilde{T}^S} > 0, \quad \lim_{\tilde{T}^S \to 1} \phi(\tilde{T}^S, z) < 0, \quad \lim_{\tilde{T}^S \to \tilde{\theta}_{NS}} \phi(\tilde{T}^S, z) > 0. \tag{38}$$

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 $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z) - \tilde{\pi}^N(\tilde{\theta})$. As $\tilde{\pi}^S(\tilde{\theta}; \tilde{T}^S, z) - \tilde{\pi}^N(\tilde{\theta}) = 0$ at $\tilde{\theta} = \tilde{T}^S = \tilde{\theta}_{NS}$ and $\tilde{\theta}^\dagger > \tilde{T}^S$, the sign of the second limit follows. Thus, by the fixed point theory, there exists a unique $\tilde{T}^{S*} \in (1, \tilde{\theta}_{NS})$ for $z \in (z^*(1), \bar{z})$, such that (37) is satisfied.

To show the relationship between $T^{S*}$ and $z$, take the total differentiation of (37) to obtain

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

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 $z \geq \bar{z}$.

■

*Proof of Propositions 6–8.* To determine the signs of (28)–(32), first note that $\Sigma > 0$ holds at a stable steady state. Also recall the signs for the critical elements $\Lambda > 0$ and $\Gamma_Q > 0$, as well as those for $\frac{\partial\theta_1}{\partial T^S}$ and $\frac{\partial\theta_0}{\partial T^S}$ from Lemma 2. Finally, note that based on the definition for the technology content of inward FDI, (11)–(12), it follows that

$$\frac{\partial\theta_1}{\partial q} \equiv \left[\pi_\theta^N(\theta_1) - \pi_\theta^S(\theta_1)\right]^{-1}\left[\pi_q^S(\theta_1) - \pi_q^N(\theta_1)\right], \tag{39}$$

$$\frac{\partial\theta_0}{\partial q} \equiv \begin{cases} \left[\pi_\theta^N(\theta_0) - \pi_\theta^S(\theta_0)\right]^{-1}\left[\pi_q^S(\theta_0) - \pi_q^N(\theta_0)\right], & \text{if } 1 \le T^S < \theta_{NS}, \\ \left[\pi_\theta^N(\theta_{NS}) - \pi_\theta^S(\theta_{NS})\right]^{-1}\left[\pi_q^S(\theta_{NS}) - \pi_q^N(\theta_{NS})\right], & \text{if } \theta_{NS} \le T^S. \end{cases} \tag{40}$$

where $\pi_q^l \equiv \frac{\partial\pi^l}{\partial q}$ for $l \in \{N, S\}$. Recall that $\frac{\partial\chi}{\partial\theta_0} < 0$ and $\frac{\partial\chi}{\partial\theta_1} > 0$. Thus, to determine the sign of $\Xi$, it remains to show the signs of the derivatives $\frac{\partial\theta_1}{\partial q}$, $\frac{\partial\theta_0}{\partial q}$, and $\frac{\partial\chi}{\partial q}$, using the profit functions (9)–(10), and the FDI aggregate production function (17), for each parameter. We show the detailed derivations below.

For each parameter $q \in \{T_0^S, \delta_D, \delta_L, w^S, f^S, f^N, z, \rho, w^N, k, \alpha\}$, we first show the signs of $\frac{\partial\theta_1}{\partial q}$, $\frac{\partial\theta_0}{\partial q}$, and $\frac{\partial\chi}{\partial q}$, based on (9), (10), and (17), as well as (39) and (40). The results will help determine the sign of $\Xi$. Given the signs of $\Xi$, $\frac{\partial\theta_1}{\partial q}$, and $\frac{\partial\theta_0}{\partial q}$, the signs of the comparative statics for (28)–(32) then follow straightforwardly.

(i) $q = T_0^S$: As the parameter $T_0^S$ does not appear in the profit functions (9) and (10), and the aggregate production function (17), it follows that $\frac{\partial\theta_1}{\partial T_0^S} = 0$, $\frac{\partial\theta_0}{\partial T_0^S} = 0$, and $\frac{\partial\chi}{\partial T_0^S} = 0$. Thus, $\Xi = \ominus 0 + \oplus 0 + 0 = 0$, and

$$\begin{aligned}
\frac{dT^S}{dT_0^S} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial\delta}{\partial T_0^S} + \Sigma^{-1}\frac{\partial T_0^S}{\partial T_0^S} = \oplus 0 + \oplus 0 + \Sigma^{-1} > 0 \\
\frac{dX^S}{dT_0^S} &= \Xi + \Lambda\frac{dT^S}{dT_0^S} = 0 + \oplus\oplus > 0 \\
\frac{dQ^S}{dT_0^S} &= \delta\frac{dX^S}{dT_0^S} + X^S\frac{\partial\delta}{\partial T_0^S} = \oplus\oplus + \oplus 0 > 0 \\
\frac{d\theta_1}{dT_0^S} &= \frac{\partial\theta_1}{\partial T_0^S} + \frac{\partial\theta_1}{\partial T^S}\frac{dT^S}{dT_0^S} = 0 + \oplus\oplus > 0 \\
\frac{d\theta_0}{dT_0^S} &= \begin{cases} \frac{\partial\theta_0}{\partial T_0^S} + \frac{\partial\theta_0}{\partial T^S}\frac{dT^S}{dT_0^S} = 0 + \ominus\oplus < 0, & \text{if } 1 \le T^S < \theta_{NS} \\ \frac{\partial\theta_0}{\partial T_0^S} = 0, & \text{if } \theta_{NS} \le T^S \end{cases}
\end{aligned}$$

(ii) $q = \delta_D$:

As the parameter $\delta_D$ does not appear in the profit functions (9) and (10), and the aggregate production function (17), it follows that $\frac{\partial\theta_1}{\partial\delta_D} = 0$, $\frac{\partial\theta_0}{\partial\delta_D} = 0$, and $\frac{\partial\chi}{\partial\delta_D} = 0$.

