ABSTRACT

It is widely believed that an important factor underlying the rapid growth in China is increased foreign direct investment (FDI) and the transfer of foreign technology capital, which is accumulated know-how from investment in research and development (R&D), brands, and organizations that is not specific to a plant. In this paper, we study two channels through which FDI can contribute to upgrading of the stock of technology capital: knowledge spillovers and appropriation. Knowledge spillovers lead to new ideas that do not directly compete or devalue the foreign affiliate’s stock. Appropriation, on the other hand, implies a redistribution of property rights over patents and trademarks; the gain to domestic companies comes at a loss to the multinational company (MNC). In this paper we build these sources of technology capital transfer into the framework developed by McGrattan and Prescott (2009, 2010) and introduce an endogenously-chosen intensity margin for operating technology capital in order to capture the trade-offs MNCs face when expanding their markets internationally. We show that economic outcomes differ dramatically depending on which channel of technology capital transfer is operative.

* The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.
1. Introduction

The knowledge stock of Chinese enterprises has grown in dramatic fashion. A country known twenty years ago for manufacturing cheap toys has made significant inroads in its capacity to innovate in high tech industries like semiconductors and supercomputers. It is widely believed that an important factor underlying this growth is the opening of China to foreign direct investment, following economic reforms beginning in 1978.

We can think of there being two channels through which FDI can contribute to upgrading of the knowledge stock of Chinese enterprises. First, a Chinese enterprise may appropriate a given knowledge stock from a foreign affiliate. That is, there can be a redistribution of property rights over a fixed knowledge stock. Second, Chinese enterprises might enjoy knowledge spillovers from a foreign affiliate. That is, the knowledge emanating out of the affiliate might lead to new ideas that do not directly compete or devalue the affiliate’s knowledge stock. The key distinction here is that with the appropriation channel, the gain to the Chinese enterprise in knowledge capital comes at the expense of a loss by the multinational company setting up a foreign affiliate. The MNC might fully anticipate this transfer, viewing it as part of the quid pro quo in return for access to the Chinese market. With the spillover channel, the MNC is not losing knowledge capital.

In this paper we build on the framework developed in McGrattan and Prescott (2009, 2010) to analyze knowledge flows out of MNCs. The original framework puts the Arrow-Debreu model of perfect competition to work in the analysis of foreign direct investment. The key concept of the framework is technology capital. A given unit of technology capital can be used at multiple locations. Examples of technology capital include accumulated know-how from investments in research and development (R&D), brands, and organizations that is not specific to a plant. Agents in the model are price takers as to the rents that can be earned on technology capital at the various locations.

The innovation of this paper is to incorporate appropriation and spillover into the
original framework. This paper also introduces an intensity margin for operating technology capital that we call the *quality level* of the operation. The quality level potentially interacts with the two mechanisms for knowledge flows. Specifically, if a MNC operates a given unit of its technology capital at its Chinese affiliate at high quality intensity level, this might make it easier for other domestic enterprises to appropriate the capital. Intuitively, the higher end the operation, the more trade secrets are utilized, and the greater the risk. In addition, the potential for beneficial spillovers is also greater when the operation is run at a high quality level.

The long-run objective of the research project is to conduct a quantitative analysis. In this preliminary version of the work, we focus on understanding how the introduction of the appropriation and spillover mechanisms, in conjunction with the introduction of the quality margin for technology capital, impact the dynamics of growth. We show how appropriation and spillover operate in distinct ways. Suppose we take the equivalent of China in the model and increase its degree of openness to FDI, holding everything else fixed. To the extent that the appropriation force is operative, the MNC will tend to operate its technology capital in China at higher quality levels, at the risk of increased appropriation. The increase in effective TFP in the Chinese market makes the increased risk worthwhile. In contrast, the spillover force does not generate such a trade-off.

