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Technology Capital Transfer*

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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 first demonstrate that abstracting from technology capital transfers results in predicted bilateral FDI inflows to China that are grossly at odds with the data. We then use the bilateral inflows to parameterize the model with technology capital transfers and compute the global economic impact of Chinese policies that encouraged greater inflows of FDI and technology capital transfers. Microevidence on automobile patents is used to support our parameter choices and main findings.

*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.

We find that abstracting from technology capital transfers has significant consequences for the model's predictions: it implies global capital flows that are grossly at odds with data from international accounts. Including capital transfers, we can account for the fact that when China opened up to FDI in the early 1990s, the advanced countries did not significantly increase FDI there. Quantitatively, we find that appropriation is the most important channel for accounting for observed capital flows and transfers. Spillovers increase the amount of technology capital developed, but do not change the bilateral flows significantly. Allowing for appropriation in our theory, we better account for flows into China and elsewhere, specifically to countries such as the United States, Japan, and those in the European Union. We use microevidence from automobile patent data that support our model parameter choices and findings.

We use the version of the model that includes both types of capital transfers to compare welfare and GDP across steady-states of the model economy. We consider four policy changes that were potentially important in China between 1990 and 2007: increased openness to FDI, improved domestic institutions leading to higher TFP, decreased tax rates on business profits, and increased requirements for technology transfers by foreigners in exchange for market access. Comparing the Chinese economy in 1990 to 2007, we find significant gains in welfare and GDP for China in the case of all four policies. However, if the goal of China has been to increase home-grown technology capital, theory and data indicate that the policies have failed.

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 multicountry application of the theory that uses data for China and many of its FDI partners.

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.[1]

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

[1] 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).

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. 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 is 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.[2] 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.

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

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

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 multicountry general equilibrium model with two types of firms: multinationals that have *proprietary technology capital* and appropriators that either copy foreign firms or receive quid pro quo transfers for access to the local market. Appropriators operate locally with technology capital that has been copied or knowingly transferred. We use the theory to quantify the economic impact of technology capital transfer.

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

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

where A is total factor productivity, ϕ is the share of income accruing to the owners of technology capital and q is an indicator of whether the unit of technology capital is deployed. If there are no costs to deployment, we assume that $q = 1$.

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

$$\max_{q,\{z_i\},n} \sum_i Aq^{\phi} z_i^{1-\phi} \quad \text{s.t.} \quad \sum_i z_i \leq z, \; n \leq N$$

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,

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

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

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

In the aggregate, we interpret q as the fraction of total technology capital that is deployed and qM as the effective stock of technology capital. Thus, the domain of q is $[0,1]$.

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, $i = 1, \ldots, I$. Let j index the country of origin of the technology capital, $j = 1, \ldots, I$. 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

$$Y_{it}^{j} = A_{it}\sigma_{it}^{j}\left(q_{it}^{j}M_{it}^{j}N_{it}\right)^{\phi}\left(Z_{it}^{j}\right)^{1-\phi} \tag{4.1}$$

$$Z_{it}^{j} = \left(K_{T,it}^{j}\right)^{\alpha_T}\left(K_{I,it}^{j}\right)^{\alpha_I}\left(L_{it}^{j}\right)^{1-\alpha_T-\alpha_I}, \tag{4.2}$$

where σ_{it}^{j} is country i's degree of openness to FDI which is equal to 1 if $j = i$ and less than 1 if $j \neq 1$, q_i^j is the intensity level chosen by firms in j when investing in i, M_i^j is the stock of j's technology capital that is proprietary and used in i by multinationals in j, Z_i^j is a composite input used 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. We view the degree of openness parameters σ_{it}^{j} and the TFP parameters A_{it} as government policies taken as given by multinationals when deciding how much FDI to do in country i. 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. Below, we assume that $A_{it} = A_i(1+\gamma_A)^t$ and $N_{it} = N_i(1+\gamma_N)^t$ where γ_A and γ_N are common trend growth rates of TFP and locations, respectively.

An innovation in the model here, relative to McGrattan and Prescott (2009, 2010), is the fact that technology capital can be appropriated in countries with weak intellectual property protection. Thus, we index M with both the country of origin (j) and the country where FDI occurs (i).

4.1.4. Appropriators production

With no appropriation of technology capital, aggregate output in country i is the sum of output produced by all multinationals operating in i. With appropriation, some capital is transferred and can be used without paying rents to the original investors. However, to produce with the transferred capital, some non-technology capital and labor must be allocated and an intensity margin must be chosen. The output is then

$$\tilde{Y}_{it} = A_{it}\left(\tilde{q}_{it}\tilde{M}_{it}N_{it}\right)^{\phi}\left(\tilde{Z}_{it}\right)^{1-\phi} \tag{4.3}$$

$$\tilde{Z}_{it} = \left(\tilde{K}_{T,it}\right)^{\alpha_T}\left(\tilde{K}_{I,it}\right)^{\alpha_I}\left(\tilde{L}_{it}\right)^{1-\alpha_T-\alpha_I} \tag{4.4}$$

where $\tilde{M}_i$ is the technology capital appropriated from foreign multinationals investing in country i, $\tilde{q}_i$ is the intensity level chosen by firms using the transferred capital available, $\tilde{Z}_i$ is a composite input used by these firms which depends on the stock of tangible capital $\tilde{K}_{T,i}$, the stock of plant-specific intangible capital $\tilde{K}_{I,i}$, and labor $\tilde{L}_i$. We use a $\tilde{}$ on variables in (4.3) to distinguish them from variables in the multinational's problem. As before, TFP is A_i and the number of locations where production can occur is N_i.

In setting up the optimization problems solved by the two types of firms, it will be clear how the multinational's technology capital M_i^j and the transferred technology capital $\tilde{M}_i$ are related. We turn to that next.

4.2. Optimization

In this section, we lay out the optimization problems of the stand-in multinational j that owns proprietary technology capital in country i M_i^j and the stand-in appropriator in country i that uses transferred technology capital $\tilde{M}_i$.

4.2.1. Multinational problem

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

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

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 τ_{pi}, output produced Y_i^j, the wage rate W_i, the labor input L_i^j, the rate of depreciation of tangible capital δ_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 in country i, and proprietary technology capital M_i^j used in country i.