Thus, $\Xi = \ominus 0 + \oplus 0 + 0 = 0$, and

$$\begin{aligned}
\frac{dT^S}{d\delta_D} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial\delta}{\partial\delta_D} + \Sigma^{-1}\frac{\partial T_0^S}{\partial\delta_D} = \oplus 0 + \oplus\ominus + \oplus\, 0 < 0 \\
\frac{dX^S}{d\delta_D} &= \Xi + \Lambda\frac{dT^S}{d\delta_D} = 0 + \oplus\ominus < 0 \\
\frac{dQ^S}{d\delta_D} &= \delta\frac{dX^S}{d\delta_D} + X^S\frac{\partial\delta}{\partial\delta_D} = \oplus\ominus + \oplus\ominus < 0 \\
\frac{d\theta_1}{d\delta_D} &= \frac{\partial\theta_1}{\partial\delta_D} + \frac{\partial\theta_1}{\partial T^S}\frac{dT^S}{d\delta_D} = 0 + \oplus\ominus < 0 \\
\frac{d\theta_0}{d\delta_D} &= \begin{cases} \frac{\partial\theta_0}{\partial\delta_D} + \frac{\partial\theta_0}{\partial T^S}\frac{dT^S}{d\delta_D} = 0 + \ominus\ominus > 0, & \text{if } 1 \le T^S < \theta_{NS} \\ \frac{\partial\theta_0}{\partial\delta_D} = 0, & \text{if } \theta_{NS} \le T^S \end{cases}
\end{aligned}$$

(iii) $q = \delta_L$:

As the parameter $\delta_L$ does not appear in the profit functions (9) and (10), and the aggregate production function (17), it follows that $\frac{\partial\theta_1}{\partial\delta_L} = 0$, $\frac{\partial\theta_0}{\partial\delta_L} = 0$, and $\frac{\partial\chi}{\partial\delta_L} = 0$. Thus, $\Xi = \ominus 0 + \oplus 0 + 0 = 0$, and

$$\begin{aligned}
\frac{dT^S}{d\delta_L} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial\delta}{\partial\delta_L} + \Sigma^{-1}\frac{\partial T_0^S}{\partial\delta_L} = \oplus 0 + \oplus\oplus + \oplus\, 0 > 0 \\
\frac{dX^S}{d\delta_L} &= \Xi + \Lambda\frac{dT^S}{d\delta_L} = 0 + \oplus\oplus > 0 \\
\frac{dQ^S}{d\delta_L} &= \delta\frac{dX^S}{d\delta_L} + X^S\frac{\partial\delta}{\partial\delta_L} = \oplus\oplus + \oplus\oplus > 0 \\
\frac{d\theta_1}{d\delta_L} &= \frac{\partial\theta_1}{\partial\delta_L} + \frac{\partial\theta_1}{\partial T^S}\frac{dT^S}{d\delta_L} = 0 + \oplus\oplus > 0 \\
\frac{d\theta_0}{d\delta_L} &= \begin{cases} \frac{\partial\theta_0}{\partial\delta_L} + \frac{\partial\theta_0}{\partial T^S}\frac{dT^S}{d\delta_L} = 0 + \ominus\oplus < 0, & \text{if } 1 \le T^S < \theta_{NS} \\ \frac{\partial\theta_0}{\partial\delta_L} = 0, & \text{if } \theta_{NS} \le T^S \end{cases}
\end{aligned}$$

(iv) $q = w^S$:

Using (9) and (10), note that

$$\begin{aligned}
\pi^S_{w^S}(\theta) - \pi^N_{w^S}(\theta) &= \frac{\partial\psi^S}{\partial w^S}\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha - \frac{z}{1-\alpha}} < 0, \text{ for } T^S < \theta, \\
\pi^S_{w^S}(\theta) - \pi^N_{w^S}(\theta) &= \frac{\partial\psi^S}{\partial w^S}\theta^{\nu\alpha} < 0, \text{ for } \theta \le T^S.
\end{aligned}$$

Plug the above signs into (39) and (40); it follows that $\frac{\partial\theta_1}{\partial w^S} < 0$ and $\frac{\partial\theta_0}{\partial w^S} > 0$. Next, using (17), note that

$$\frac{\partial \chi}{\partial w^S} = \frac{\partial \Omega^S}{\partial w^S}\frac{\chi}{\Omega^S} < 0,$$

as $\frac{\partial \Omega^S}{\partial w^S} < 0$. As a result, $\Xi = \ominus \oplus + \oplus \ominus + \ominus < 0$, and

$$\begin{aligned}
\frac{dT^S}{dw^S} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial \delta}{\partial w^S} + \Sigma^{-1}\frac{\partial T_0^S}{\partial w^S} = \oplus \ominus + \oplus\, 0 + \oplus 0 < 0 \\
\frac{dX^S}{dw^S} &= \Xi + \Lambda\frac{dT^S}{dw^S} = \ominus + \oplus\ominus < 0 \\
\frac{dQ^S}{dw^S} &= \delta\frac{dX^S}{dw^S} + X^S\frac{\partial \delta}{\partial w^S} = \oplus \ominus + \oplus\, 0 < 0 \\
\frac{d\theta_1}{dw^S} &= \frac{\partial \theta_1}{\partial w^S} + \frac{\partial \theta_1}{\partial T^S}\frac{dT^S}{dw^S} = \ominus + \oplus\ominus < 0 \\
\frac{d\theta_0}{dw^S} &= \begin{cases} \frac{\partial \theta_0}{\partial w^S} + \frac{\partial \theta_0}{\partial T^S}\frac{dT^S}{dw^S} = \oplus + \ominus\ominus > 0, & \text{if } 1 \leq T^S < \theta_{NS} \\ \frac{\partial \theta_0}{\partial w^S} > 0, & \text{if } \theta_{NS} \leq T^S \end{cases}
\end{aligned}$$

