

Federal Reserve Bank of Minneapolis  
Research Department

March 2011

## Technology Capital Transfer\*

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### ABSTRACT

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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.

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\* 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.

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.

We can think of there being two channels through which FDI can contribute to upgrading of the technology capital of Chinese enterprises. First, a Chinese enterprise may appropriate capital from a foreign affiliate. That is, there can be a redistribution of property rights over a fixed 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 technology capital. The key distinction here is that with the appropriation channel, the gain to the Chinese enterprise in technology 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 technology capital.

The innovation of this paper is to incorporate appropriation and spillover into McGrattan and Prescott's original framework and to use it to study China's rapidly changing economy. This paper also introduces an intensity margin for operating technology capital that we call the *intensity level* of the operation. The intensity 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 a high 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 intensity level.

The long-run objective of the research project is to conduct a fully 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 intensity margin for technology capital, impact growth and welfare. 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 intensity 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 our 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.

### 3. Case Study: China

The remarkable growth of China and its potential link to technology capital transfer is the motivation for this paper.<sup>1</sup>

#### 3.1. China's Growth

We first use the set of graphs in Figures 1 through 4 to make four points regarding China's growth.

First, Figures 1A and 1B illustrate China's remarkable growth in per capita real GDP. Figure 1A shows per capita real GDP in levels (based on constant 2005 international prices). Figure 1B shows per capital real GDP as an index. The latter shows how dramatically China's per capita GDP has grown between 1980 and 2010, by roughly a factor of twelve.

Second, FDI inflows into China have increased in an extraordinary fashion, as illustrated in Figure 2. China was completely closed to FDI until Deng Xiaoping opened the door in 1978 and began introducing reforms. Initially investment trickled in. Coca Cola, for example, opened up a joint venture bottling plant in 1984. Following further economic reforms, the trickle grew to a gusher by 1992. The late 1980s, for example, was a period in which China switched from a regulatory regime of "permitting" to "encouraging" FDI with tax advantages (Huang 2003). As a share of GDP, FDI inflow leveled off beginning in 2000, but given how quickly GDP grew, it is noteworthy that FDI net inflows kept pace.

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<sup>1</sup> Until very recently, China has not come up in discussions of which nations are accumulating stocks of knowledge. For example, 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).

Growth in FDI was commensurate with growth in GDP, maintaining a high FDI to GDP ratio of over 3 percent.

Third, China has experienced a remarkable growth in R&D expenditures, patent applications, and trademark applications, which corresponds to investment in technology capital in our theory. Figure 3A shows that beginning in the mid-1990s, China increased R&D expenditures relative to GDP, with the ratio tripling between 1995 and 2009. Figure 3B shows the time series for patent applications. Patenting activity has increased worldwide, and we can see in the graph that patent applications in the United States more than tripled over a twenty-year period. The key thing to emphasize here is that while patenting activity was negligible in China before the mid 1990s, it has subsequently exploded, exceeding 200,000 (not shown) as of 2008, and closing the gap between the United States and China. Figure 3B shows that for trademark applications, China was lower than the United States before 2000, but subsequently exceeds the United States by more than a factor of two.

Fourth, China has shifted the composition of its output away from “low-tech” to “high-tech.” While once known for producing cheap toys, it now produces the fastest supercomputer. Figure 4A shows the dramatic growth in the share of high-technology manufacturing exports from China since 1990, which has caught up to the share for the United States at approximately 30 percent.<sup>2</sup> Of course, the export of an iPad assembled in China includes the value added of component production made elsewhere and, thus, may be adding little value before shipping. Figure 4B shows value added in high-technology manufacturing as a share of the world level. The Chinese share has grown from 2 percent to around 15 percent, which is about half of the U.S. level. This is a notable change.

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<sup>2</sup> The NSF includes aerospace, computers and office machinery, electronics and communications equipment, and pharmaceuticals in their definition of a high-technology manufacturing industry.

### 3.2. Technology Capital Transfer in China

When China began opening in 1978, production technologies used in China were primitive compared to those in developed countries. As part of the opening, the Chinese government had an explicit policy goal of bringing in technology. For example, an early Congressional report, “Technology Transfer to China,” (U.S. Congress 1987), notes that in China’s Seventh Five Year Plan (1986-1990), the Chinese government “has set the acquisition of technology as a high priority, especially in the fields of transportation, electronics and computers, telecommunications and energy.”

The study also notes that although progress by China in upgrading technology had been slow, it could point to several instances of technology transfer from the United States. Specifically, the report noted that when “U.S. firms approach the China market with the intent to sell products, many find they must include technology transfer if they wish to gain access to the China market.” It gave an example of General Electric selling locomotives: “G.E. is not setting up any manufacturing facilities in China, though an important part of the contract stipulated that China would produce several of the parts for the locomotives.” In another example, American Motors set up a joint venture with Beijing Automotive Works to produce the Jeep Cherokee.

Twenty three years later, the U.S. government produced another report on China with a title that begins “China: Intellectual Property Infringement...,” (USITC 2010). In one important way the story line of this report is quite different from the earlier report: the new report depicts China as a manufacturing powerhouse and an important economic power, in contrast to the low-tech, poorer China described in 1987. But in another important way, the second report tells the same story of how firms who want to sell in China pay for market access through technology transfer, either as part of a formal agreement, as an



informal “quid pro quo,” or illicitly. As an example of illicit transfers, the report relates anecdotes of U.S. and European companies setting up a factories in China, where workers steal blueprints from the factory to make a competing versions across the street. In some instances, these workers brazenly open a secret night shift within the same plant.

An anecdote regarding high-speed rail from the report is of particular interest, given the high-technology involved and given the large scale of the project:

German-based Siemens joined with China National Railway (CNR) to build China’s first high-speed rail line between Beijing and Tianjin for an estimated contract value of almost \$1 billion; this project was successfully concluded in 2008. Shortly thereafter, Siemens announced that it had won a contract to build a high-speed rail line between Beijing and Shanghai, but China’s Ministry of Railways ultimately awarded the \$5.7 billion contract to CNR, with Siemens effectively demoted to a subcontractor role. While details of the technology transfer process are not public, it appears that CNR did benefit from its joint venture relationship with Siemens and has now become an important competitor in the industry.

Another interesting example is Microsoft. After Microsoft entered the Chinese market in 1992, the “business was a disaster... for a decade.” (See “How Microsoft conquered China,” *Fortune*, July 17, 2007.) The vast majority of software users had pirated copies. Microsoft used its resources to enforce intellectual property laws, making people pay the same high prices as in the United States. This strategy did not work, and Microsoft was forced to change it in two ways. First, they offered an extremely low price (e.g. students can pay \$3, including Windows and Office). Second, they agreed to technology transfer with the Chinese government in exchange for laws requiring that personal computers be sold with licensed software.

One form of technology transfer was a research center in Beijing established in 1998. A second form of technology transfer was a 2007 joint venture with a Chinese company. According to Craig Mundie, a senior Vice President of Microsoft,

Microsoft has long been, and continues to be, committed to partnering and growing with the local IT industry in China. This is demonstrated by Microsoft's investment in and support of Zhongguancun Software Company to develop software products with their own intellectual property rights. The establishment of Zhongguancun Software Company is a positive response to the Chinese Government's recognition that China needs to establish a world leading software industry in China. It's also one of the important measures taken by Microsoft to support the city of Beijing as a leader in the information industry.

Noteworthy is the particular reference to "intellectual property rights" that will accrue to the Chinese company. This is not just about Microsoft utilizing low cost, skilled technicians to write code that Microsoft will own. Through Microsoft's efforts, Chinese firms will own more technology capital than they otherwise would.

It is useful to come back to the distinction between technology transfer that is appropriation, and that which is spillover. Appropriation takes place when a Chinese company's gain comes at the expense of the particular multinational transferring technology. The case of Siemens' transfer of technology to CNR to make one high-speed train line, and the deal for a second line is consistent with our notion of appropriation. In contrast, with spillover, a Chinese company gets knowledge, but this acquisition has zero (or negligible) impact on the multinational engaging in FDI. For example, if the Chinese scientists employed by the Microsoft Research Center in Beijing leave the company to create products that do not compete with Microsoft, we consider this a knowledge spillover.

Another avenue for technology capital transfer is through worker flows. Workers within a plant gain access to ideas. There is evidence in the literature that workers from multinationals bring ideas with them when they switch jobs. Balsvik (2011) uses detailed micro data at the worker and plant level to analyze worker flows from multinational firms to domestic companies. He finds a connection between higher productivity of domestic plants and such flows. If the higher productivity is a direct result of stolen blueprints, we

would consider this technology transfer through appropriation. On the other hand, if the higher productivity is due to skilled workers learning good practices at their former job, we would consider this technology transfer through knowledge spillovers.