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

$$\begin{aligned} K_{T,i,t+1}^j &= (1-\delta_T) K_{T,it}^j + X_{T,it}^j \\ K_{I,i,t+1}^j &= (1-\delta_I) K_{T,it}^j + X_{I,it}^j \\ M_{i,t+1}^j &= (1-\delta_M) \left(1 - h\left(q_{it}^j\right)\right) M_{it}^j + g\left(\mu_t^j\right) X_{M,t}^j. \end{aligned} \tag{4.5}$$

The first two accumulation equations are standard. The third is not because of the inclusion of the functions $h(\cdot)$ and $g(\cdot)$. The function $h(\cdot)$ maps the percent of the proprietary technology capital brought from j in period t and appropriated in country i.[3] We allow the intensity choices to impact the rate at which capital is transferred in country i. We assume that function h is weakly increasing in q_{it}^j. If $h(q_i^j)$ is equal to zero for all i and j, then $M_{it}^j = M_t^j$ as in McGrattan

[3] We interpret h as standing in for Chinese policies described in its *Medium- to Long-Term Plan for the Development of Science and Technology* intended to increase *zizhu chuangxin*; zizhu means "indigenous" or "self-owned" and chuangxin means "innovation." According to the U.S. ITC (2010), these policies enable China "to intervene in the market for IP, help its own companies re-innovate competing IP as a substitute to American and other foreign technologies and potentially misappropriate IP from U.S. and other foreign companies" (p. 1-7).

and Prescott (2009, 2010). In that case, all technology capital is proprietary and, because it is nonrival, it can be used simultaneously in many locations, both domestically and abroad. On the other hand, if some countries allow appropriation, say through weak protection of intellectual property, then the fraction of the ownership will differ by country and needs to be tracked.

The function $g(\mu_t^j)$ in (4.5) represents knowledge spillovers which are modeled as an externality lowering the cost of technology capital investment. Positive spillovers from foreign technology capital depend on μ_t^j, which is defined to be

$$\mu_t^j = \{M_{jt}^j + \tilde{M}_{jt} + \sigma_{jt}^{\frac{1}{\phi}} \sum_{\ell \neq j} q_{jt}^{\ell} M_{jt}^{\ell}\} / (1+\gamma_Y)^t$$

where γ_Y is the trend growth rate of output. Note that μ^j is not a choice of the firm; it is taken as given when solving their maximization problem.

The new elements here relative to the framework of McGrattan and Prescott (2009, 2010) are the choice of intensity level q_i^j, the externalities $g(\cdot)$ from the technology capital of others investing in j, and the appropriation of technology capital, $h(\cdot)$. Another novelty is the incorporation of both multinationals and domestic firms using appropriated technology capital. We turn next to the optimization problem of the appropriators.

4.2.2. Appropriators problem

Appropriators also maximize the present after-tax discounted stream of dividends. Dividends accruing to the appropriated technology capital are given by

$$\tilde{D}_{it} = (1-\tau_{p,it}) \left(\tilde{Y}_{it} - W_{it}\tilde{L}_{it} - \delta_T \tilde{K}_{T,it} - \tilde{X}_{I,it}\right) - \tilde{K}_{T,i,t+1} + \tilde{K}_{T,it}. \tag{4.6}$$

and are distributed to households in country i. The relevant inputs in this case are the profits tax rate τ_{pi}, output produced $\tilde{Y}_i$, the wage rate W_i, the labor input $\tilde{L}_i$, the rate of depreciation of tangible capital δ_T, tangible capital $\tilde{K}_{T,i}$, intangible investment $\tilde{X}_{I,i}$, the intensity level of the operation $\tilde{q}_i$, and the appropriated technology capital M_i. Notice that, unlike the multinationals with proprietary capital, the appropriator firm does not invest in new technology capital.

The maximization of after-tax dividends is subject to constraints on capital as follows:

$$\tilde{K}_{T,i,t+1} = (1-\delta_T)\,\tilde{K}_{T,i,t+1} + \tilde{X}_{T,i,t+1}$$

$$\tilde{K}_{I,i,t+1} = (1 - \delta_I)\, \tilde{K}_{I,i,t+1} + \tilde{X}_{I,i,t+1}$$
$$\tilde{M}_{i,t+1} = (1 - \delta_M)\, \tilde{M}_{it} + \sum_j (1 - \delta_M)\, h\left(q_{it}^j\right) M_{it}^j.$$

As before, the nonstandard equation is that for technology capital. Notice that appropriators do not make new investments, they just accumulate knowledge from others.

We view the appropriation, modeled as the function h, as government policy related to intellectual property protection. Countries with weak laws have a high value for $h(q)$, those with perfect protection have $h(q)$ equal to 0.

4.2.3. Household problem

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

$$\max \sum_t \beta^t \log\left(C_{it}/N_{it}\right) + \psi \log\left(1 - L_{it}/N_{it}\right) N_{it} \tag{4.7}$$

subject to

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

where τ_{li} and τ_d are tax rates on labor and company distributions, r_b is the after-tax return on international lending and borrowing, N_{it} is the population in country i, and κ_{it} is exogenously-determined income which includes both government transfers and nonbusiness net income. The latter is included because we want to match accounts of the model to accounts in the data and, therefore, want to distinguish value-added and investment from business and nonbusiness sectors.

In (4.7), 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).

4.3. Market clearing

The worldwide resource constraint is

$$\sum_i \left\{ C_{it} + \sum_j \left(X_{T,it}^j + X_{I,it}^j\right) + X_{M,t}^i + \tilde{X}_{T,it} + \tilde{X}_{I,it} + \bar{X}_{nb,it} \right\}$$

$$= \sum_{i,j} Y_{it}^j + \sum_i \left(\tilde{Y}_{it} + \bar{Y}_{nb,it} \right)$$

which is the market-clearing condition for the goods market that includes nonbusiness output $\bar{Y}_{nb}$ and investment $\bar{X}_{nb}$. Market clearing in asset markets occurs if $\sum_i B_{it} = 0$ and market clearing in labor markets occurs if

$$L_{it} = \sum_j L_{it}^j + \tilde{L}_{it} + \bar{L}_{nb,it}, \quad i = 1, \ldots, I.$$

where $\bar{L}_{nb}$ is the fraction of time devoted to nonbusiness work.

5. A Multi-Country Application

We now use our theory to analyze global capital flows. For now, we look at two snapshots in time: 1990 and 2007.[4] The year 1990 is of interest because it is before the significant rise in Chinese inward FDI. The year 2007 is of interest because it follows close to two decades of large capital flows into China but does not include the large drop in global activity that occurs in 2008 and 2009. The countries—or, in some cases, regions—that we analyze are the United States, the European Union (EU), Japan, China (including the mainland and provinces of Hong Kong and Taiwan), a combined entity consisting of Brazil, Russia, and India (BRI), and the rest of world (ROW). We include BRI as a comparison to China and its provinces since there are many similarities between them in 1990. For the rest of world we include all countries with FDI over a certain threshold in China (equal to 0.1 billion U.S. dollars in 2007).[5]

We start by discussing how we parameterize the model. We then consider macroevidence on bilateral FDI flows and microevidence on the auto industry and show that abstracting from technology transfers implies predictions that are grossly at odds with the data. Adding these transfers—which involves adding only two free parameters—completely changes the global capital flow patterns, yielding a theory that fits the facts surprisingly well. With the transfers included in the model, we conduct welfare analyses, computing the gains and losses to China attributable to key policy changes that were made that impacted FDI openness.

[4] We are in the process of extending the analysis to study transitional dynamics.

[5] We purposely leave out countries in the world doing little or no FDI and countries in the Caribbean since the FDI of the latter is more related to sheltering taxes than to employing accumulated R&D and brands.