(v) $q = f^S$:

Using (9) and (10), note that

$$\pi^S_{f^S}(\theta) - \pi^N_{f^S}(\theta) \;=\; -w^N < 0.$$

Plug the above signs into (39) and (40); it follows that $\frac{\partial \theta_1}{\partial f^S} < 0$ and $\frac{\partial \theta_0}{\partial f^S} > 0$. Furthermore, note that $\frac{\partial \chi}{\partial f^S} = 0$. Thus, $\Xi = \ominus \oplus + \oplus \ominus + 0 < 0$, and

$$\begin{aligned}
\frac{dT^S}{df^S} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial \delta}{\partial f^S} + \Sigma^{-1}\frac{\partial T_0^S}{\partial f^S} = \oplus \ominus + \oplus\, 0 + \oplus 0 < 0 \\
\frac{dX^S}{df^S} &= \Xi + \Lambda\frac{dT^S}{df^S} = \ominus + \oplus\ominus < 0 \\
\frac{dQ^S}{df^S} &= \delta\frac{dX^S}{df^S} + X^S\frac{\partial \delta}{\partial f^S} = \oplus \ominus + \oplus\, 0 < 0 \\
\frac{d\theta_1}{df^S} &= \frac{\partial \theta_1}{\partial f^S} + \frac{\partial \theta_1}{\partial T^S}\frac{dT^S}{df^S} = \ominus + \oplus\ominus < 0 \\
\frac{d\theta_0}{df^S} &= \begin{cases} \frac{\partial \theta_0}{\partial f^S} + \frac{\partial \theta_0}{\partial T^S}\frac{dT^S}{df^S} = \oplus + \ominus\ominus > 0, & \text{if } 1 \leq T^S < \theta_{NS} \\ \frac{\partial \theta_0}{\partial f^S} > 0, & \text{if } \theta_{NS} \leq T^S \end{cases}
\end{aligned}$$

(vi) $q = f^N$:

Using (9) and (10), note that

$$\pi^S_{f^N}(\theta) - \pi^N_{f^N}(\theta) \;=\; w^N > 0.$$

Plug the above signs into (39) and (40); it follows that $\frac{\partial\theta_1}{\partial f^N} > 0$ and $\frac{\partial\theta_0}{\partial f^N} < 0$. Note as well that $\frac{\partial\chi}{\partial f^N} = 0$. Thus, $\Xi = \ominus\ominus + \oplus\oplus + 0 > 0$, and

$$\begin{aligned}
\frac{dT^S}{df^N} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial\delta}{\partial f^N} + \Sigma^{-1}\frac{\partial T_0^S}{\partial f^N} = \oplus\oplus + \oplus 0 + \oplus 0 > 0 \\
\frac{dX^S}{df^N} &= \Xi + \Lambda\frac{dT^S}{df^N} = \oplus + \oplus\oplus > 0 \\
\frac{dQ^S}{df^N} &= \delta\frac{dX^S}{df^N} + X^S\frac{\partial\delta}{\partial f^N} = \oplus\oplus + \oplus 0 > 0 \\
\frac{d\theta_1}{df^N} &= \frac{\partial\theta_1}{\partial f^N} + \frac{\partial\theta_1}{\partial T^S}\frac{dT^S}{df^N} = \oplus + \oplus\oplus > 0 \\
\frac{d\theta_0}{df^N} &= \begin{cases} \frac{\partial\theta_0}{\partial f^N} + \frac{\partial\theta_0}{\partial T^S}\frac{dT^S}{df^N} = \ominus + \ominus\oplus < 0, & \text{if } 1 \le T^S < \theta_{NS} \\ \frac{\partial\theta_0}{\partial f^N} < 0, & \text{if } \theta_{NS} \le T^S \end{cases}
\end{aligned}$$

(vii) $q = z$:

Using (9) and (10), note that

$$\begin{aligned}
\pi_z^S(\theta) - \pi_z^N(\theta) &= \frac{1}{1-\alpha}\psi^S\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha-\frac{z}{1-\alpha}}(\ln T^S - \ln\theta) < 0, \text{ for } T^S < \theta, \\
\pi_z^S(\theta) - \pi_z^N(\theta) &= 0, \text{ for } \theta \le T^S.
\end{aligned}$$

Plug the above signs into (39) and (40); it follows that $\frac{\partial\theta_1}{\partial z} < 0$, while $\frac{\partial\theta_0}{\partial z} > 0$ if $1 \le T^S < \theta_{NS}$ and $\frac{\partial\theta_0}{\partial z} = 0$ if $\theta_{NS} \le T^S$. Next, using (17), note that if $1 \le T^S < \theta_{NS}$,

$$\frac{\partial\chi}{\partial z} = -\frac{1}{1-\alpha}\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[J(\theta_0) - J(\theta_1)],$$

where $J(\theta) \equiv \left(\frac{1}{a} - \ln\frac{T^S}{\theta}\right)\theta^{-a}$, which is flat at $\theta = T^S$ and everywhere decreasing for $\theta > T^S \ge 1$. In the current case, $T^S < \theta_0 < \theta_1$, it follows that $J(\theta_0) - J(\theta_1) > 0$ and $\frac{\partial\chi}{\partial z} < 0$. Alternatively, if $T^S \ge \theta_{NS}$,

$$\frac{\partial\chi}{\partial z} = -\frac{1}{1-\alpha}\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[J(T^S) - J(\theta_1)].$$

Given the property of $J(\theta)$ and that $T^S < \theta_1$, it follows that $\frac{\partial\chi}{\partial z} < 0$ in this case as well. Hence, $\Xi = \ominus\oplus + \oplus\ominus + \ominus < 0$, if $1 \le T^S < \theta_{NS}$, and $\Xi = \ominus 0 + \oplus\ominus + \ominus < 0$, if