Finally, there is evidence that appropriation, or the threat of appropriation, can impact foreign investment. Intel is an example of a company at the top of the high-tech ladder making some of the world's most advanced chips. Intel does produce chips in China, but according to Intel officials, "they will not produce the company's core technology here, the powerful microprocessing chips that are at the heart of modern PCs and servers." (See "Intel to Build Advanced Chip-Making Plant in China," *New York Times*, March 27, 2007.) Weak enforcement of intellectual property rights is one reason why companies like Intel do not put their cutting-edge technology in China.

We have emphasized that inward FDI has been high over the past two decades in China, but perhaps it would be even higher without intellectual property concerns. Figure 5 illustrates the breakdown of FDI by source. The United States, which is a relatively large source of FDI at the global level, is arguably a relatively small source of FDI into China.

## **4. Theory**

The model we use to assess the importance of technology capital transfer is an extension of McGrattan and Prescott (2010) that includes the choice of intensity for technology capital, externalities in the accumulation of new technology capital, and appropriation of technology capital used abroad. We work with an aggregate production function, derived by aggregating first across plants and then across companies. The derived technologies

are embedded in a multi-country general equilibrium model used to quantify technology capital transfers.

## 4.1. Aggregation

We start with production at a plant and build up to the problem of a multinational.

### 4.1.1. Plant-level production

A firm with 1 unit of technology capital operated at intensity level  $q$  and  $z$  units of a composite input of labor and other capital produces

$$F(z, q) = Aq^\phi z^{1-\phi} - f(q)$$

where  $A$  is total factor productivity,  $\phi$  is the share of income accruing to the owners of technology capital and  $f(q)$  is the intermediate cost of using technology capital at the level of intensity  $q$ . We assume that the domain of  $q$  is  $[0,1]$  and  $f$  is increasing in  $q$ .

### 4.1.2. Firm-level production

Countries are modeled as a set of locations that can be used by firms for production. Technology capital is nonrival and can therefore be used simultaneously in multiple locations. In a closed economy with  $N$  locations, the maximization problem of a firm with a unit of technology capital is given by

$$\begin{aligned} \max_{q, \{z_i\}, n} \quad & \sum_i Aq^\phi z_i^{1-\phi} - nf(q) \\ \text{s.t.} \quad & \sum_i z_i \leq z, \quad n \leq N \end{aligned}$$

which is the sum of plant output less intermediate costs and is subject to the restriction that it not use more of the composite output than  $z$  or more locations than are available.

Because of decreasing returns to the rival factors in  $z$ , the solution to this maximization problem is to split the composite input  $z$  evenly across all available locations. The maximal output is therefore,

$$F(z, q) = A(qN)^\phi z^{1-\phi} - Nf(q).$$

Aggregating across all firms that have a total of  $M$  units of technology capital, the maximal output is

$$F(M, Z, q) = A(qMN)^\phi Z^{1-\phi} - MNf(q).$$

#### 4.1.3. Multinational production

The problem for a multinational is to choose how intensively to operate in different countries. Countries differ in size and in policies that impact how much FDI is done. Let  $i$  index the country where production occurs,  $i = 1, \dots, I$ . Let  $j$  index the country of origin of the technology capital,  $j = 1, \dots, I$ . The size of country  $i$  is determined by the number of production locations it has,  $N_i$ , and the level of its TFP,  $A_i$ .

Aggregated output in country  $i$  produced by multinationals from country  $j$  are given by

$$Y_{it}^j = A_{it}^j \left( q_{it}^j M_t^j N_{it} \right)^\phi \left( Z_{it}^j \right)^{1-\phi}$$

$$Z_{it}^j = \left( K_{T,it}^j \right)^{\alpha_T} \left( K_{I,it}^j \right)^{\alpha_I} \left( L_{it}^j \right)^{1-\alpha_T-\alpha_I},$$

where  $q_i^j$  is the intensity level chosen by firms in  $j$  when investing in  $i$ ,  $M^j$  is the stock of technology capital from  $j$ ,  $Z_i^j$  is a composite input used by multinationals  $j$  in country  $i$ ,  $A_i^j$  is the level of technology parameter faced by multinationals  $j$  in country  $i$ ,  $K_{T,i}^j$  is the stock of tangible capital used by multinationals  $j$  in country  $i$ ,  $K_{I,i}^j$  is the stock of

plant-specific 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, where  $\sigma_{it}$  is a country's *degree of openness* to FDI.

We view the degree of openness as a government policy taken as given by multinationals which determines how much FDI is allowed into the country. The intensity margin plays a similar role in that it determines the level of FDI, but it is a choice of multinationals, not the government.

## 4.2. Multinational Problem

Next, consider the full problem of the multinational. Multinational  $j$  maximizes the present value of after-tax world-wide dividends

$$\max \sum_t p_t (1 - \tau_{dt}) D_t^j,$$

where dividends are given by

$$D_t^j = \sum_i \left\{ (1 - \tau_{p,it}) (Y_{it}^j - W_{it}L_{it}^j - \delta_T K_{T,it}^j - X_{I,it}^j - \chi_i^j X_{M,t}^j - M_t^j N_{it} f(q_{it}^j)) - K_{T,i,t+1}^j + K_{T,it}^j \right\}$$

and  $\chi_j^j = 1$  and  $\chi_i^j = 0$ , 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  $Y_i^j$ , the wage rate  $W_i$ , the labor input  $L_i^j$ , the rate of depreciation of tangible capital  $\delta_T$ , tangible capital  $K_{T,i}^j$ , intangible investment  $X_{I,i}^j$ , technology capital investment  $X_M^j$ , the intensity level of the operation  $q_i^j$ , and technology capital  $M^j$ . Additional constraints on the multinational's problem are the capital accumulation equations:

$$K_{T,i,t+1}^j = (1 - \delta_T) K_{T,it}^j + X_{T,it}^j$$

$$K_{I,i,t+1}^j = (1 - \delta_I) K_{T,it}^j + X_{I,it}^j$$

$$M_{i,t+1}^j = (1 - \delta_M) M_t^j - h^j(\{q_{kt}^\ell M_t^\ell\}_{\text{all } k,\ell}) + X_{M,t}^j g(\mathcal{M}_t^j).$$

The new elements here relative to the framework of McGrattan and Prescott (2010) are the choice of intensity level  $q_i^j$ , the intermediate cost of investing this level of  $q$ , namely  $f(q)$ , the externalities  $g(\mathcal{M}^j)$  from the technology capital of others  $\mathcal{M}^j$  (which will be defined below), and the appropriation from and by companies involved in foreign direct investment  $h(\{qM\})$ . Note that the set  $\{q_{kt}^\ell M_t^\ell\}$  might include all effective technology capital stocks in the world economy (i.e.,  $\ell, k = 1, \dots, I$ ). Multinationals take into account how their choices affect this appropriation but take as given the intensity level choices and technology capital stocks of others.

The total stock of technology capital in a country  $j$  is our measure of the externality  $\mathcal{M}^j$ , that is:

$$\mathcal{M}_t^j = q_{jt}^j M_t^j + \sigma_{jt}^{\frac{1}{\phi}} \sum_{\ell \neq j} q_{jt}^\ell M_t^\ell.$$

Note that  $\mathcal{M}^j$  is not a choice of the firm; it is taken as given when solving their maximization problem.

### 4.3. Household problem

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

$$\max \sum_t \beta^t \log(C_{it}/N_{it}) + \psi \log(1 - L_{it}/N_{it}) N_{it}$$

subject to

$$\sum_t p_t [C_{it} + B_{i,t+1} - B_{it}] \leq \sum_t p_t [(1 - \tau_{l,it}) W_{it} L_{it} + (1 - \tau_{dt}) D_t^i + r_{bt} B_{it} + \kappa_{it}],$$

where  $\tau_{li}$  and  $\tau_d$  are tax rates on labor and company distributions,  $r_b$  is the after-tax return on international lending and borrowing, and  $N_{it}$  is the population in country  $i$ . We use the notation  $N_{it}$  for population here because we assume 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).