Section 2 discusses the related literature. Section 3 provides evidence that China’s technology capital stock is increasing. Section 4 lays out the multicountry general equilibrium model used in the analysis. Section 5 is a two-country application of the theory, which highlights properties of the balanced growth equilibrium and the model’s transitional dynamics. Section 6 (which is not included in this draft) is a fully quantitative application of the theory.
2. Related Literature

The theoretical literature on FDI is large. Much of the theoretical literature, such as Horstmann and Markusen (1992), Markusen and Venables (2000), and Helpman, Melitz, and Yeaple (2004) models a firm’s decision problem of whether to sell in foreign markets through exports versus setting up a foreign affiliate. Relatedly, Ramondo and Rodríguez-Clare (2010) allow for both trade and multinational production and determine the welfare gains from openness in each dimension individually and combined. While this literature focuses on the contrast between exports and FDI, our work is different in focusing how MNC technology capital is channeled to domestic companies.

There are a number of similarities in the model developed here and that of Eaton and Kortum (1999). Eaton and Kortum develop a variant of the Grossman and Helpman (1991a) quality ladder model in which innovations displace existing goods at lower rungs on the quality ladder. A firm creating a new idea can potentially put the idea to work in multiple countries, analogous to the way technology capital works in our framework. Furthermore, the paper has knowledge spillover and appropriation, like here. An important way our papers differ is that we model the multinational’s decision of the intensity level with which to operate its technology capital in the various countries, a margin that impacts both appropriation and spillover. This key margin in our analysis plays no role in their paper.

Second, we focus on the dynamics of knowledge transfer between developed and developing countries, like the U.S. to China, while Eaton and Kortum is about a steady state relationship between developed countries like United States and Germany. Third, we look broadly at foreign direct investment, while they focus on international patenting. Fourth, our modeling environment with perfectly competitive firms is different from the Grossman-Helpman structure of Bertrand oligopoly that has a continuum of different products. Our
use of the perfect competition structure makes it computationally tractable to consider a rich structure.

We note that there are a variety of papers in the literature that highlight, as we do here, that the greater the extent of FDI, the greater the ability of entrepreneurs in the host nations to imitate and appropriate technology. Lai (1998) extended Grossman and Helpman (1991b) and Helpman (1993) to make the probability of imitation by developing countries depend upon whether the developed countries engaged in FDI. See also Markusen (2001). An implication of this trade-off is that multinational companies will be more likely to invest in host nations with greater intellectual property protection. Branstetter et al. (2011) provides evidence that U.S.-based MNCs respond this way when countries make policy changes to strengthen intellectual property protection.

There is an enormous literature examining the extent to which knowledge spillovers from multinational investment flow to domestic companies in host nations. Typically, these studies regress measures of productivity of local companies on some measure of geographic proximity of FDI. There are a wide range of results found in the literature; Keller (2009) provides an extensive review.

It is useful to discuss why local production by a MNC might facilitate knowledge transfer. Note that FDI is not necessary for imitation—a company in one country may be able to “reverse engineer” a product manufactured in another country. Or, if the product is patented in another country, one can simply read the patents to figure out how to imitate production. FDI can facilitate knowledge transfer when reverse engineering the product and reading the foreign patents is insufficient. In particular, knowledge capital and trade secrets may be transferred to the workforce. Through workforce mobility, as employees of the foreign multinationals leave for domestic companies, ideas may move with them. In some cases, the ideas may be from memory. In other cases, the ideas might be physically in blueprints. One might expect that it is easier to steal a blueprint and take it across
the street than it is to take it from one country to another. This is especially true since legal authorities in the host country might be willing to look the other way when there is blueprint theft from a foreign multinational. A recent by the United States International Trade Commission (2010) provides a number of anecdotes about the appropriation of intellectual property from multinational companies that has taken place in China in recent years.

3. Empirical motivation

In this section we discuss evidence that China’s knowledge stock is increasing.

Until very recently, China has not come up in discussions of which nations are accumulating stocks of knowledge. Eaton and Kortum (1999) do not mention China, focusing instead on the five leading research nations in the OECD (that is, the United States, Japan, Germany, the United Kingdom, and France).

Patent applications within China from Chinese residents have exploded. The number of invention patent applications (the kind of patents comparable to U.S. patents) increased from 25,000 in 2000 to 122,000 in 2006, almost a five-fold increase. Foreign companies have only recently started to patent in China: there has been an increase from 26,000 in 2000 to 88,000 in 2006. With this increase in applications, China is now the third largest source of all applications in the world. Total applications by Chinese inventors throughout the world equaled 202,000 in 2008. Notably, while China has been applying for many more patent applications, the rate of success is not as great. China was successful in only 48,000 out of its 203,000 applications, while Germany was successful in 53,000 out of its 136,000 applications.