$\theta_{NS} \leq T^S$ as well. As a result,

$$
\begin{aligned}
\frac{dT^S}{dz} &= \Sigma^{-1}\delta\Gamma_Q\Xi + \Sigma^{-1}X^S\Gamma_Q\frac{\partial\delta}{\partial z} + \Sigma^{-1}\frac{\partial T_0^S}{\partial z} = \oplus\ominus + \oplus\, 0 + \oplus 0 < 0 \\
\frac{dX^S}{dz} &= \Xi + \Lambda\frac{dT^S}{dz} = \ominus + \oplus\ominus < 0 \\
\frac{dQ^S}{dz} &= \delta\frac{dX^S}{dz} + X^S\frac{\partial\delta}{\partial z} = \oplus\ominus + \oplus\, 0 < 0 \\
\frac{d\theta_1}{dz} &= \frac{\partial\theta_1}{\partial z} + \frac{\partial\theta_1}{\partial T^S}\frac{dT^S}{dz} = \ominus + \oplus\ominus < 0 \\
\frac{d\theta_0}{dz} &= \begin{cases} \frac{\partial\theta_0}{\partial z} + \frac{\partial\theta_0}{\partial T^S}\frac{dT^S}{dz} = \oplus + \ominus\ominus > 0, & \text{if } 1 \leq T^S < \theta_{NS} \\ \frac{\partial\theta_0}{\partial z} = 0, & \text{if } \theta_{NS} \leq T^S \end{cases}
\end{aligned}
$$

(viii) $q = \rho$:

Using (9) and (10), note that

$$
\begin{aligned}
\pi_\rho^S(\theta) - \pi_\rho^N(\theta) &= \alpha\frac{\partial\nu}{\partial\rho}\left[\psi^S\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha-\frac{z}{1-\alpha}} - \psi^N\theta^{\nu\alpha}\right]\ln\theta, \text{ for } T^S < \theta, \\
&= \alpha\frac{\partial\nu}{\partial\rho}\left[w^N(f^S - f^N)\right]\ln\theta < 0, \text{ for } T^S < \theta = \{\theta_0, \theta_1\}, \\
\pi_\rho^S(\theta) - \pi_\rho^N(\theta) &= \alpha\frac{\partial\nu}{\partial\rho}\left[\psi^S\theta^{\nu\alpha} - \psi^N\theta^{\nu\alpha}\right]\ln\theta < 0, \text{ for } \theta \leq T^S
\end{aligned}
$$

where we have used the fact that $\frac{\partial\nu}{\partial\rho} < 0$. Plug the above signs into (39) and (40); it follows that $\frac{\partial\theta_1}{\partial\rho} < 0$, and $\frac{\partial\theta_0}{\partial\rho} > 0$. Next, note that if $1 \leq T^S < \theta_{NS}$,

$$
\frac{\partial\chi}{\partial\rho} = -\frac{\partial a}{\partial\rho}\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}\left[\hat{J}(\theta_0, a) - \hat{J}(\theta_1, a)\right]
$$

where $\frac{\partial a}{\partial\rho} > 0$ and $\hat{J}(\theta, r) \equiv \left(\frac{1}{r} + \ln\theta\right)\theta^{-r}$, which is a decreasing function of $\theta$, for any $r > 0$ and $\theta > 1$. Note that in the current case, $1 \leq T^S < \theta_0 < \theta_1$, it follows that $\hat{J}(\theta_0, a) - \hat{J}(\theta_1, a) > 0$ and $\frac{\partial\chi}{\partial\rho} < 0$. Alternatively, if $T^S \geq \theta_{NS}$,

$$
\begin{aligned}
\frac{\partial\chi}{\partial\rho} = & - \frac{\partial(k-\nu)}{\partial\rho}\frac{\Omega^S k}{(k-\nu)}[\hat{J}(\theta_0, k-\nu) - \hat{J}(T^S, k-\nu)] \\
& - \frac{\partial a}{\partial\rho}\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[\hat{J}(T^S, a) - \hat{J}(\theta_1, a)].
\end{aligned}
$$

Note that $\frac{\partial(k-\nu)}{\partial\rho} > 0$. Given the property of $\hat{J}(\theta, r)$ and that $\theta_0 \leq T^S < \theta_1$ in this case, it follows that $\frac{\partial \chi}{\partial \rho} < 0$. As a result, $\Xi = \ominus \oplus + \oplus \ominus + \ominus < 0$, and

$$\begin{aligned}
\frac{dT^S}{d\rho} &= \Sigma^{-1}\delta\Gamma_Q \Xi + \Sigma^{-1} X^S \Gamma_Q \frac{\partial \delta}{\partial \rho} + \Sigma^{-1} \frac{\partial T_0^S}{\partial \rho} = \oplus \ominus + \oplus\, 0 + \oplus 0 < 0 \\
\frac{dX^S}{d\rho} &= \Xi + \Lambda \frac{dT^S}{d\rho} = \ominus + \oplus\ominus < 0 \\
\frac{dQ^S}{d\rho} &= \delta \frac{dX^S}{d\rho} + X^S \frac{\partial \delta}{\partial \rho} = \oplus \ominus + \oplus\, 0 < 0 \\
\frac{d\theta_1}{d\rho} &= \frac{\partial \theta_1}{\partial \rho} + \frac{\partial \theta_1}{\partial T^S} \frac{dT^S}{d\rho} = \ominus + \oplus\ominus < 0 \\
\frac{d\theta_0}{d\rho} &= \begin{cases} \frac{\partial \theta_0}{\partial \rho} + \frac{\partial \theta_0}{\partial T^S} \frac{dT^S}{d\rho} = \oplus + \ominus\ominus > 0, & \text{if } 1 \leq T^S < \theta_{NS} \\ \frac{\partial \theta_0}{\partial \rho} > 0, & \text{if } \theta_{NS} \leq T^S \end{cases}
\end{aligned}$$

(ix) $q = w^N$: **"Not for Publication"**

Note that

$$\pi^S_{w^N}(\theta) - \pi^N_{w^N}(\theta) \;=\; -f^S - \frac{\partial \psi^N}{\partial w^N} \theta^{\nu\alpha} + f^N,$$

whose sign is not definite. Thus, it follows that $\frac{\partial \theta_1}{\partial w^N}$ and $\frac{\partial \theta_0}{\partial w^N}$ do not have definite signs, and so does $\Xi$ and the rest of the comparative statics.