#### 4.4. Market clearing

The worldwide resource constraint is

$$\sum_i \left\{ C_{it} + \sum_j (X_{T,it}^j + X_{I,it}^j) + X_{M,t}^i \right\} = \sum_{i,j} Y_{it}^j$$

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

$$L_{it} = \sum_j L_{it}^j, \quad i = 1, \dots, I.$$

## 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 (ROW). 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 equal ( $N_c = N_r = 1$ ), that Chinese TFP is lower than the ROW's ( $A_c < A_r = 1$ ), that tax rates are zero ( $\tau_{li} = \tau_d = \tau_{pi} = 0$ ), and that depreciation rates are equal across all types of capital ( $\delta_T = \delta_I = \delta_M = \delta$ ). 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:

$$\begin{aligned}
r_b &= (1 + \gamma_y) / \beta - 1 \\
y_i^j / k_{Ti}^j &= (r_b + \delta) / (\alpha_T (1 - \phi)) \equiv 1 / \kappa_T, \quad \forall i, j \\
y_i^j / k_{Ii}^j &= (r_b + \delta) / (\alpha_I (1 - \phi)) \equiv 1 / \kappa_I, \quad \forall i, j \\
y_i / l_i &= y_i^j / l_i^j, \quad \forall j \\
\Rightarrow y_i^j &= a_i^j \left( q_i^j m^j \right)^\phi \left( \left( k_{Ti}^j \right)^{\alpha_T} \left( k_{Ii}^j \right)^{\alpha_I} \left( l_i^j \right)^{1 - \alpha_T - \alpha_I} \right)^{1 - \phi} \\
&= \left( a_i^j \right)^{\frac{1}{\phi}} q_i^j m^j \left( \kappa_T^{\alpha_T} \kappa_I^{\alpha_I} \left( l_i / y_i \right)^{1 - \alpha_T - \alpha_I} \right)^{(1 - \phi) / \phi}
\end{aligned}$$

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

$$y_c^f / y_c^d = \sigma_c^{\frac{1}{\phi}} q_c^f m^f / (q_c^d m^d)$$

$$y_r^d/y_r^f = \sigma_r^{\frac{1}{\phi}} q_r^d m^d / (q_r^f m^f)$$

and  $l_c^f/l_c^d = y_c^f/y_c^d$ ,  $l_r^f/l_r^d = y_r^f/y_r^d$ . 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 intensity choices depends on the knowledge spillovers and appropriation. Here, we make the following functional form assumptions:

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

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

$$\mu^d = 1 + \sigma_c^{\frac{1}{\phi}} q_c^f m^f / (q_c^d m^d)$$

$$\mu^f = 1 + \sigma_r^{\frac{1}{\phi}} q_r^d m^d / (q_r^f m^f)$$

$$h^d = \lambda_r \sigma_r^{\frac{1}{\phi}} q_r^d m^d - \lambda_c \sigma_c^{\frac{1}{\phi}} q_c^f m^f$$

$$h^f = -h^d$$

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  $q_i^j$ , technology capital stocks  $m^j$ , and the investment in technology capital  $x_M^j$ :

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

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

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

$$\frac{\eta\rho}{(1 - q_r^f)^{\rho+1}} = \frac{\phi y_r^f}{q_r^f m^f} \quad (5.4)$$

$$r_b + \delta = g(\mu^f) \phi (y_r^f + y_c^f) / m^f - q_c^f h_c^f \quad (5.5)$$

$$r_b + \delta = g(\mu^d) \phi (y_r^d + y_c^d) / m^d - q_r^d h_r^d \quad (5.6)$$

$$x_M^d = ((\gamma_Y + \delta) m^d + h^d) / g(\mu^d) \quad (5.7)$$

$$x_M^f = ((\gamma_Y + \delta) m^f + h^f) / g(\mu^f). \quad (5.8)$$

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

$$\frac{y_c^f}{q_c^f m^f} = \sigma_c^{\frac{1}{\phi}} \frac{y_c^d}{q_c^d m^d} \quad (5.9)$$

$$\frac{y_r^d}{q_r^d m^d} = \sigma_r^{\frac{1}{\phi}} \frac{y_r^f}{q_r^f m^f} \quad (5.10)$$

implying that the ratio  $(1 - q_c^d)/(1 - q_c^f)$  is a function only of China's openness  $\sigma_c$ , and the ratio  $(1 - q_r^f)/(1 - q_r^d)$  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 intensity choices are the same in China, and the same is true for the ROW if  $\sigma_r = 1$ . If  $\sigma_c < 1$ , then  $q_c^d > q_c^f$ , 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  $q_r^d = q_c^f$ .

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,  $q_r^d > q_c^f$ .

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.,  $q_c^f$  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 intensity choice for Dongfeng in the ROW ( $q_r^d$ ) is lower and Chinese consumption is certainly lower than in the world with no appropriation or blocking.

## 5.2. Transitional dynamics

Next, we consider transitional dynamics in response to two policy changes to increase inward FDI: (1) China increases its degree of openness to FDI (that is,  $\sigma_{ct}$  increases over time) and (2) China lowers its tax rate on corporate profits (that is,  $\tau_{pct}$  falls over time). We conduct these experiments for three alternative parameterizations: the original McGrattan-Prescott case (with  $f(q) = 0$  and  $q = 1$ ) and two economies with endogenously chosen intensity levels—one with appropriation and knowledge spillovers ( $\lambda_c = .1, \nu = .2$ ) and one with only appropriation ( $\lambda_c = .1, \nu = 0$ ). The point of the experiments is to show

that economic outcomes can differ dramatically depending on which channel of technology capital transfer is operative.

To parameterize the model, we use estimates from McGrattan and Prescott (2010) for all parameters except those that govern country size.<sup>3</sup> We normalize China's population at  $N_c = 1$  and set the ROW at  $N_r = 2$ .<sup>4</sup> To roughly match GDP levels in 1990, the year taken as the start of the policy change, we set  $A_c = .5$  and  $A_r = 1$ .

The first experiment has China unilaterally opening to ROW's FDI. Figure 6A shows the path of  $\sigma_{ct}$  we use as an input to the computations and the model's implied ratio of inward FDI relative to GDP in China. Notice that the rise in the ratio is similar in magnitude and pattern to that of the actual data shown in Figure 2.

Figure 6B shows the predicted paths of domestic technology capital for the three alternative parameterizations of the model. In the baseline case, with  $q = 1$  and no technology transfer, we find a large decline in China's technology capital, which falls roughly in half by 2005. This is inconsistent with actual measures of R&D, patents and trademarks shown in Figures 3A-3C which show increased investment taking place. With appropriation and knowledge spillovers included, the model predicts a much smaller decline in domestic technology capital because technology is transferred to domestic companies as foreign investment enters China. These transfers also have a significant impact on the level of effective foreign technology capital. With a greater degree of country openness comes a greater response by multinationals to increase the intensity of their technology capital, even though they know some will be appropriated.

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<sup>3</sup> McGrattan and Prescott's application involved the United States and the Rest-of-World. Here, we consider China and the Rest-of-World.

<sup>4</sup> Here, as in McGrattan and Prescott (2010), we are not including countries in the ROW that do little or no FDI.

Figure 6C shows the impact of greater openness on China’s per capita consumption and employment. The results show that welfare is unequivocally higher since both consumption and leisure rise. The magnitudes, however, depend on the whether there is technology transfer and its source. In the baseline case without any technology transfer, the policy change implies a shift in production to the ROW from China, but because China allows more FDI from a country with higher technology capital, it benefits from the change. Adding appropriation and spillovers amplifies the benefits because, in addition to having the benefit of more effective technology capital from abroad, they increase their own technology relative to the baseline case.<sup>5</sup>

Figures 7A–7C show the results of the second policy experiment: lower taxes on profits in China. Figure 7A shows the tax rate used in the computations and the implied ratio of inward foreign direct investment to GDP. Despite the large drop in profits—from a rate of 30 percent to a rate of 12—the increase in net inflows of FDI relative to GDP is not nearly as large as that achieved by the increase in  $\sigma_{ct}$ . (See Figure 6A.)

However, the impact on other economic activity is large. Figure 7B shows the impact on technology capital stocks. The lower taxes in China lead to a boom in domestic investment in technology capital and a rise in stocks close to 60 percent after a decade. As in the first experiment, the two channels of technology transfer are offsetting factors for domestic technology capital. And, as before, they amplify the predicted change in foreign technology capital in China.

Figure 7C shows the paths of per capita consumption and employment in China

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<sup>5</sup> For the baseline model, McGrattan (2011) shows that once a certain threshold level for  $\sigma_{it}$  is passed, domestic production is done entirely by foreign multinationals and, at that point, employment and per capita GDP rise relative to their historical trend.

implied by a fall in tax rates. Here, the results are similar for the three parameterizations, and all predict large increases in both consumption and employment.

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...