Also notable is that the less technical the application, the more likely the Chinese
numbers are large. Trends in trademark applications at selected IP offices show the emergence, almost from out of nowhere, of China beginning in 1990.

In summary, there is clear evidence that China is making increased claims on intellectual property. Less clear is the significance of the inventiveness of these claims. Virtually all of China’s patent applications are directed in China, where they are certain to get a good hearing. Also, a patent can be an invention patent or a utility or design patent. The standards for originality are lower for utility or design, and these are the bulk of China’s patents. That is, foreign applicants dominate invention patents, while Chinese applicants dominate utility and design.

4. Theory

The model used here nests a version of McGrattan and Prescott (2010) with a simplified portfolio choice.\(^1\) We extend the model to include the choice of quality for technology capital, externalities in the accumulation of new technology capital, and appropriation of technology capital used abroad.

4.1. Stand-In Multinational Problem

We start with the problem of the multinational. Let \(i\) index the country where production occurs, \(i = 1, \ldots, I\). Let \(j\) index the country of origin of the technology capital, \(j = 1, \ldots, I\). Multinational \(j\) maximizes the present value of dividends

\[
\max \sum_t p_t (1 - \tau_{dt}) D^j_t,
\]

where dividends are given by

\[
D^j_t = \sum_i \left\{ (1 - \tau_{p,it}) (Y^j_{it} - W^j_{it}L^j_{it} - \delta_t K^j_{x,it} - X^j_{i,it} - \chi^j_i X^j_{M,t} - f(q^j_{it}) M^j_t) - K^j_{r,i,t+1} + K^j_{r,it} \right\}
\]

\(^1\) This is without loss of generality and matters only if we wanted to distinguish between flows of equity and debt portfolio income across borders.
and $\chi^j_i = 1$ and $\chi^j_j = 0$, if $i \neq j$. Here, the relevant inputs for the problem of multinational $j$ operating in $i$ is the profits tax rate $\tau_{pi}$, output produced $Y^j_i$, the wage rate $W$, the labor input $L^j_i$, the rate of depreciation of tangible capital $\delta_T$, tangible capital $K^j_{T,i}$, intangible investment $X^j_{I,i}$, technology capital investment $X^j_{M,i}$, the quality level of the operation $q^j_i$, and technology capital $M^j$.

Additional constraints on the multinational’s problem are the capital accumulation equations:

$$K^j_{T,i,t+1} = (1 - \delta_T) K^j_{T,it} + X^j_{T,it}$$
$$K^j_{I,i,t+1} = (1 - \delta_I) K^j_{I,it} + X^j_{I,it}$$
$$M^j_{t+1} = (1 - \delta_M) M^j_t - h^j(\{q^j_{k_t}M^j_{t}\}_{all \ k,\ell}) + X^j_{M,t}g(M^j_t).$$

The new elements here relative to the framework of McGrattan and Prescott (2010) are the choice of quality level $q^j_i$, the intermediate cost of investing this level of $q$, namely $f(q)$, the externalities $g(M^j)$ from the technology capital of others $M^j$ (which will be defined below), and the appropriation from and by companies involved in foreign direct investment $h(\{qM\})$. Note that the set $\{q^j_{k_t}M^j_{t}\}$ might include all quality-adjusted technology capital stocks in the world economy (i.e., $\ell, k = 1, \ldots I$).

Outputs are given by

$$Y^j_{it} = A^j_{it} \left( N_{it} q^j_{it} M^j_t \right)^\phi \left( Z^j_{it} \right)^{1-\phi}$$
$$Z^j_{it} = \left( K^j_{T,it} \right)^{\alpha_T} \left( K^j_{I,it} \right)^{\alpha_I} \left( L^j_{it} \right)^{1-\alpha_T-\alpha_I},$$

where $N_i$ is the number of locations in country $i$, $q^j_i$ is the quality level chosen by firms in $j$ when investing in $i$, $M^j$ is the stock of technology capital from $j$, $Z^j_i$ is a composite input used by multinationals $j$ in country $i$, $A^j_i$ is the level of technology parameter faced by multinationals $j$ in country $i$, $K^j_{T,i}$ is the stock of tangible capital used by multinationals $j$ in country $i$, $K^j_{I,i}$ is the stock of intangible capital used by multinationals $j$ in country
\( i \), and \( L_i^j \) is the labor supplied to multinationals \( j \) in country \( i \). Below, we assume that 
\( A_{it}^j = A_i(1 + \gamma_A)^t \) if \( i = j \) and \( A_i \sigma_{it}(1 + \gamma_A)^t \) otherwise.