(x) $q = k$: **"Not for Publication"**

The parameter $k$ does not appear in the profit functions (9) and (10); thus, $\frac{\partial \theta_1}{\partial k} = 0$ and $\frac{\partial \theta_0}{\partial k} = 0$. Next, using (17), note that

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

whose sign is not definitive, but can be shown to depend on the sign of $(\frac{1}{k} - \ln \theta)$, i.e., the level of $k$ and the range of FDI. The above results imply that the sign of $\Xi$ is not definitive and so are the signs of the comparative statics.

(xi) $q = \alpha$: **"Not for Publication"**

Note that $\frac{\partial \psi^l}{\partial \alpha} = \frac{1}{(1-\alpha)^2} \ln\left(\frac{\alpha}{w^l}\right) \psi^l$. Using (9) and (10), note that for $T^S < \theta$,

$$\begin{aligned}
\pi_\alpha^S(\theta) - \pi_\alpha^N(\theta) &= \frac{1}{(1-\alpha)^2}\left[\ln\left(\frac{\alpha}{w^S}\right)\psi^S\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha-\frac{z}{1-\alpha}} - \ln\left(\frac{\alpha}{w^N}\right)\psi^N\theta^{\nu\alpha}\right] \\
&+ \frac{1-\rho}{\rho}\frac{1}{(1-\alpha)^2}\left[\psi^S\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha-\frac{z}{1-\alpha}} - \psi^N\theta^{\nu\alpha}\right]\ln\theta \\
&+ \frac{z}{(1-\alpha)^2}\left[\psi^S\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha-\frac{z}{1-\alpha}}\right]\left[\ln T^S - \ln\theta\right], \\
&= \frac{1}{(1-\alpha)^2}\psi^N\theta^{\nu\alpha}\left[\ln\left(\frac{w^N}{w^S}\right) + z\left(\ln T^S - \ln\theta\right)\right] \\
&+ \frac{1}{(1-\alpha)^2}w^N\left(f^S - f^N\right)\left[\left(\frac{1-\rho}{\rho}\right)\ln\theta + \ln\left(\frac{\alpha}{w^S}\right) + z\left(\ln T^S - \ln\theta\right)\right], \\
&\text{for } T^S < \theta = \{\theta_0, \theta_1\},
\end{aligned}$$

where to get the second equality, we have used the fact that $\psi^S\left(T^S\right)^{\frac{z}{1-\alpha}}\theta^{\nu\alpha-\frac{z}{1-\alpha}} = \psi^N\theta^{\nu\alpha} + w^N\left(f^S - f^N\right)$ at $\theta = \{\theta_0, \theta_1\}$, as profits of producing in the South and in the North are the same at these two technology levels. Use the definition of $x^N(\theta)$ and $x^S(\theta)$ for $T^S < \theta$, it follows that $\pi_\alpha^S(\theta) - \pi_\alpha^N(\theta) = \left(x^N(\theta)\right)^\alpha\left(\ln x^S(\theta) - \ln x^N(\theta)\right) + \frac{1}{(1-\alpha)}w^N(f^S - f^N)\left(\ln x^S(\theta)\right)$ at $T^S < \theta = \{\theta_0, \theta_1\}$, where $\left(\ln x^S(\theta) - \ln x^N(\theta)\right) > 0$ at $\theta = \{\theta_0, \theta_1\}$, but the sign of $\left(\ln x^S(\theta)\right)$ depends on the parameters.

Alternatively, for $\theta \le T^S$, based on similar manipulations, we can show that

$$\begin{aligned}
\pi_\alpha^S(\theta) - \pi_\alpha^N(\theta) &= \frac{1}{(1-\alpha)^2}\left[\ln\left(\frac{\alpha}{w^S}\right)\psi^S\theta^{\nu\alpha} - \ln\left(\frac{\alpha}{w^N}\right)\psi^N\theta^{\nu\alpha}\right] \\
&+ \frac{1-\rho}{\rho}\frac{1}{(1-\alpha)^2}\left[\psi^S\theta^{\nu\alpha} - \psi^N\theta^{\nu\alpha}\right]\ln\theta \\
&= \frac{1}{(1-\alpha)^2}\psi^N\theta^{\nu\alpha}\left[\ln\left(\frac{w^N}{w^S}\right)\right] \\
&+ \frac{1}{(1-\alpha)^2}w^N\left(f^S - f^N\right)\left[\left(\frac{1-\rho}{\rho}\right)\ln\theta + \ln\left(\frac{\alpha}{w^S}\right)\right], \\
&\text{for } \theta = \{\theta_0\} \le T^S,
\end{aligned}$$

Again, use the definition of $x^N(\theta)$ and $x^S(\theta)$ for $\theta \le T^S$, it follows that $\pi_\alpha^S(\theta) - \pi_\alpha^N(\theta) = \left(x^N(\theta)\right)^\alpha\left(\ln x^S(\theta) - \ln x^N(\theta)\right) + \frac{1}{(1-\alpha)}w^N(f^S - f^N)\left(\ln x^S(\theta)\right)$ at $\theta = \{\theta_0\} \le T^S$. Thus, the sign of $\pi_\alpha^S(\theta) - \pi_\alpha^N(\theta)$ again depends on the parameters.