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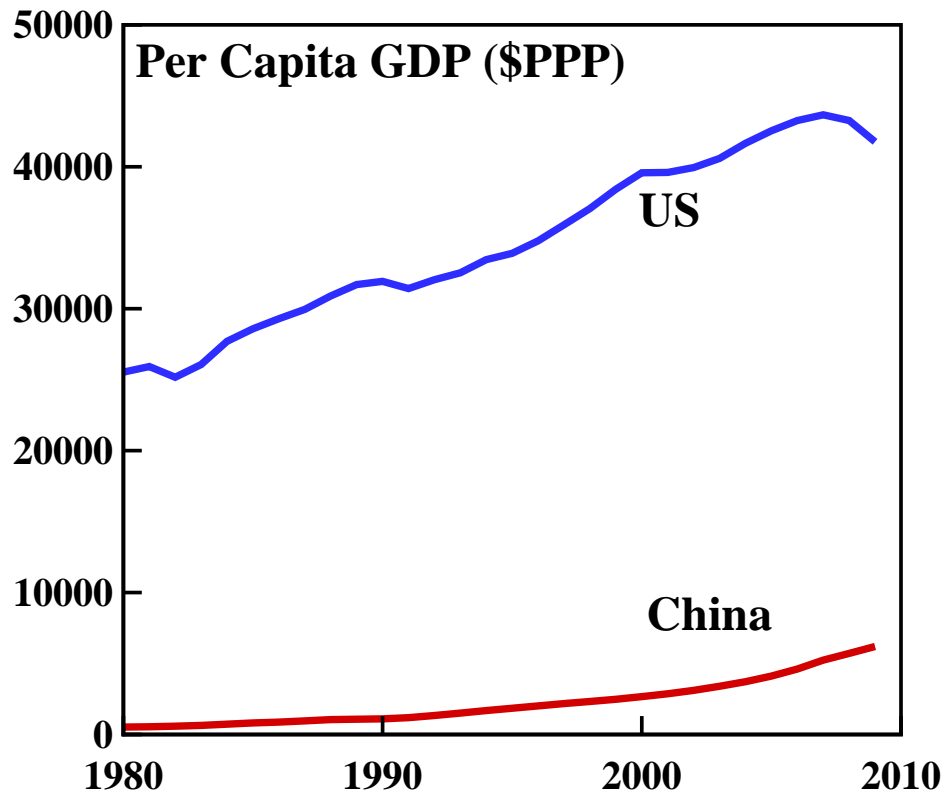


FIGURE 1A. PER CAPITA REAL GDP IN US AND CHINA  
SOURCE: WORLD DEVELOPMENT INDICATORS

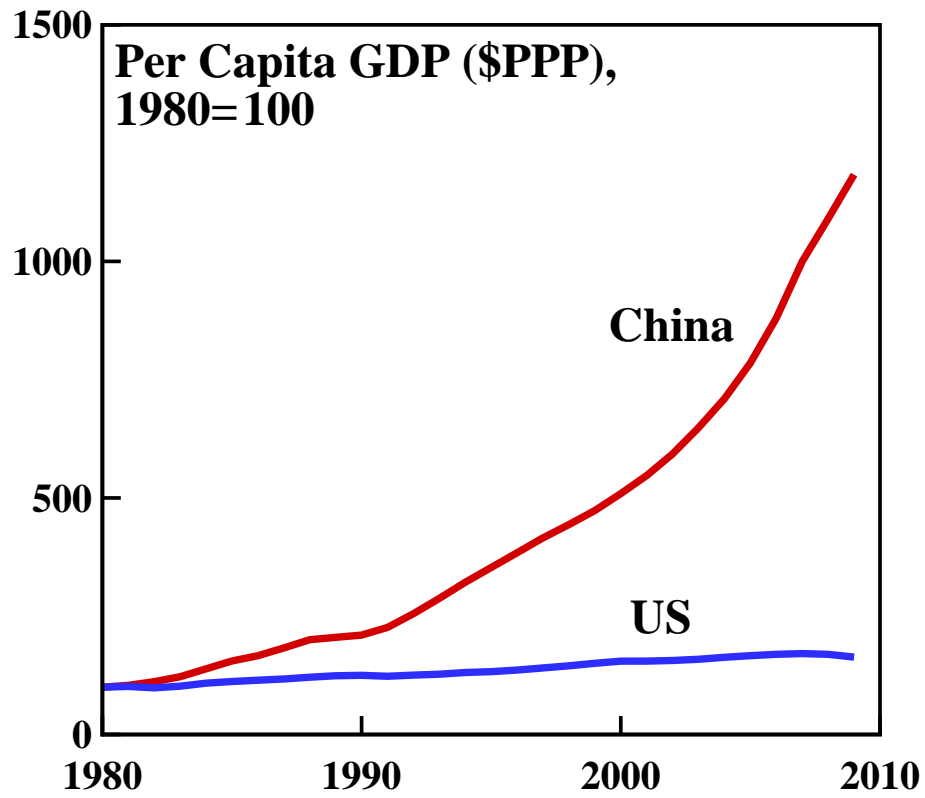


FIGURE 1B. PER CAPITA REAL GDP INDEX IN US AND CHINA  
SOURCE: WORLD DEVELOPMENT INDICATORS

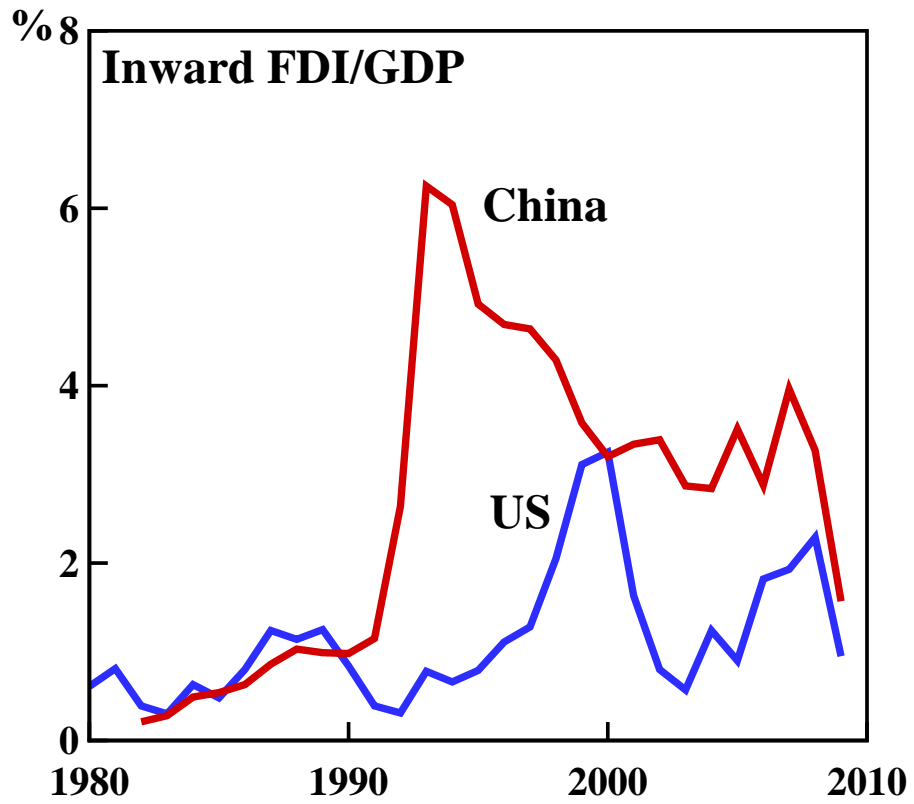


FIGURE 2. FDI NET INFLOWS TO US AND CHINA (% OF GDP)  
 SOURCE: WORLD DEVELOPMENT INDICATORS

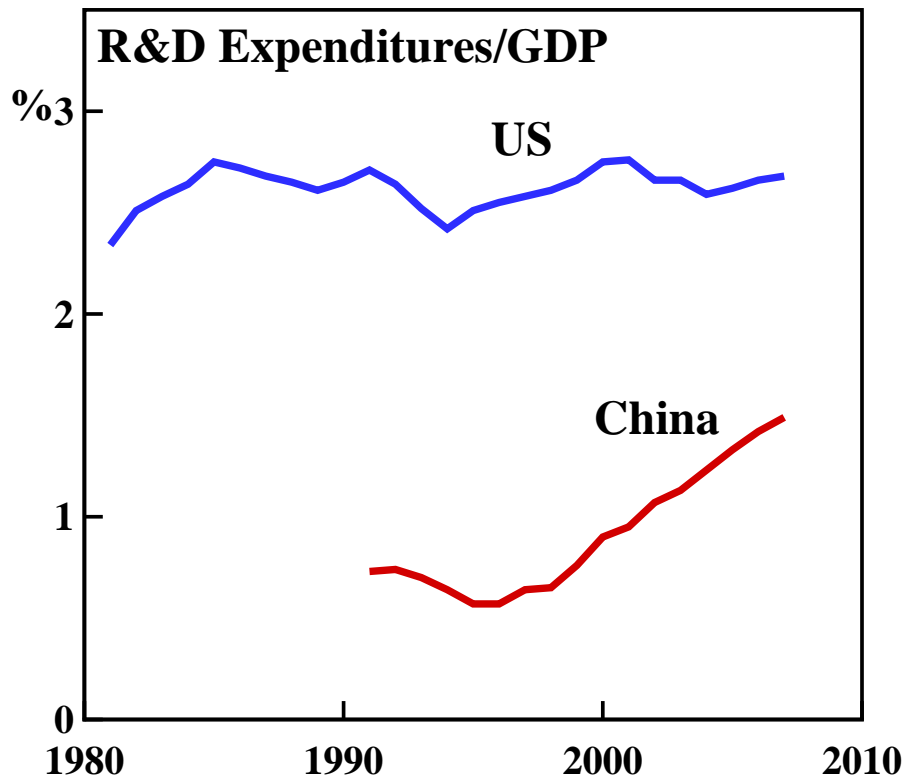


FIGURE 3A. R&D EXPENDITURES IN US AND CHINA (% OF GDP)