5.1. Parameters

We assume that countries differ in total populations (N_i), tax policies related to business profits (τ_{pi}), TFP (A_i), and FDI openness (σ_i). In all other respects, they are assumed to be the same. Thus, we use parameters for household preferences, trend growth, income shares, nonbusiness activities, depreciation rates, and tax rates on individual incomes. We use estimates from McGrattan and Prescott's (2010) study of the U.S. current account. These are shown in Table 1.

The parameters that differ across countries are shown in Tables 2 and 3. In Table 2, we show total populations relative to the United States from the *World Development Indicators* in the first column and estimates of tax rates on profits from the OECD (if available) in the second column. The third and fourth column are data on inward FDI relative to GDP from the IMF balance of payments and real GDP per capita from the Total Economy Database at the Conference Board; these data are used to parameterize FDI openness (σ) and TFP (A) shown in Table 3. This is done for three versions of the model.

The version of the model depends on the choice of functions governing spillovers $g(\mu)$ and appropriation $h(q)$. The "no transfer" model is McGrattan and Prescott (2010) with $g(\mu) = 1$ and $h(q) = 0$. The "only appropriation" model has $g(\mu) = 1$ and $h(q) > 0$. Adding spillovers implies $g(\mu) > 1$ and $h(q) > 0$. Our choice of functional form for spillovers is $g(\mu) = \mu^\theta$ with the elasticity θ equal to 0.05 when spillovers are turned on. This is consistent with evidence in Ciccone and Hall (1996).

For appropriation, we use a functional form given by

$$h\left(q\right) = \min\{\bar{h}q \exp\left(-\eta\left(1-q\right)\right), 1\} \tag{5.1}$$

which is weakly increasing in q. We need some curvature in the function (that is, $\eta > 0$) for an interior equilibrium to exist so we set $\eta = 10$ and check to make sure that the results are robust to a wide range of values for η. The one free parameter that we vary in certain simulations discussed later is $\bar{h}$.[6] In all simulations, we assume that $\bar{h} = 0$ for FDI coming into the United States, EU, Japan, and ROW. On the other hand, when we turn on appropriation, we assume transfers do occur in China and BRI, where intellectual property rights are weak. In China and BRI, technology

[6] Note that there is appropriation even at $q = 1$ if $\bar{h} > 0$.

capital is transferred from the United States, the EU, and Japan. For the benchmark simulation, we assume they also appropriate from each other, but the quantitative results are little affected if we assume that China does not appropriate from BRI and vice versa. That leaves rest of world as the region that can do FDI in China and BRI without worrying about having their capital appropriated.[7]

5.2. Macroevidence on Bilateral FDI Flows

We turn now to the predictions of the model for bilateral FDI flows. We establish first that the predictions are grossly at odds with capital flow data if we abstract from technology transfer. We then add in spillovers and appropriation and show that the impact on the model predictions are improved significantly, especially when we include transfers through appropriation.

The main results are shown in Tables 4A and 4B for 1990 and 2007, respectively. For both years, the first rows contain the bilateral flows for the data. Note that the sources of FDI are summarized as the combined flow from the United States, EU, and Japan, the combined flow from the BRICs (BRI plus China), and the rest of world as defined in Table 1. The totals are the same as the inward FDI to GDP figures shown in Table 2.

The rows below the data show the predicted inward flows to the United States, EU, Japan, and China for three versions of the model: (1) without transfers, (2) with only appropriation, and (3) with spillovers and appropriation. When we add spillover, we use the elasticity of 0.05 as mentioned above. When we add appropriation, we choose $\bar{h}$ in (5.1) so as to get one bilateral flow correct for the model with both transfers on. The choice was to set $\bar{h}$ to generate an inflow from ROW to China relative to Chinese GDP equal to 0.25 in 1990 and 1.00 in 2007. These choices imply that in 1990, $q = 0.37$ and $h(.37) = 0.036$, and in 2007, $q = 0.25$ and $h(.25) = 0.053$ for all countries with $h(q) > 0$.[8]

As is clear from the results, we could have picked *almost any* of the combinations of sender and receiver and done equally well. This is because the model and data line up surprisingly well

[7] This is an extreme assumption based on a narrow investigation of patents in the automobile industry. We are in the process of considering other industries and the types of FDI done by countries grouped in our rest of world.

[8] For our choice of $h(\cdot)$, if $\bar{h} = 0.013$, then the equilibrium q and $h(q)$ are 1 and 0.013, respectively.

when transfers are included. And, the match of data and model is much improved over the model without transfers. Without transfers, the model predicts that the BRICs are doing a lot of FDI abroad. For example, for 1990 the inward FDI to GDP ratio is 0.85 percent. The data show that the BRICs are responsible for only 0.01 of the 0.85 percent. The model without transfers predicts an inflow of 0.28 of the 0.85 from the BRICs. By 2007, nothing has changed in the data, but the model predicts the contribution of inward FDI from the BRICs to the United States has risen from 33 percent to 43 percent, with 0.68 percent of the 1.58 percent inflow in 2007 attributed to them.

Compare these results to the case with transfers shown in the last two panels of Tables 4A and 4B. With transfers included in the model, the BRICs are predicted to do almost no FDI abroad, which is consistent with the data. Also consistent with the data is the fact that the United States, EU, and Japan send more FDI to each other than to China. This is true regardless of the size of the spillovers, which do not have a large effect on the global FDI patterns.

5.3. Microevidence on Automobile Patents

Next we consider microevidence from patent data in the automobile industry to evaluate our choices of appropriation parameters used to match bilateral FDI flows. We narrow our focus to the automobile industry in China, for two reasons. First, it is an extremely important industry in China, and now China produces more automobiles than any other country. Consider that in 2010, China produced 18.2 million vehicles, while the next two highest, Japan and the U.S, produced 9.6 and 7.7 million.[9] Second, given the importance of this industry, there is much public information about how the technology transfer process is taking place in this industry, and we have used this public information to guide our approach.[10]

The automobile industry provides an excellent example of the role of technology capital. The world leading automobile producers, such as General Motors (GM) and Ford from the United States, and Toyota from Japan, develop new designs for cars and then produce from this common platform at their various production plants throughout the world. The typical approach is to open up wholly-owned local affiliates. For example, GM has wholly owed subsidiaries throughout

[9] These production statistics are obtained from the International Organization of Motor Vehicle Manufacturers.

[10] We intend to discuss a broader set of industries in a future version of the paper.

Europe, North and South America, South Africa, and Australia. Some countries, however, require a joint venture with a local partner as a pre-condition for market access. There are a number of reasons to believe that knowledge transfer takes places through these joint ventures and this in many cases is clearly the intent of making a joint venture a precondition for market access.

There are eleven different multinational automobile firms producing in China and in all cases they are through joint ventures that are 50/50 with local Chinese partners (or 49/51 or 51/49). While there are also several independent automobile producers, the joint ventures produce the overwhelming majority of vehicles. In 2010, the joint ventures accounted for 82.3 percent of all vehicle production, while the independents accounted for 17.7 percent.