Next, note that if $1 \leq T^S < \theta_{NS}$,

$$\begin{aligned}\frac{\partial \chi}{\partial \alpha} = & - \frac{\partial a}{\partial \alpha}\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[\hat{J}(\theta_0, a) - \hat{J}(\theta_1, a)] \\ & + \frac{1}{(1-\alpha)}\left[\frac{1}{\alpha} + \ln \Omega^S + \ln\left(T^S\right)^{\frac{z}{1-\alpha}}\right]\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[(\theta_0)^{-a} - (\theta_1)^{-a}],\end{aligned}$$

where the first term is positive, given that $\frac{\partial a}{\partial \alpha} < 0$ and the property of $\hat{J}(\theta, r)$; the sign of the second term depends on the sign of $\left[\frac{1}{\alpha} + \ln \Omega^S + \ln\left(T^S\right)^{\frac{z}{1-\alpha}}\right]$, which depends on the parameters. Alternatively, if $T^S \geq \theta_{NS}$,

$$\begin{aligned}\frac{\partial \chi}{\partial \alpha} = & - \frac{\partial (k-\nu)}{\partial \alpha}\frac{\Omega^S k}{(k-\nu)}[\hat{J}(\theta_0, k-\nu) - \hat{J}(T^S, k-\nu)] \\ & - \frac{\partial a}{\partial \alpha}\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[\hat{J}(T^S, a) - \hat{J}(\theta_1, a)] \\ & + \frac{1}{(1-\alpha)}\left[\frac{1}{\alpha} + \ln \Omega^S\right]\frac{\Omega^S k}{(k-\nu)}[(\theta_0)^{-(k-\nu)} - (\theta_1)^{-(k-\nu)}] \\ & + \frac{1}{(1-\alpha)}\left[\frac{1}{\alpha} + \ln \Omega^S + \ln\left(T^S\right)^{\frac{z}{1-\alpha}}\right]\frac{\Omega^S k}{a}\left(T^S\right)^{\frac{z}{1-\alpha}}[\left(T^S\right)^{-a} - (\theta_1)^{-a}],\end{aligned}$$

where the first and the second terms are positive given that $\frac{\partial(k-\nu)}{\partial \alpha} < 0$ and the property of $\hat{J}(\theta, r)$; the signs of the third and fourth terms again depend on the parameters. Thus, it follows that $\frac{\partial \theta_1}{\partial \alpha}$, $\frac{\partial \theta_0}{\partial \alpha}$, and $\frac{\partial \chi}{\partial \alpha}$ do not have definite signs, and so does $\Xi$ and the rest of the comparative statics.