SOURCE: NATIONAL SCIENCE FOUNDATION

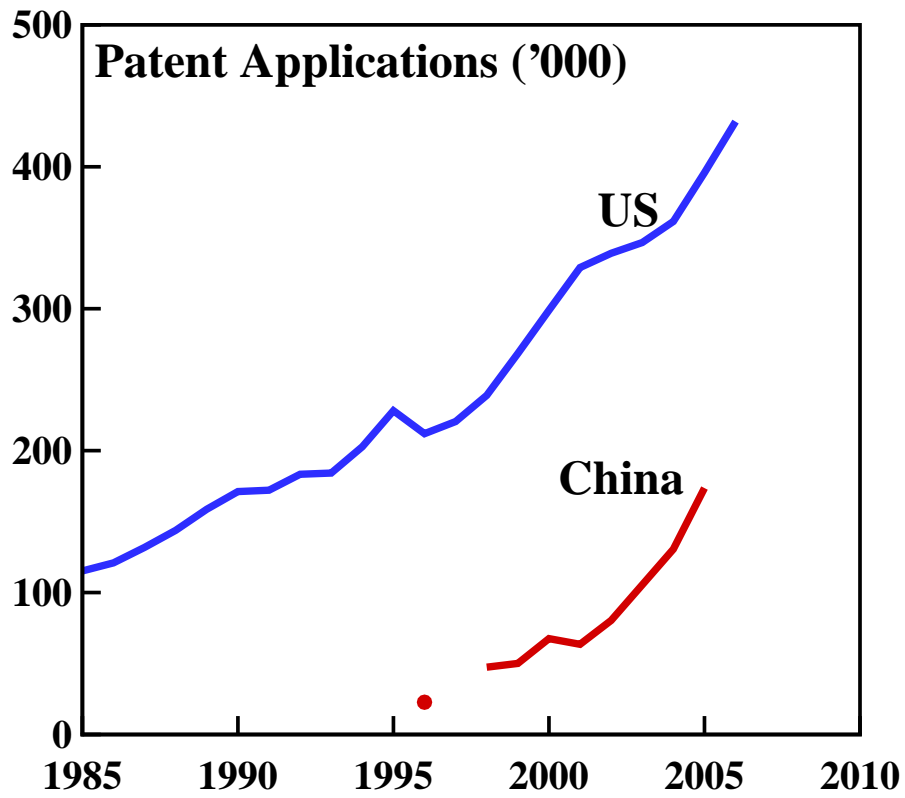


FIGURE 3B. PATENT APPLICATIONS IN US AND CHINA  
SOURCE: WORLD DEVELOPMENT INDICATORS

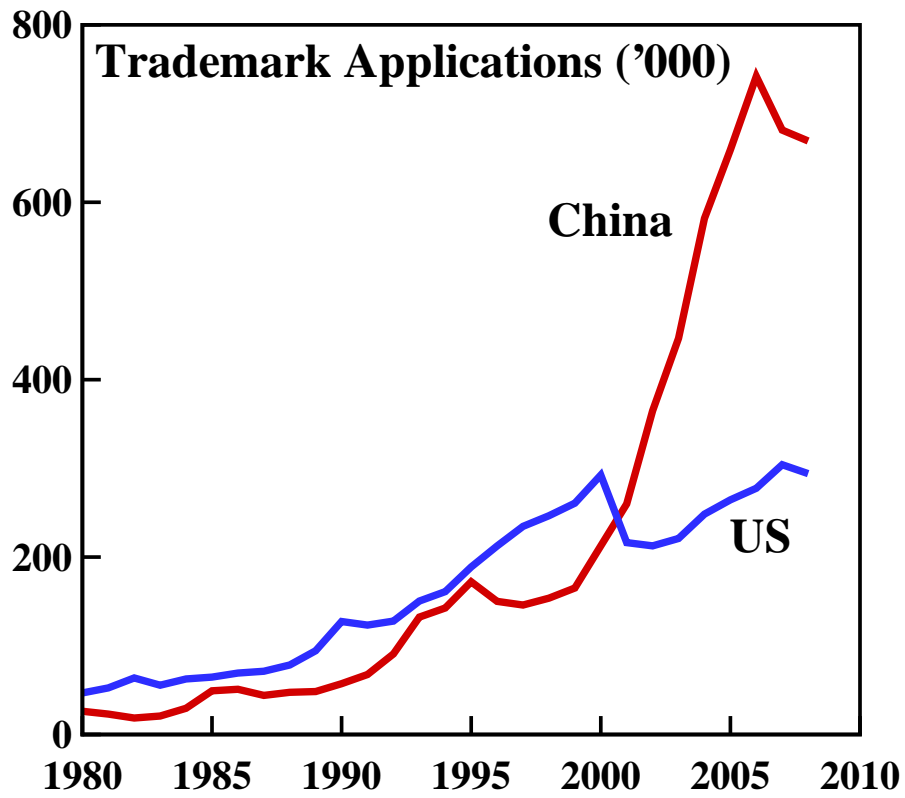


FIGURE 3C. TRADEMARK APPLICATIONS IN US AND CHINA  
 SOURCE: WORLD DEVELOPMENT INDICATORS

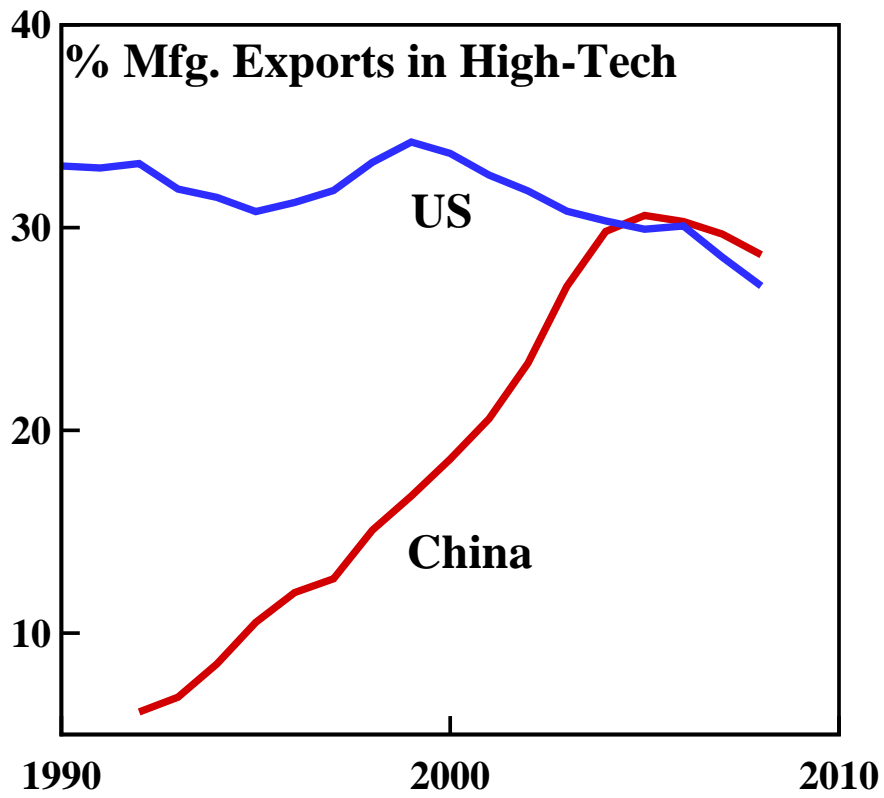


FIGURE 4A. HIGH-TECHNOLOGY EXPORTS IN US AND CHINA  
 (% OF MANUFACTURING EXPORTS)

SOURCE: WORLD DEVELOPMENT INDICATORS



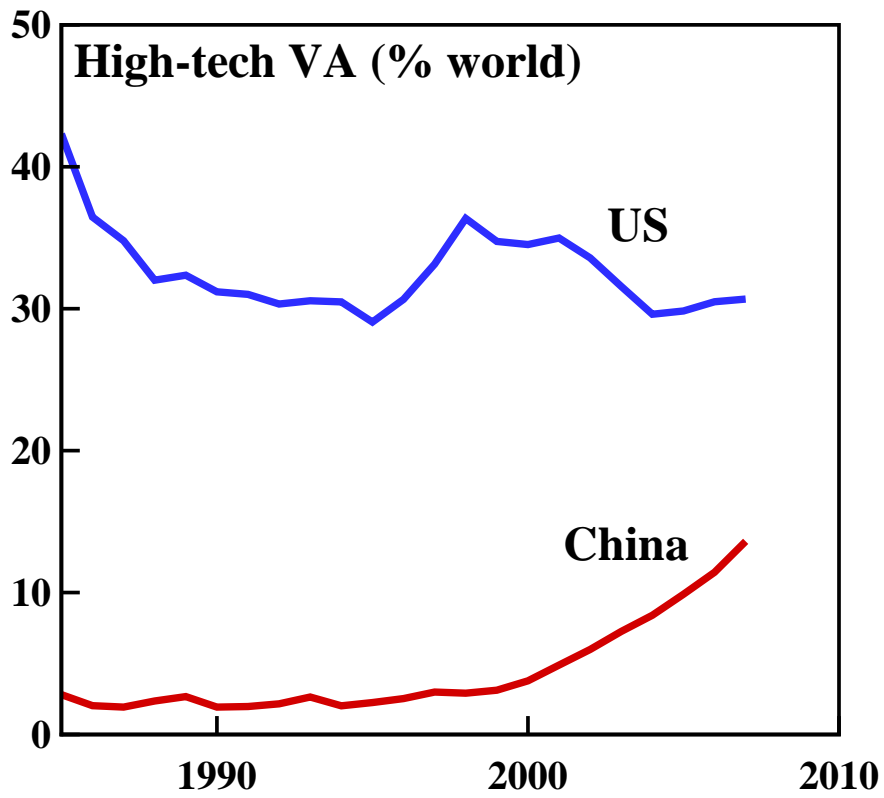


FIGURE 4B. HIGH-TECHNOLOGY VALUE ADDED IN US AND CHINA  
 (% OF WORLD'S HIGH-TECHNOLOGY VALUE ADDED)