The total stock of technology capital in a country \( j \) is our measure of the externality \( M^j \), that is:
\[
M_i^j = q_j^i M_t^j + \sigma_{jt}^{\frac{1}{\sigma}} \sum_{\ell \neq j} q_{jt}^\ell M_t^\ell.
\]
Note that \( M^j \) is not a choice of the firm; it is taken as given when solving their maximization problem.

### 4.2. Household problem

Households choose sequences of consumption \( C_{it} \), labor \( L_{it} \), and assets \( B_{it+1} \) to solve the following problem:

\[
\max \sum_t \beta^t \log \left( C_{it}/N_{it} \right) + \psi \log \left( L_{it}/N_{it} \right) N_{it}
\]
subject to

\[
\sum_t p_t [C_{it} + B_{i,t+1} - B_{it}] \leq \sum_t p_t \left[ (1 - \tau_{li, it}) W_{it} L_{it} + (1 - \tau_{dt}) D_i^t + r_{bt} B_{it} + \kappa_{it} \right],
\]
where \( \tau_{li} \) and \( \tau_{d} \) are tax rates on labor and company distributions, and \( r_{ht} \) is the after-tax return on lending/borrowing. I assume that country \( i \) has a population of size \( N_{it} \). Note that the measure of a country’s production locations is proportional to its population. Hence, we use the same notation for both variables and set the constant of proportionality equal to one (without loss of generality).

### 4.3. Market clearing

The worldwide resource constraint is

\[
\sum_i \left\{ C_{it} + \sum_j \left( X_{R, it}^j + X_{i, it}^j \right) + X_{M, t}^i \right\} = \sum_{i,j} Y_{it}^j
\]
which is the market-clearing condition for the goods market. Market clearing in asset markets occurs if \( \sum_i B_{it} = 0 \) and market clearing in labor markets occurs if

\[
L_{it} = \sum_j L^j_{it}, \quad i = 1, \ldots, I.
\]

5. A Two-Country Analysis

Next, we consider a two “country” example: the first country is China and the second is a union of developed nations (which will treat as a unified country for now). The main goal of our exercises are to quantify the impact of spillovers and appropriation. We start with results for the balanced growth steady state and then consider transitional dynamics.

5.1. Balanced growth steady state

Here, we use country indices \( c \) for China and \( r \) for the Rest-of-World. We use multinational indices \( d \) for China’s multinational (e.g., Dongfeng or domestic) and \( f \) for the ROW’s multinational (e.g., Ford or foreign). For simplicity, we’ll start by assuming that populations are the same size \( (N_c = N_r = 1) \), that Chinese TFP is lower than the ROW’s \( (A_c < A_r = 1) \), that tax rates are zero \( (\tau_{ti} = \tau_d = \tau_{pi} = 0) \), and that depreciation rates are equal across all types of capital \( (\delta_r = \delta_i = \delta_M = \delta) \). For these choices, we’ll calculate the balanced growth equilibrium.

Above, capital letters were used to denote totals. Here, small letters are used to denote detrended (stationary) variables on a balanced growth path. To detrend outputs, consumptions, and investments, we divide by population times the growth in output. To detrend technology capital and investment we divide only by the growth in output since technology capital is used simultaneously in all available production locations. Labor is divided by population.