We consider the use of patents as a potential proxy of technological capital. Table 5 reports patent counts by firm. The first column of counts are "invention" patents granted in China over the period 2000-2010 (virtually all of these are in the second half of the decade). Multinational firms have amassed 13,721 patents in China over this period, while the Chinese Joint Venture firms have collected 1,076, and the independents 3,602. Given the huge difference in patent counts between the multinationals and the joint venture firms, the table makes clear that the foreign firms are the source of the technology for joint-venture firms. Interestingly, even though the independent firms produce only 17.7 percent of the vehicles, then have three and a half times as many patents as the Chinese joint-venture firms.

What is the source of the technology capital embodied in the Chinese patents? We consider three alternatives. In the first scenario, the patents listed in the table emerge from each firm's own research activities and there is no transfer of ownership of technology capital, that is, $h(q) = 0$, where $h(q)$ is the earlier notation for the share of technology that must be transferred as a condition for a given market access.

The second alternative is that the 1,076 patents granted to the Chinese Joint Venture firms represent technology transfer from the multinationals, as part of the quid-pro-quo for market access. As some evidence on this point, consider that if these 1,076 patents represented true original ideas, we would expect these companies would be able to obtain patents on these new ideas elsewhere around the world. The last column contains counts of patents in the World Intellectual Property

Organization (WIPO) database. (A large fraction of these patents counts are Patent Cooperation Treaty (PCT) patents meaning a single patent has coverage in multiple countries. Patents through the European Patent Office are also included in WIPO.) We can see in the table that the multinationals have amassed a large stock of patents in WIPO, 55,258 altogether. Remarkably, even though the Chinese joint-venture firms have 1,076 Chinese patents, they account for only 17 patents in WIPO. Note the contrast with the independent Chinese firms, who have managed to obtain 577 worldwide patents, dwarfing the 17 obtained by the much larger joint venture firms. The independents themselves are not patenting internationally at a very high rate of 16 percent = 577/3602, but it vastly exceeds the 1.6 percent = 17/1076 rate of the joint ventures. The readily evident non-worldwide-patentability of the joint-venture patents is consistent with the hypothesis that the multinationals transfer ownership of ideas to the joint venture firms in China, as part of the quid-pro-quo for market access, but do not include ownership of these ideas in other parts of the world in the bargain.

The third alternative considered is that even patents held by the independent Chinese firms represent technology transfer. We view this extreme case as an upper bound. The independent firms have their own R&D labs and the patents they acquire may certainly be the result of their own R&D. However, in addition, they may claim ideas of the multinational firms as their own. If the multinationals complain, they might lose their market access (that is, acquiescence on the part of the multinational may be part of the quid-pro-quo). For example, Chery, one of the leading independents got its start making a car (called the QQ) that looks like the identical twin of a car (called the Matiz) developed by the GM subsidiary Daewoo. See Figure 1 for pictures of the two cars. The QQ used many of the same parts as the Matiz, some directly from GM's suppliers (to GM's initial surprise). GM at first complained, but eventually acquiesced. Another Chery car is claimed to resemble the Toyota RAV4.

Next we discuss how we use the patent numbers along with the model to back out estimates of appropriation $h(q)$ in China. Let $\sum_{j \neq c} M_{ct}^{j}$ be total foreign multinational technology capital in China at time t and let $\sum_{j \neq c} p_{ct}^{j}$ be the number of new patents at time t by the multinationals. Assuming a proportional relation between Chinese patents and foreign investment in technology capital, the stock of multinational technology capital evolves according to

$$\sum_j M^j_{c,t+1} = (1-\delta_M)(1-h(q_c))\sum_j M^j_{ct} + \xi \sum_j p^j_{ct}$$

where ξ is the proportionality factor. Note that, here, we are abstracting from spillovers and assuming that q_c is the same for all foreign multinationals in China. The technology capital transferred in period t equals

$$\xi p^T_{ct} = (1-\delta_M)\, h(q_c) \sum_j M^j_{ct}$$

where the above patent count includes only joint venture patents in alternative two and all Chinese automobile firm patents in alternative three. In a stationary equilibrium $\sum_j M^j_{ct}$ grows at the rate of total output. Solving out for patent counts and taking ratios yields

$$\frac{p^T_{ct}}{\sum_j p^j_{ct}} = \frac{(1-\delta_M)\, h(q_c)}{1+\gamma_Y - (1-\delta_M)(1-h(q_c))}$$

We can then substitute in the patent count values and estimates for the depreciation rate $\delta_M = .08$ and growth rate in output $\gamma_Y = 0.03$ (as assumed above), and we can back out $h(q_c)$. If we assume that all of the patents obtained by China are the result of their own investment, then $p^T_{ct} = 0$ and $h(q_c) = 0$. If we treat all joint venture patents as transferred, while independent firm patents are not, then our estimate is $h(q_c) = 0.01$. Finally, if the transferred patents include both joint venture and independent firm patents, then $h(q_c) = 0.062$. If we use these estimates for $h(q_c)$ based on patent data to construct a plausible range, we find that it contains both the 1990 and 2007 estimates needed earlier to match the bilateral capital flows. Recall that, for 1990, we needed $h(q_c) = 0.036$ to match the targeted bilateral FDI inflows and for 2007, we needed $h(q_c) = 0.053$.

The patent data are also consistent with the model's predicted outward FDI from China and its provinces. The results in Tables 4A and 4B show that almost no FDI is sent abroad to the United States, the EU, and Japan from China. Such predictions are consistent with the worldwide counts of patents in the WIPO database. Neither the joint-venture Chinese firms nor the independent Chinese firms are patenting much outside of China.

5.4. Welfare Analysis

We turn next to our welfare analysis, considering specifically the impact of several policy changes enacted over the past two decades related to China's FDI and the goal of technology transfer. The policy changes we consider are greater FDI openness, improved domestic institutions, lower tax rates on profits, and higher transfer requirements demanded of foreign firms in China, which can be summarized in the model as increases in σ and A, a decrease in τ_p, and an increase in $h(q)$.

The main results of our welfare analysis are shown in Figures 6A–6D. All figures include steady-state estimates of welfare and GDP for China as we vary one parameter, holding fixed all other parameters. The starting point is the 1990 parameterization. Our measure of welfare is the percent increase in consumption necessary for the household to be indifferent between two economies—the 1990 benchmark and the alternative being considered.

Figure 6A shows that greater openness implies higher welfare and GDP. Notice that the percentage difference is not the same — in large part because greater FDI openness implies larger increases in investments than in consumption since foreigners enter in greater numbers and domestic production rises. The figure shows that an economy with a 10 percent higher openness parameter has 7 percent higher GDP and 4 percent higher welfare. In our parameterization of 2007, we set σ for China about 4.4 percent higher than it had been in 1990.