SOURCE: NATIONAL SCIENCE FOUNDATION

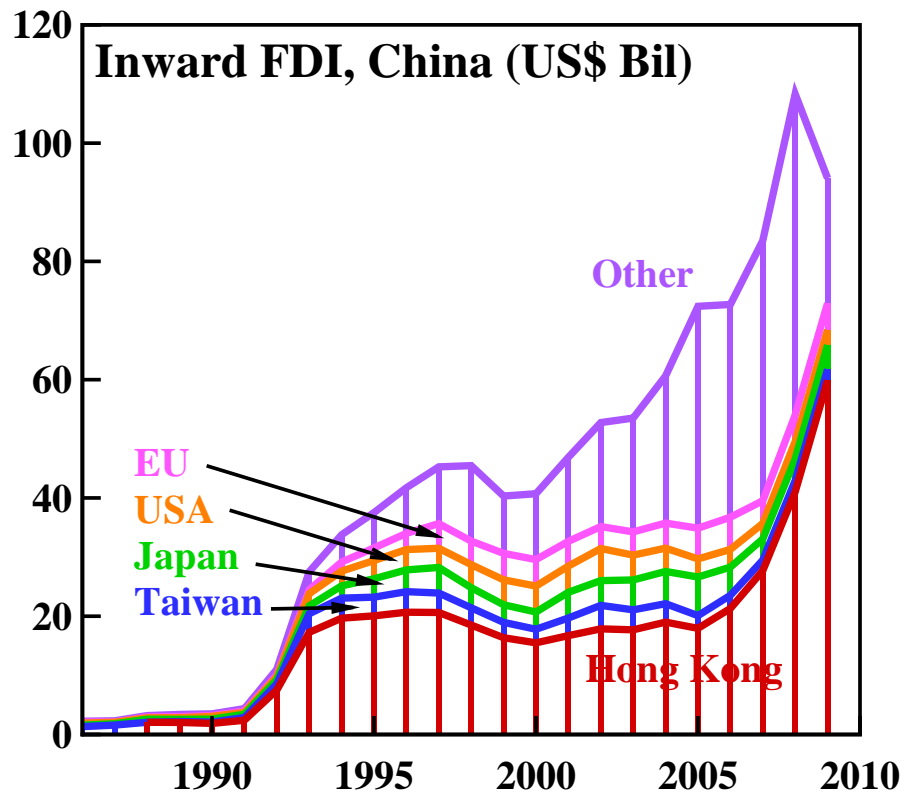


FIGURE 5. FDI NET INFLOWS TO CHINA BY SOURCE COUNTRY  
 SOURCE: CHINESE STATISTICAL YEARBOOK

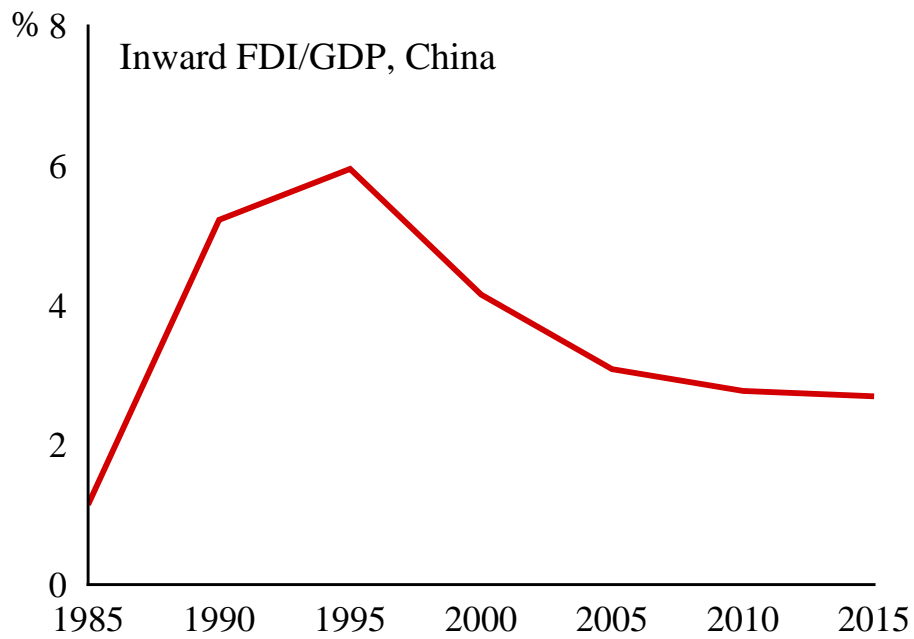
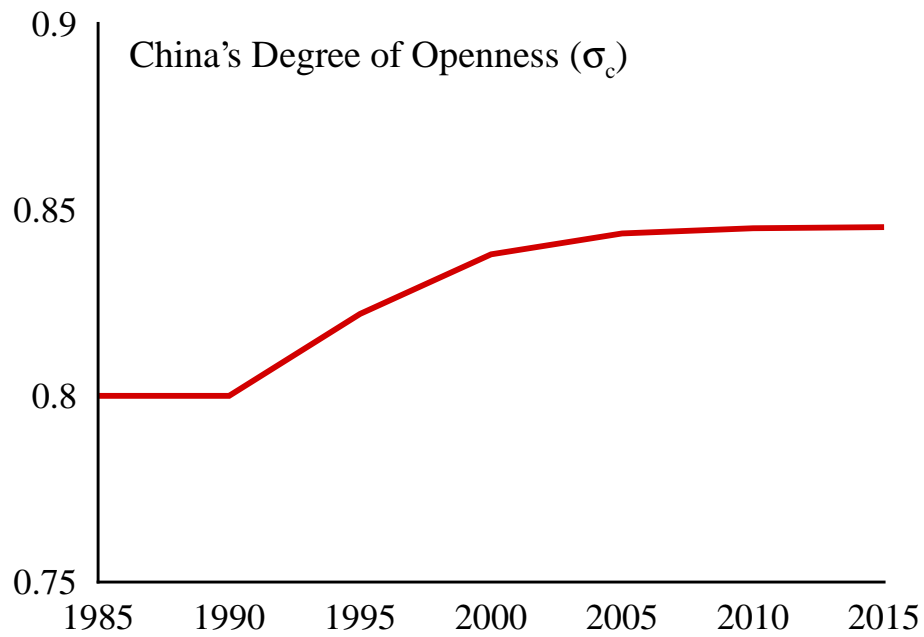