On the balanced growth path, the real interest rate is a function of per capita growth
and the rate of discounting. Furthermore, it can be used to compute ratios of tangible capital and plant-specific intangible capital to output. With that, we derive relative outputs as follows:

$$r_b = \frac{(1 + \gamma_y)}{\beta - 1}$$

$$y_i^j / k_T^i = \frac{r_b + \delta}{(\alpha_T (1 - \phi))} \equiv 1/\kappa_T, \quad \forall i, j$$

$$y_i^j / k_I^i = \frac{r_b + \delta}{(\alpha_I (1 - \phi))} \equiv 1/\kappa_I, \quad \forall i, j$$

$$y_i / l_i = y_i^j / l_i^j, \quad \forall j$$

$$y_i^j = a_i^j \left(q_i^j m^j\right)^{\phi} \left(\left(k_T^j\right)^{\alpha_T} \left(k_I^j\right)^{\alpha_I} \left(l_i^j\right)^{1-\alpha_T-\alpha_I}\right)^{1-\phi}$$

which, in turn, implies that output ratios are related to effective technology capital ratios

$$y_c^d / y_c^f = \sigma_c^d q_c^d m_f / (q_c^d m_d)$$

$$y_r^d / y_r^f = \sigma_r^d q_r^d m_d / (q_r^d m_f)$$

and $l_c^d / l_c^f = y_c^d / y_c^f$, $l_r^d / l_r^f = y_r^d / y_r^f$. If economies are closed to FDI, then $\sigma_c = \sigma_r = 0$ and there is no foreign production. If they are fully open, then the marginal products of effective technology capital converge.

The relative magnitudes of technology capital stocks and the quality choices depends on the spillovers. Here, we make the following functional form assumptions:

$$f(q) = \eta / (1 - q)^\rho$$

$$g(\mu) = \mu^\nu$$

$$\mu^d = 1 + \sigma_c^d q_c^d m_f / (q_c^d m_d)$$

$$\mu^f = 1 + \sigma_r^f q_r^d m_d / (q_r^d m_f)$$

$$h^d = \lambda_r \sigma_r^f q_r^d m_d - \lambda_c \sigma_c^d q_c^f m_f$$

$$h^f = -h^d$$
which introduces five new parameters: \( \nu, \eta, \rho, \lambda_r, \) and \( \lambda_c \) that have to ultimately be estimated (although an interesting case has no appropriation in the ROW, \( \lambda_r = 0, \) and therefore implies only four parameters.)

Substituting the functional form choices above into first-order conditions and simplifying implies the following relations that can be used to characterize the equilibrium choices of the qualities \( q_i \), technology capital stocks \( m^j \), and the investment in technology capital \( x_M^j \):

\[
\frac{\eta \rho}{(1 - q_c^d)^{\rho+1}} = \frac{\phi N_c y_c^d}{q_c^d m^d} \tag{5.1}
\]

\[
\frac{\eta \rho}{(1 - q_r^d)^{\rho+1}} = \frac{\phi N_r y_r^d}{q_r^d m^d} - \lambda_r \sigma_r^{\frac{1}{\rho}} / g (\mu^d) \tag{5.2}
\]

\[
\frac{\eta \rho}{(1 - q_c^f)^{\rho+1}} = \frac{\phi N_c y_c^f}{q_c^f m^f} - \lambda_c \sigma_c^{\frac{1}{\rho}} / g (\mu^f) \tag{5.3}
\]

\[
\frac{\eta \rho}{(1 - q_r^f)^{\rho+1}} = \frac{\phi N_r y_r^f}{q_r^f m^f} \tag{5.4}
\]

\[
rb + \delta = g (\mu^f) \phi (N_r y_r^f + N_c y_c^f) / m^f - q_c^f h_r^f \tag{5.5}
\]

\[
r_b + \delta = g (\mu^d) \phi (N_r y_r^d + N_c y_c^d) / m^d - q_r^d h_r^d \tag{5.6}
\]

\[
x_M^d = ((\gamma Y + \delta) m^d + h^d) / g (\mu^d) \tag{5.7}
\]

\[
x_M^f = ((\gamma Y + \delta) m^f + h^f) / g (\mu^f) . \tag{5.8}
\]

Consider first the case with no appropriation and no positive externalities (\( \lambda_r = \lambda_c = \nu = 0 \)). Recall that

\[
\frac{y_c^f}{q_c^f m^f} = \sigma_c^{\frac{1}{\rho}} \frac{y_c^d}{q_c^d m^d} \tag{5.9}
\]