Figure 6B shows welfare and GDP as the TFP parameter is varied. An increase in TFP affects consumption and investment similarly which is why the predictions for welfare and GDP are the same. The figure shows that an economy with a 10 percent higher TFP parameter has 14 percent higher GDP and welfare. In our parameterization of 2007, we needed to set A for China about 93 percent higher than in 1990. This large increase was needed to account for the huge increase in real per capita GDP that has occurred.

Figure 6C summarizes results as the tax rate on profits is varied. Lowering this rate implies a boom in GDP, especially investment. Eliminating it would imply an increase of close to 11 percent for GDP and 4 percent for welfare.

Figure 6D shows results for varying the policy most relevant to technology capital transfer:

the rate of appropriation $h(q)$. Changes in $h(q)$ are engineered by varying $\bar{h}$ in (5.1). Note that the 1990 benchmark has $h(q) = .036$. Increasing appropriation leads to an increase in China's welfare. However, the impact is nonmonotonic. If appropriation is lowered, welfare and GDP fall but then, at some lower point, both rise.

What we have constructed in Figures 6A–6D are the usual measures of an economy's performance. If an additional goal of the Chinese government in 1990 was to encourage FDI and as a result increase investments in technology capital done by independent Chinese firms, then that has not happened between 1990 and 2007. Consider again comparing model statistics for 1990 and 2007. To rationalize quantities observed in the data, the model has to set Chinese investment in technology capital equal to zero in both years. In other words, the model interprets any technology capital in China as appropriated.

These statistics are shown in Table 6. For each country, we report the size of technology capital investment relative to the U.S. level, the investment in technology capital as a share of own GDP, and three capital stocks—own, appropriated, and the total stock available in the economy. The latter is the sum of own capital, appropriated capital, and capital brought in by foreigners. As a share of GDP, China and BRI have a lot of technology capital in their economies. But none of it is home-grown. And, in the case of China, which is growing rapidly, the total technology capital—appropriated plus foreign—has not kept pace with its GDP. In some sense, China is becoming a technology laggard despite attempts to become a technology leader.[11]

6. Summary

This paper explores the economic impact of greater openness in an environment in which technology capital transfer occurs through knowledge spillovers and appropriation of intellectual property. The sources of greater openness that we consider are higher degrees of openness to foreign direct investment, lower tax rates on profits for all producers, and greater domestic TFP.

We find that adding technology capital transfer into a multicountry model with FDI flows

[11] If the only change between 1990 and 2007 had been increased appropriation, China's appropriated technology capital stock as a share of the total stock of technology capital employed in China would have increased. However, other policy changes lead to an influx of foreign capital and thus a decline in the share of technology capital in China owned—either directly or indirectly through appropriation—by the Chinese.

greatly enhances the model's ability to rationalize observed international capital flows. A country of interest has been China which is growing rapidly and shifting production from low-technology to high-technology manufactured goods. Since the early 1990s, China has adopted a number of policies that have greatly enhanced its openness to FDI. Ironically, these policies, while welfare improving for China, have resulted in China's becoming a country with relatively little home-grown technology capital.

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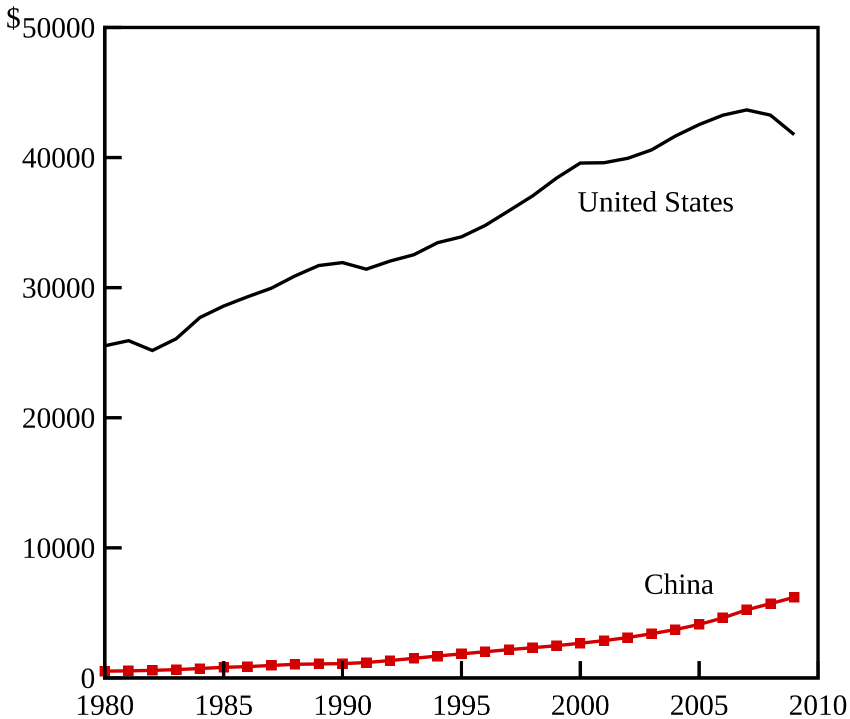