FIGURE 6A. DEGREE OF OPENNESS AND PREDICTED INWARD FDI TO GDP RATIO WITH CHINA OPENING TO FDI

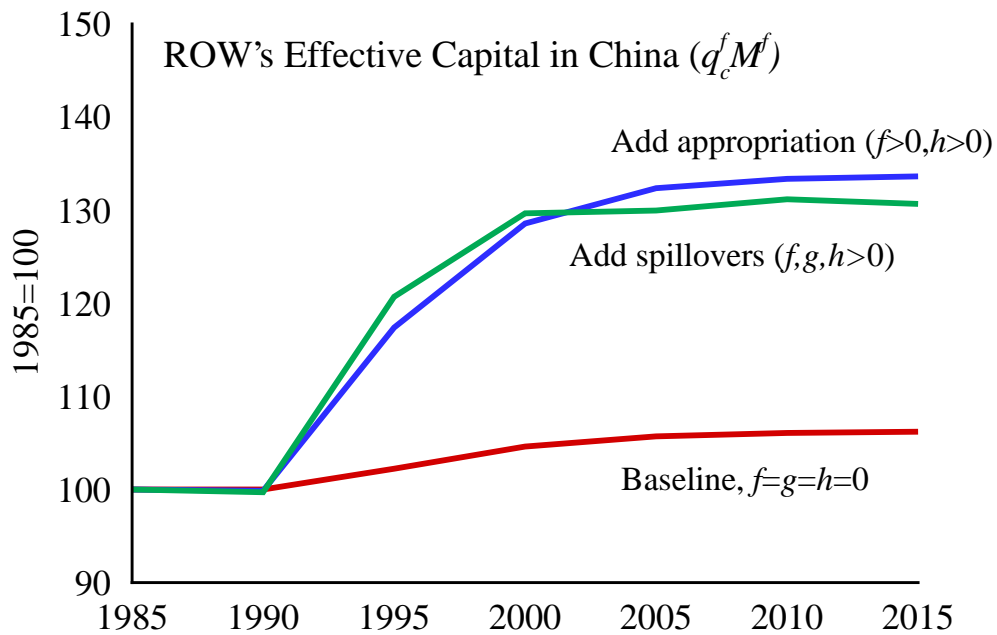
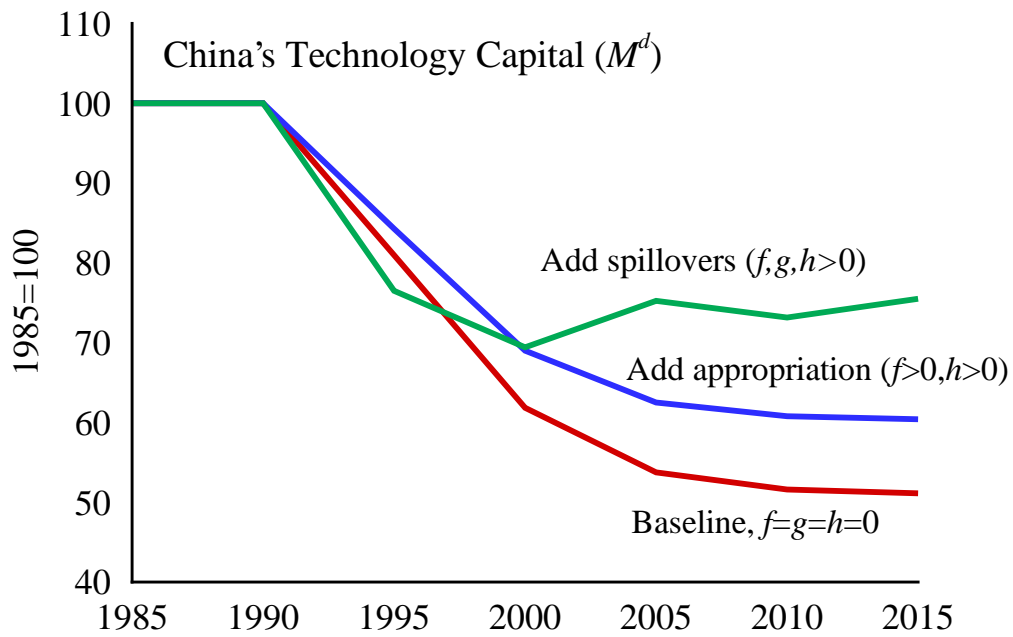


FIGURE 6B. PREDICTED PATHS FOR TECHNOLOGY CAPITAL STOCKS WITH CHINA OPENING TO FDI

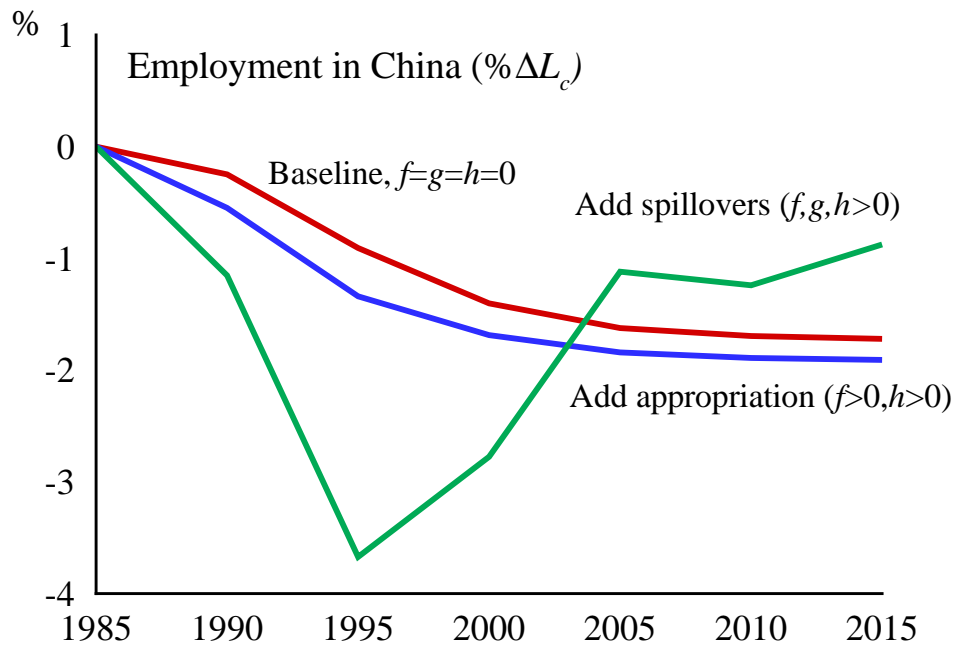
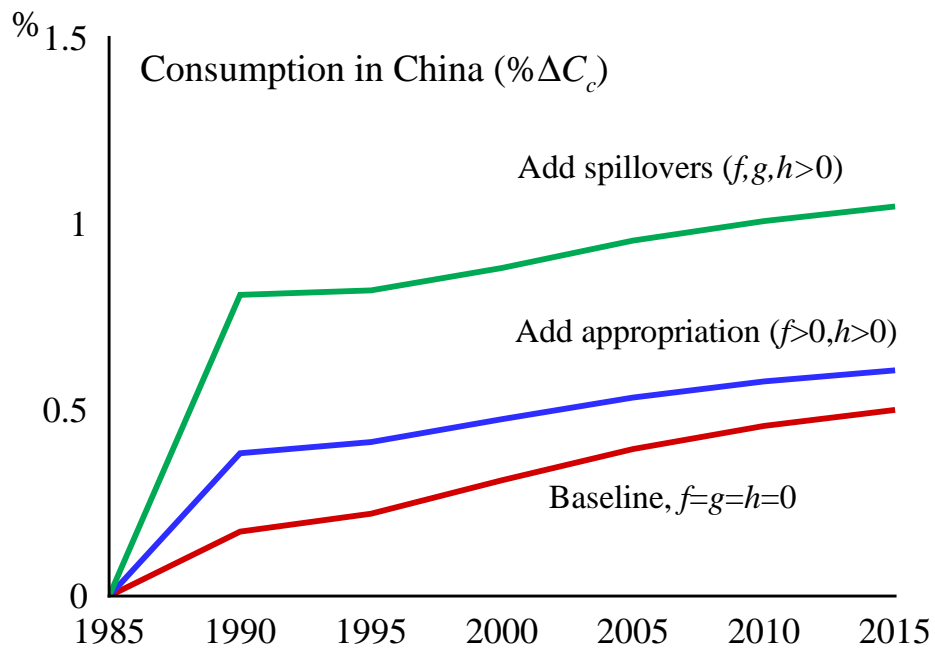