■

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

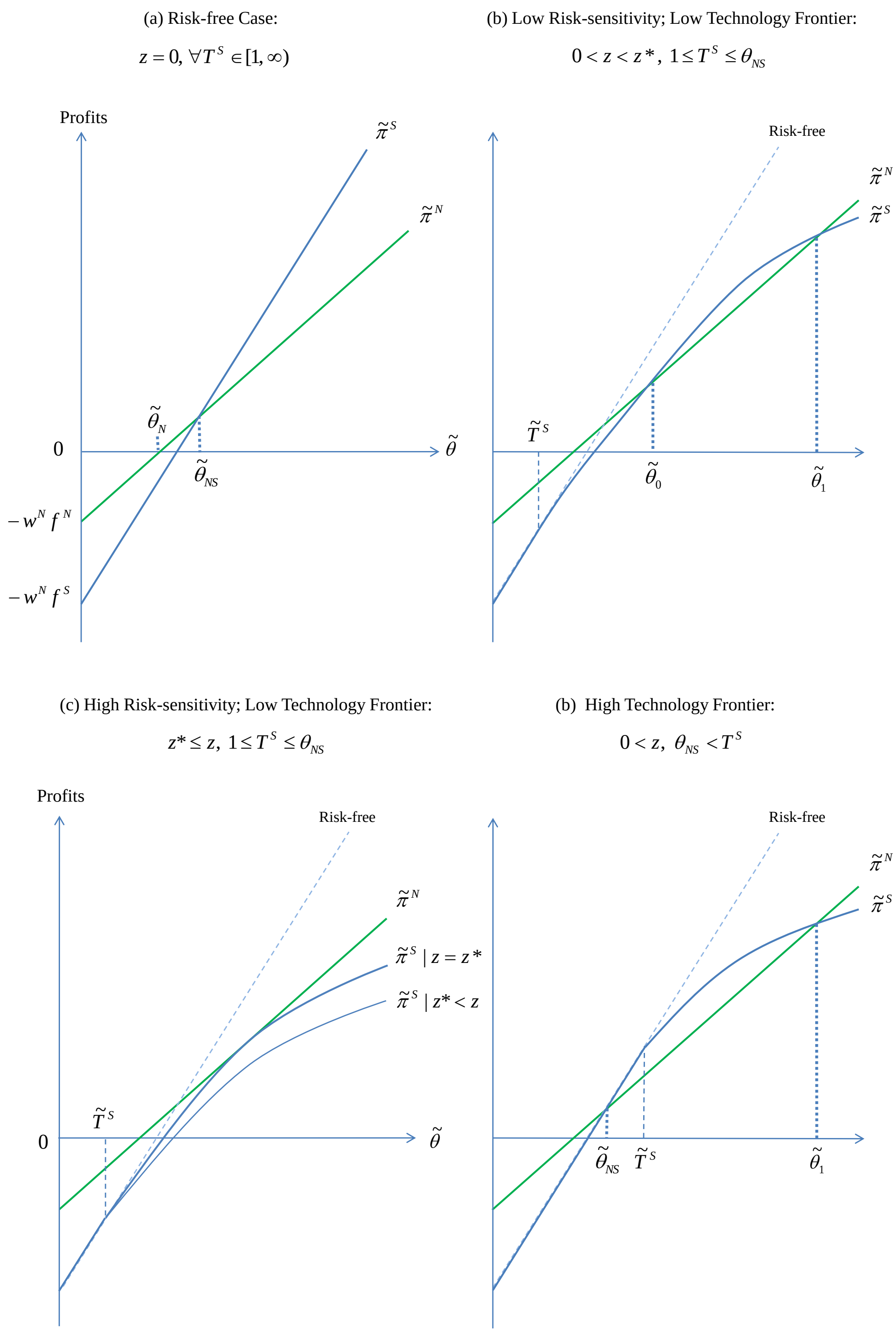


Figure 2: Threshold Technology Frontier For Inward FDI

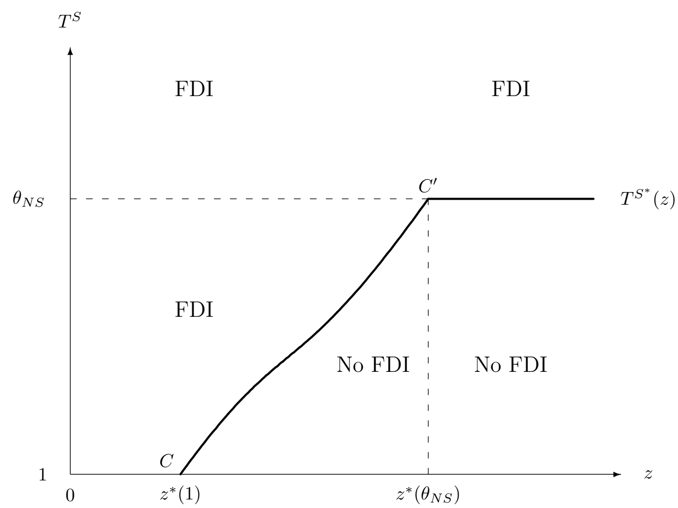



Figure 3: Dynamics of FDI

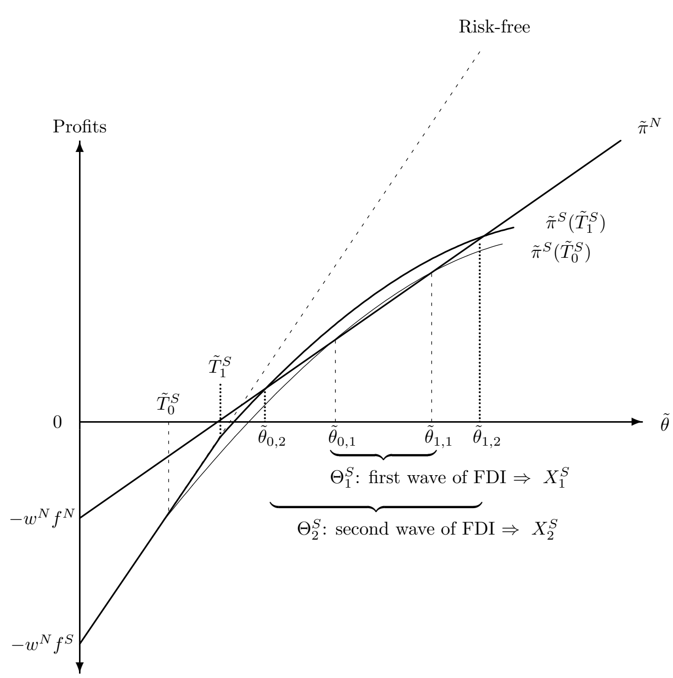
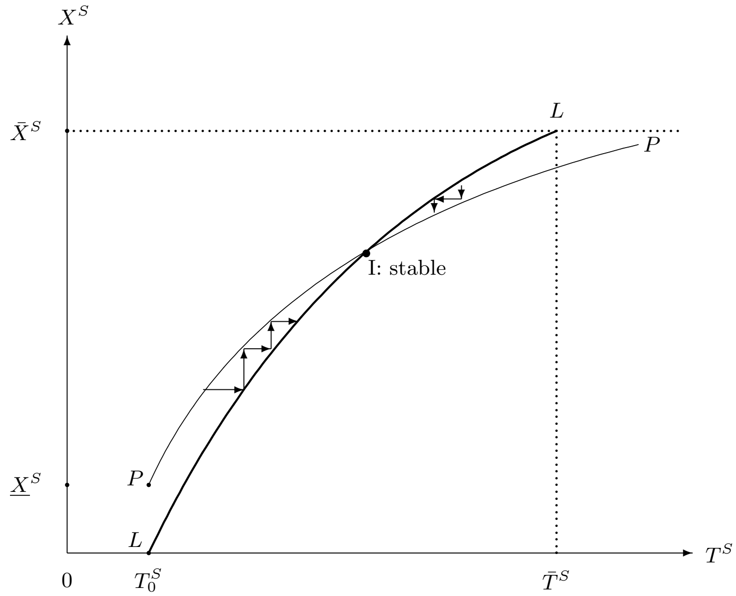