Figure 1A. Per Capita Real GDP in US and China

Source: World Development Indicators

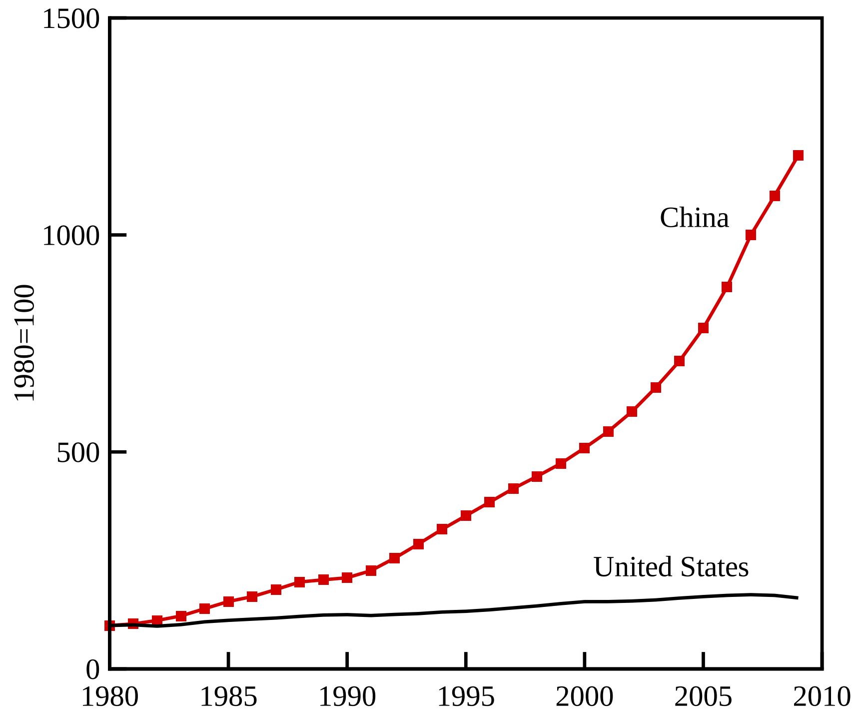

Figure 1B. Per Capita Real GDP Index in US and China

Source: World Development Indicators

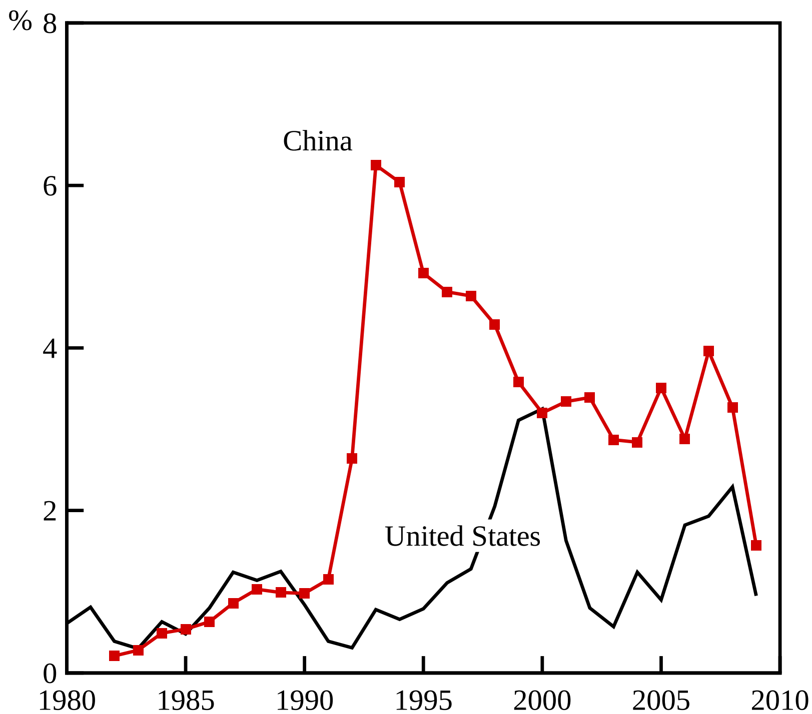

Figure 2. FDI Net Inflows to US and China (% of GDP)

Source: World Development Indicators

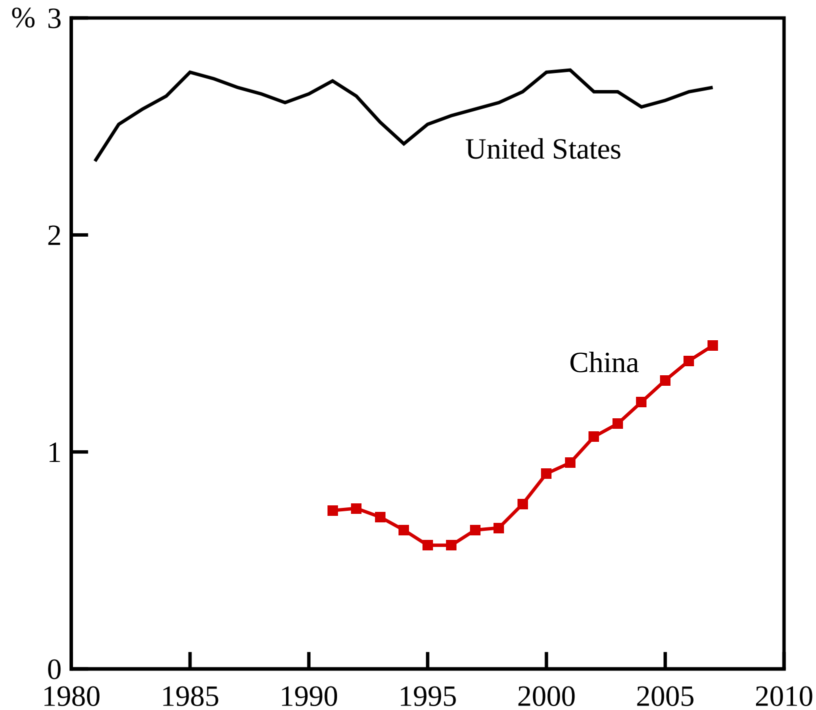

Figure 3A. R&D Expenditures in US and China (% of GDP)