FIGURE 6C. PREDICTED PATHS FOR CONSUMPTION AND EMPLOYMENT WITH CHINA OPENING TO FDI

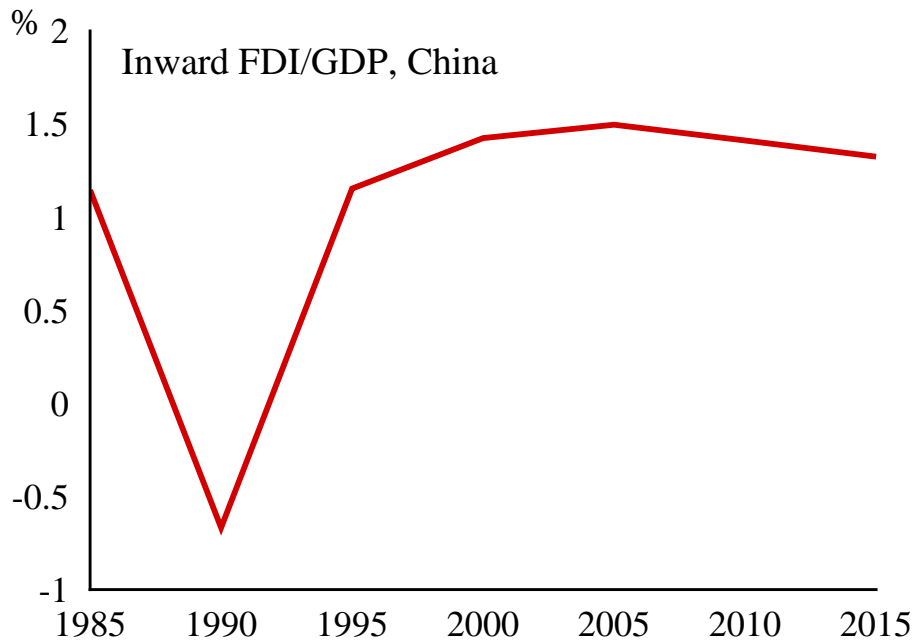


FIGURE 7A. TAX RATE ON PROFITS AND PREDICTED INWARD FDI TO GDP RATIO WITH CHINA LOWERING TAX RATES

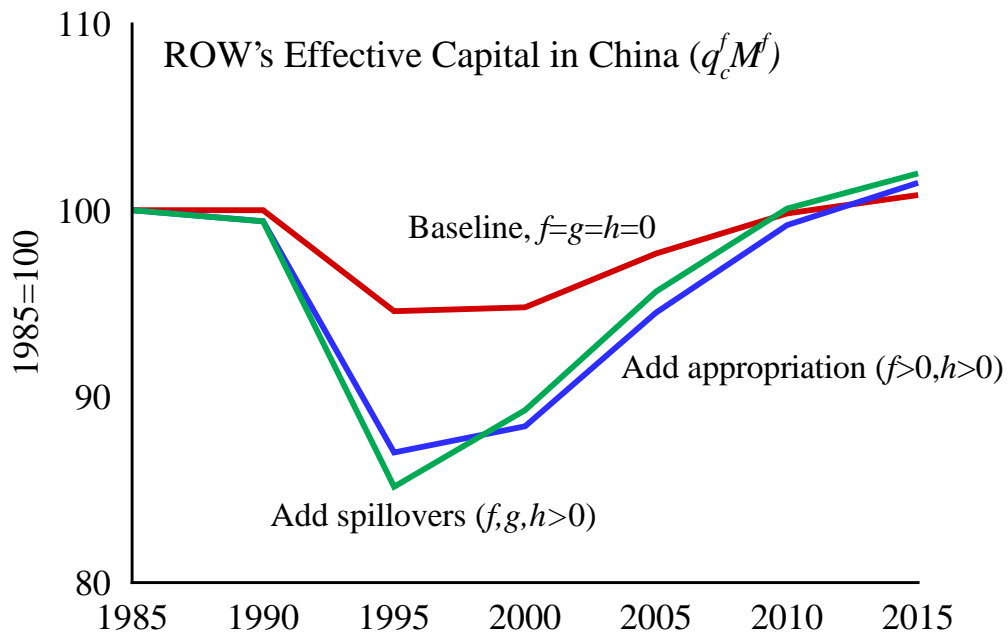
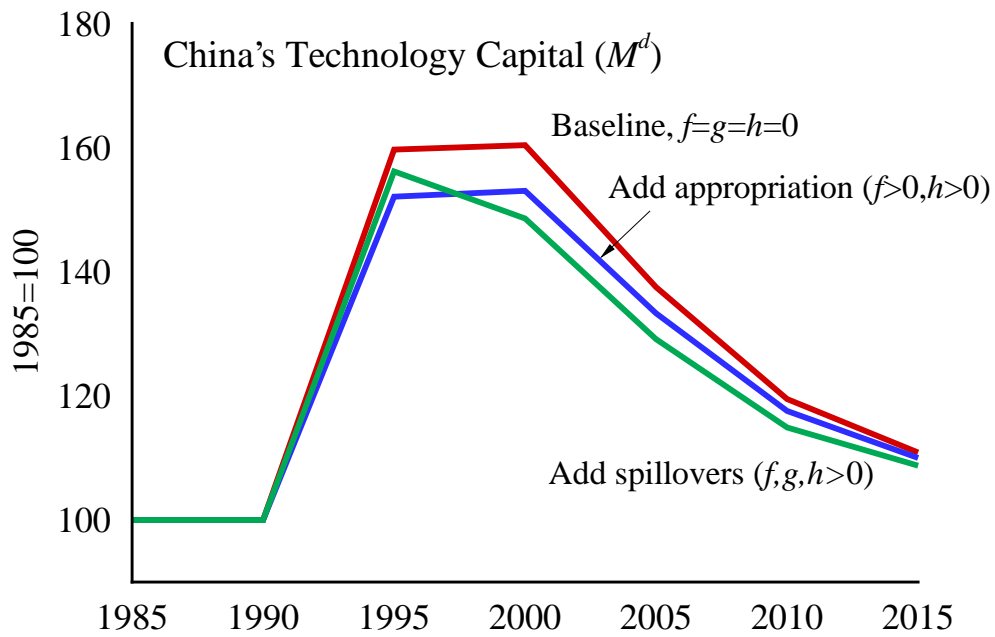


FIGURE 7B. PREDICTED PATHS FOR TECHNOLOGY CAPITAL STOCKS WITH CHINA LOWERING TAX RATES

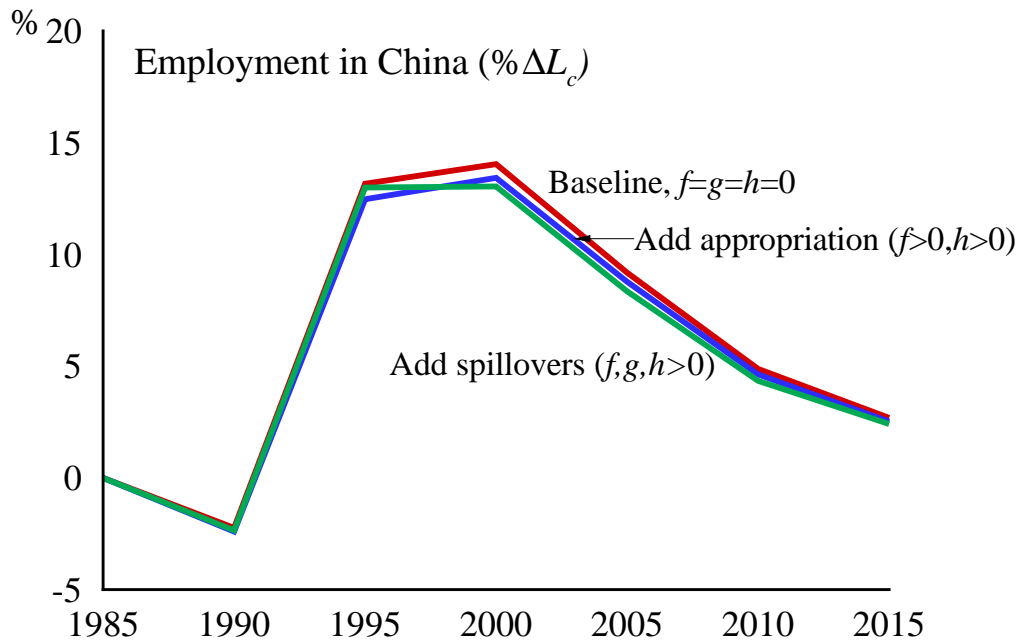
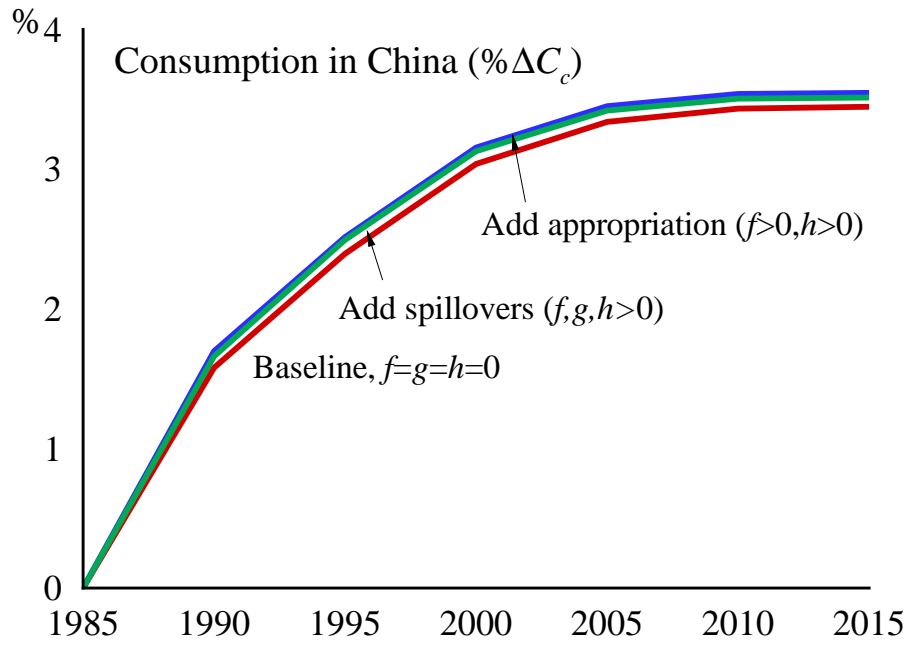


FIGURE 7C. PREDICTED PATHS FOR CONSUMPTION AND EMPLOYMENT WITH CHINA LOWERING TAX RATES