Figure 4: Existence and Stability of Steady State

(a) Unique Equilibrium




(b) Multiple Equilibrium

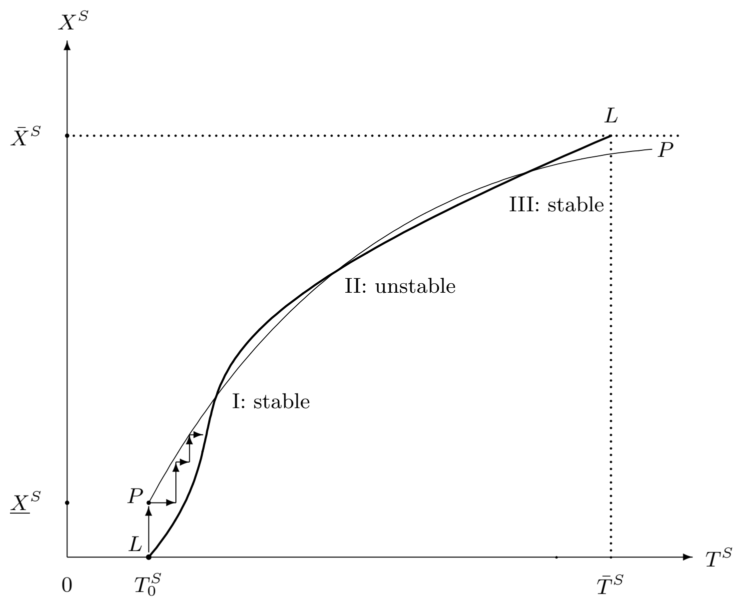
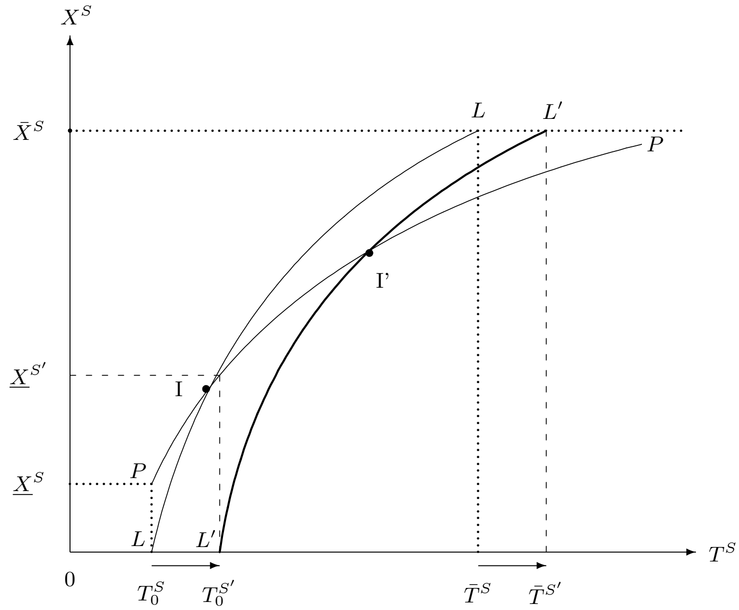


Figure 5: Comparative Static Analysis

(a) $T_0^S < T_0^{S\prime}$




(b) $\delta < \delta'$

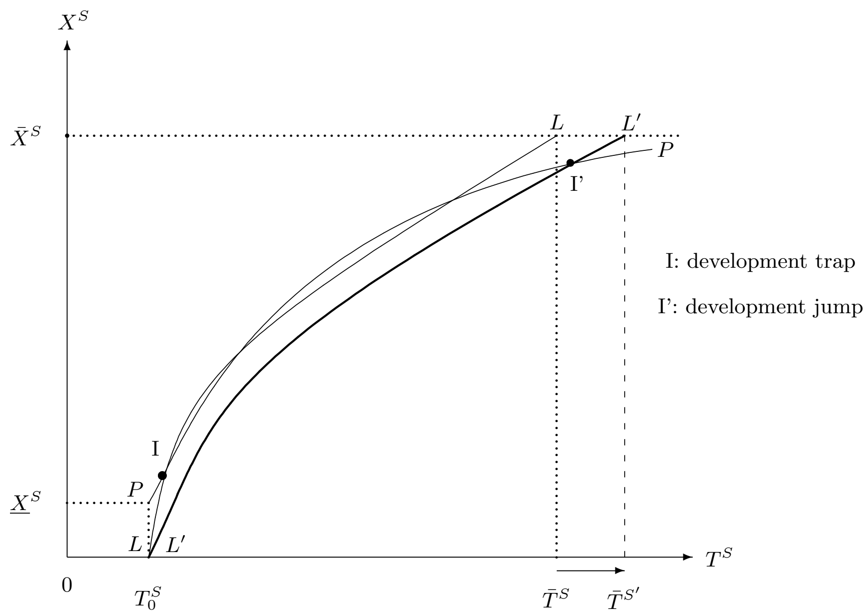
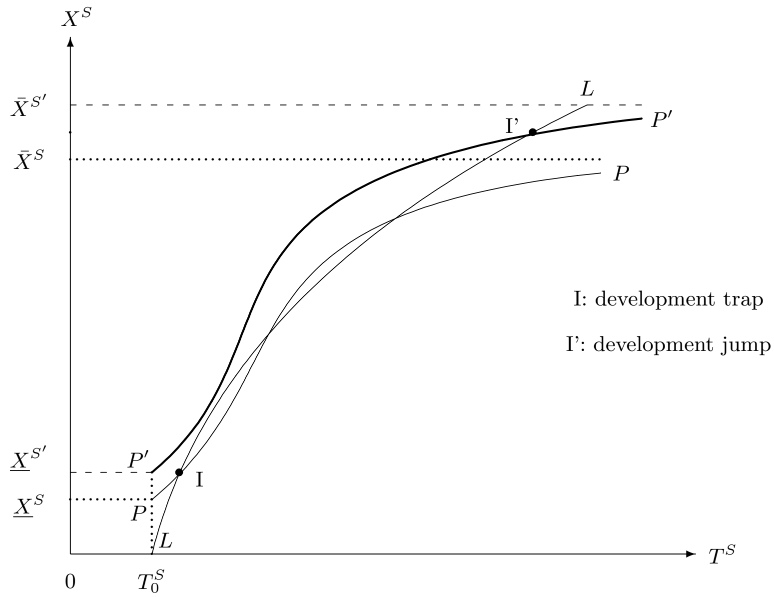


Figure 5: Comparative Static Analysis Continued

(c) $w^{S'} < w^{S}$; $z' < z$; $\rho' < \rho$




(d) $f^{S'} < f^S$