Source: National Science Foundation

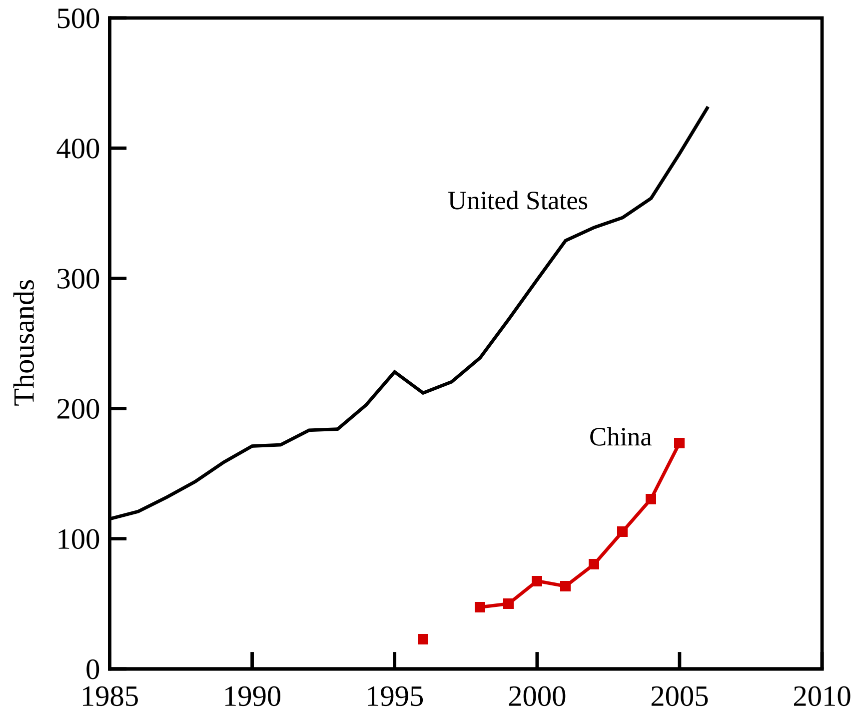

Figure 3B. Patent Applications in US and China

Source: World Development Indicators

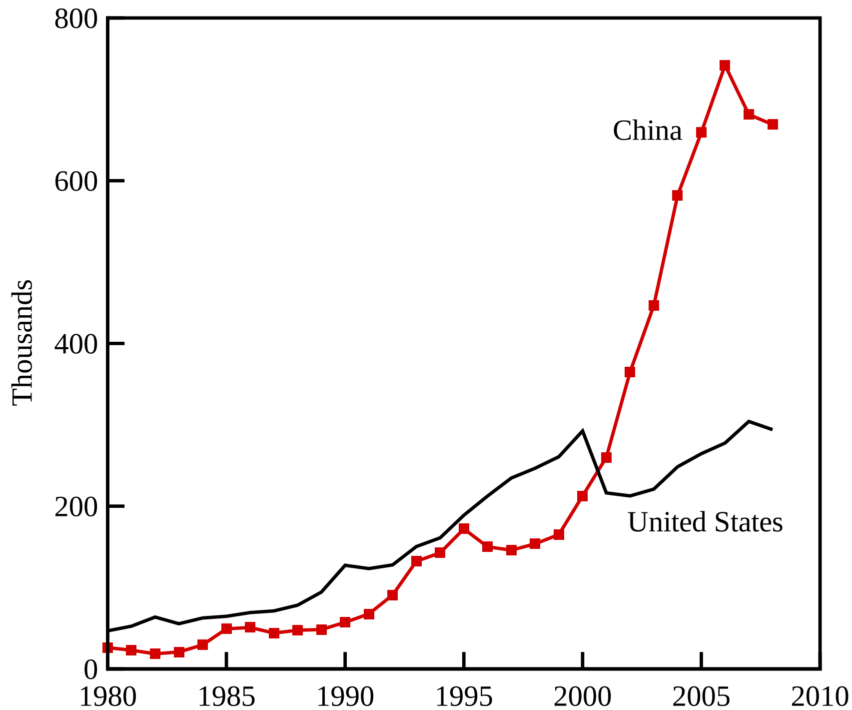

Figure 3C. Trademark Applications in US and China

Source: World Development Indicators

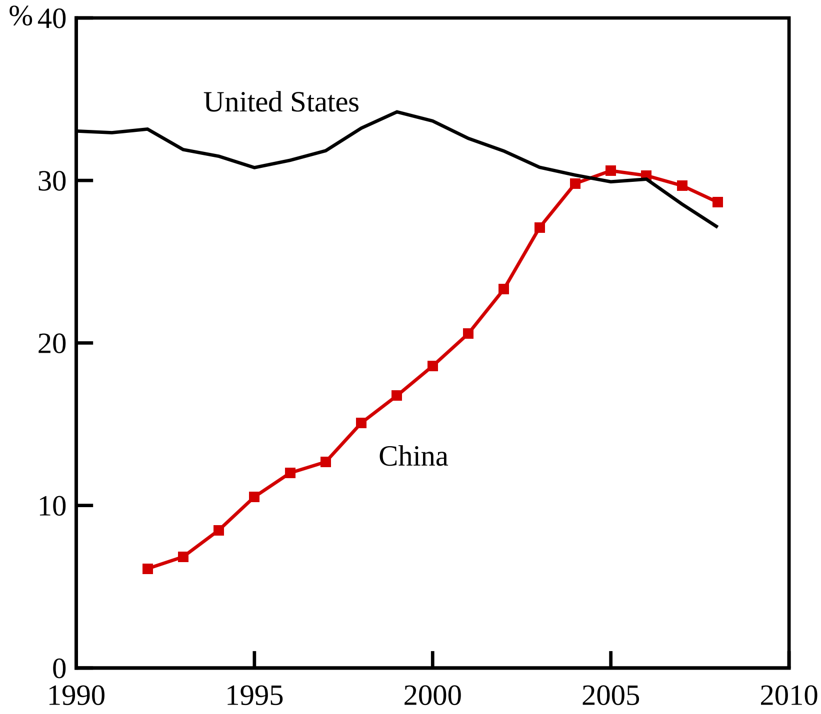

Figure 4A. High-Technology Exports in US and China (% of Manufacturing Exports)

Source: World Development Indicators

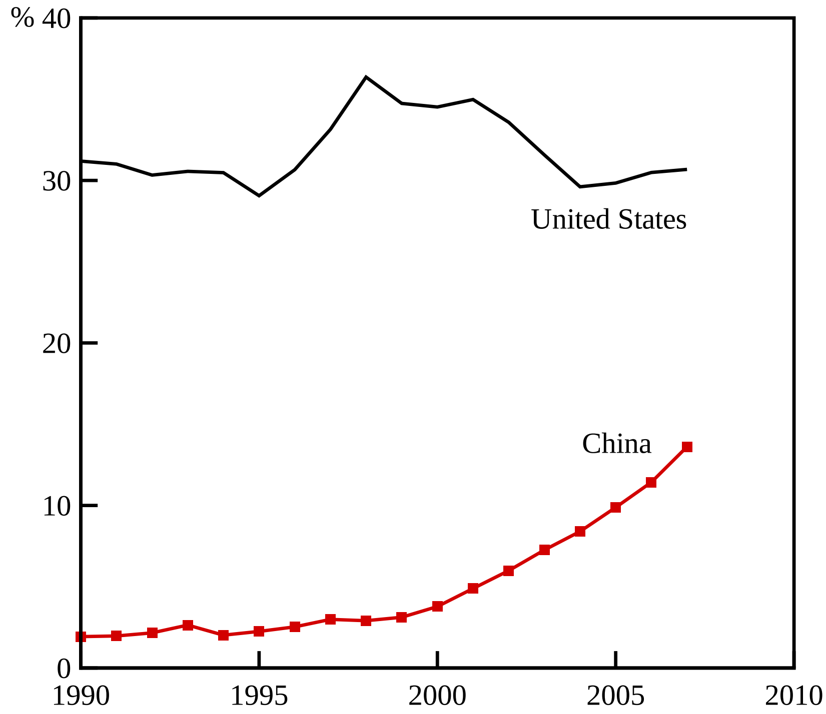

Figure 4B. High-Technology Value Added in US and China

(% of World's High-Technology Value Added)