\[
\frac{y_r^d}{q_r^d m^d} = \sigma_r^{\frac{1}{\rho}} \frac{y_r^f}{q_r^f m^f} \tag{5.10}
\]
implying that the ratio \( (1 - q^d_c)/(1 - q^f_c) \) is a function only of China’s openness \( \sigma_c \), and the ratio \( (1 - q^f_r)/(1 - q^d_r) \) is a function only of ROW’s openness \( \sigma_r \). To see this, substitute (5.9) into (5.3) take the ratio of (5.1) and (5.3). Similarly, substitute (5.10) into (5.3) take the ratio of (5.2) and (5.4). If \( \sigma_c = 1 \), then domestic and foreign quality choices are the same in China, and the same is true for the ROW if \( \sigma_r = 1 \). If \( \sigma_c < 1 \), then \( q^d_c > q^d_r \), which implies that Dongfeng puts more technology capital in China than in the ROW. With no positive externalities, there is no asymmetry for Chinese multinationals abroad and ROW multinationals in China, so \( q^d_r = q^d_c \).

Next consider the case with positive externalities \( (\nu > 0) \) but no appropriation \( (\lambda_r = \lambda_c = 0) \). In this case, the Chinese can take advantage of the relatively large stock of technology capital developed in the ROW where TFP is higher. In this case, there would be an asymmetry, with Dongfeng choosing to do more abroad than Ford in China, \( q^d_r > q^f_c \).

What happens in the world with positive externalities if China or ROW change government policies (related to FDI and intellectual property)? Consider first the case in which China allows appropriation to occur (because they have weak patent enforcement). The ROW multinationals respond by sending less to China (e.g., \( q^f_c \) falls). For some parameterizations of the model, this can lead to lower consumption in China despite the fact that the Chinese multinationals get higher future profits due to appropriating some of \( m^f \).

More realistically, appropriation of intellectual property in China would lead ROW governments to block their FDI in retaliation. This would mean \( \lambda_c > 0 \) and \( \sigma_r \) lower. With \( \sigma_r \) lower, the optimal quality choice for Dongfeng in the ROW \( (q^d_r) \) is lower and Chinese consumption is certainly lower than in the world with no appropriation or blocking.

One noteworthy property of the equilibrium is that country size—which depends on the population and the level of TFP—does not affect the equilibrium \( q^* \)’s. For example, if we double the population or the level of TFP in China, we do not alter the total output.
\((Ny)\) per unit of technology capital \((m)\) which is the ratio that appears in the first-order conditions (and is equal to \(Y/M\) in the original first order conditions).

5.2. Transitional dynamics

Next, we consider transitional dynamics in response to two policy changes: (1) China becomes more open to FDI (that is, \(\sigma_{ct}\) increases over time) and (2) China weakens patent and trademark protection of foreigners (that is, \(\lambda_{ct}\) increases over time).\(^2\) We conduct these experiments with \((\nu > 0)\) and without \((\nu = 0)\) knowledge spillovers. The results of these experiments show that economic outcomes differ dramatically depending on which channel of technology capital transfer is operative.

Figure 1 shows results for the transition as China opens up to FDI. The top graph is per capita consumption in China, the middle graph is per capital labor input in China, and the third graph is the quality level chosen by ROW companies operating in China. In each graph, two lines are shown: the case without spillovers \((\nu = 0)\) and the case with spillovers \((\nu > 0)\). Notice, first, that with spillovers, consumption and leisure both rise immediately. Without spillovers, there is an eventual rise in consumption and leisure but not immediately. Gains come as a result of increased foreign effective technology capital. We see that in the third panel that shows \(q_{ct}^f\) rising above its initial trend level.

Figure 2 shows results for the transition as intellectual property protection weakens. Comparing these results to the analogues in Figure 1 shows that the results depend sensitively on the channel of technology capital transfer. Greater appropriation does lead initially to higher consumption but ROW firms eventually send lower quality capital and \(q_{ct}^f\) falls. The impact on Chinese employment depends on the strength of the spillovers which in turn depend on the flows of foreign technology capital.

\(^2\) In both cases, we use a hyperbolic tangent function when varying the policy variable; the starting value is the initial steady state level.
Overall, the results demonstrate that the model predictions depend on the channels of capital transfer and that will prove to be useful when trying to estimate key parameters with actual data.

6. A Fully Quantitative Analysis

To be completed...
References


Figure 1. Transition as China’s Degree of Openness, $\sigma_{ct}$, Increases
Figure 2. Transition as China’s Intellectual Property Protection ($\lambda_{ct}$) Weakens