Source: National Science Foundation

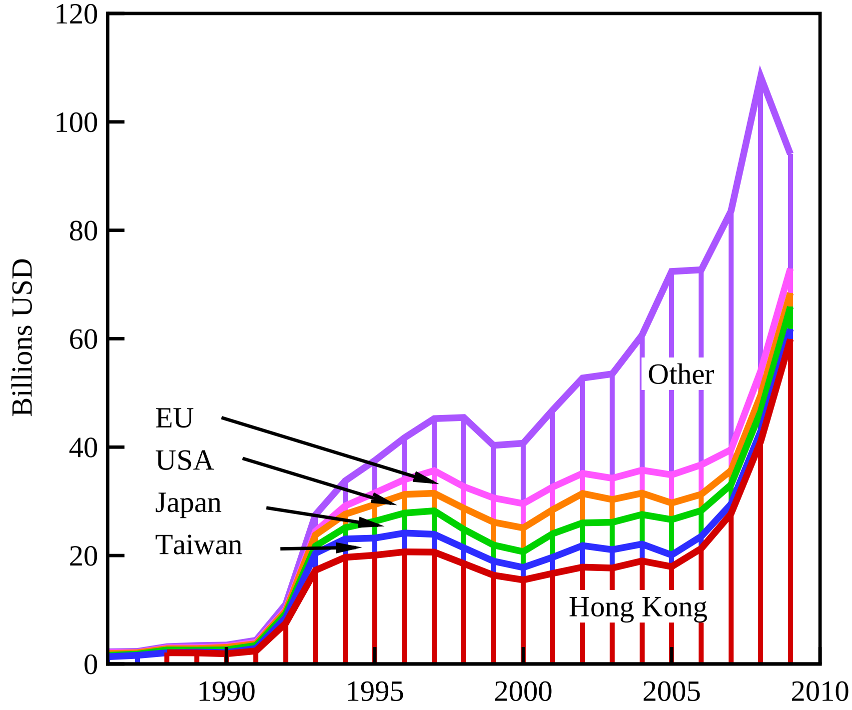

Figure 5. FDI Net Inflows to China by Source Country

Source: Chinese Statistical Yearbook

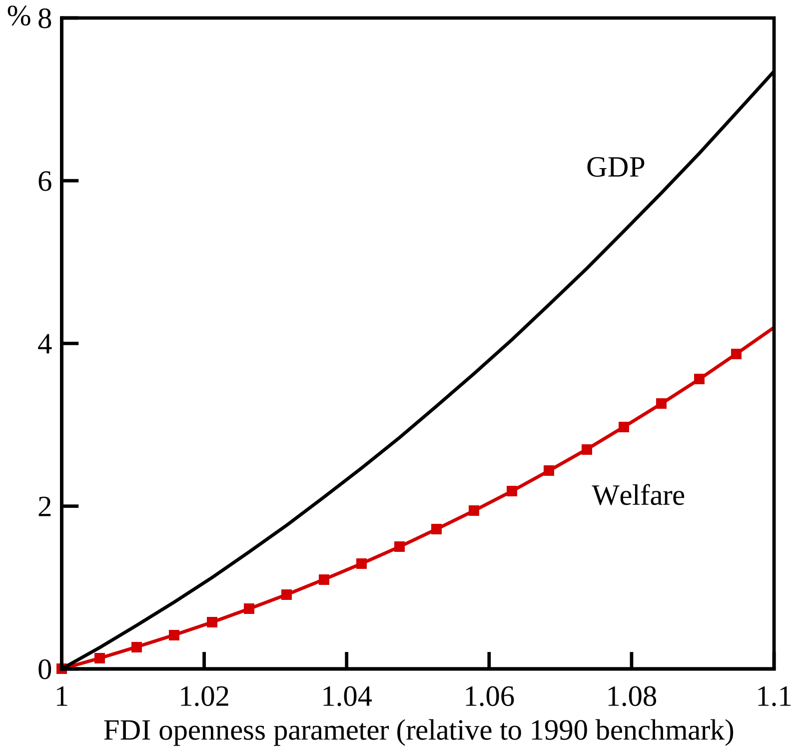

Figure 6A. Steady-state Welfare and GDP, Varying FDI Openness

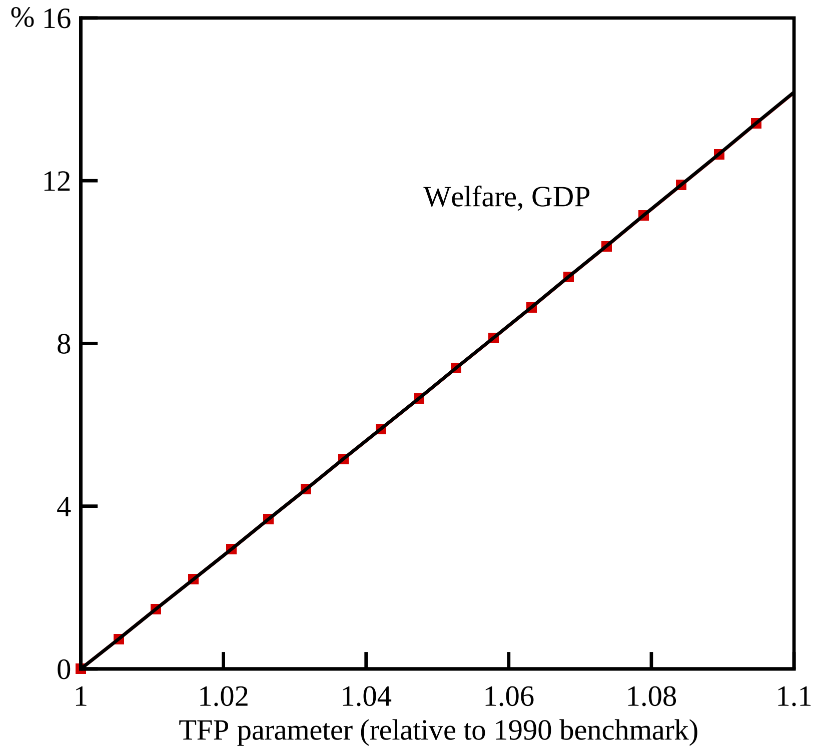

Figure 6B. Steady-state Welfare and GDP, Varying TFP

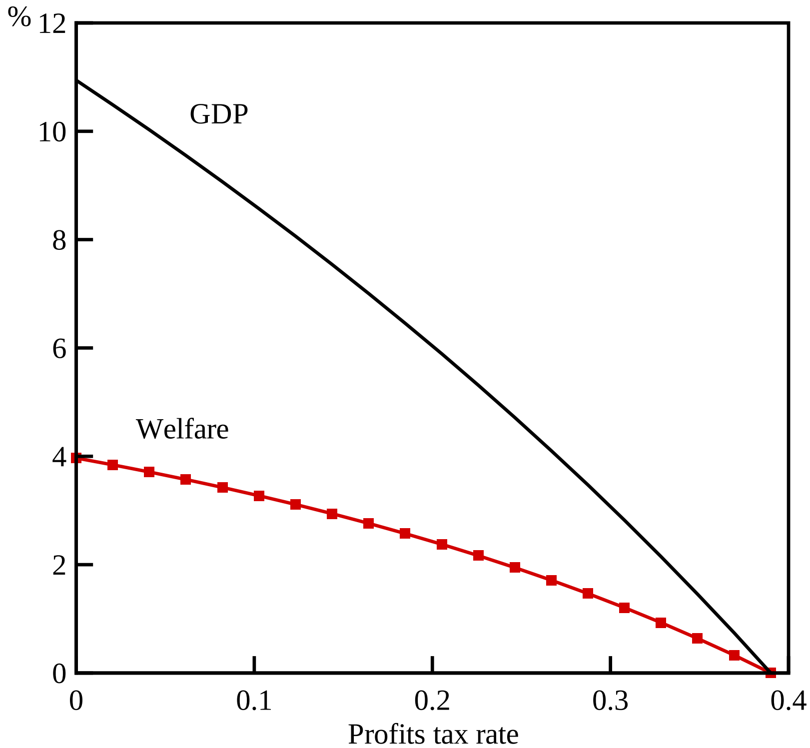

Figure 6C. Steady-state Welfare and GDP, Varying Profits Tax Rate

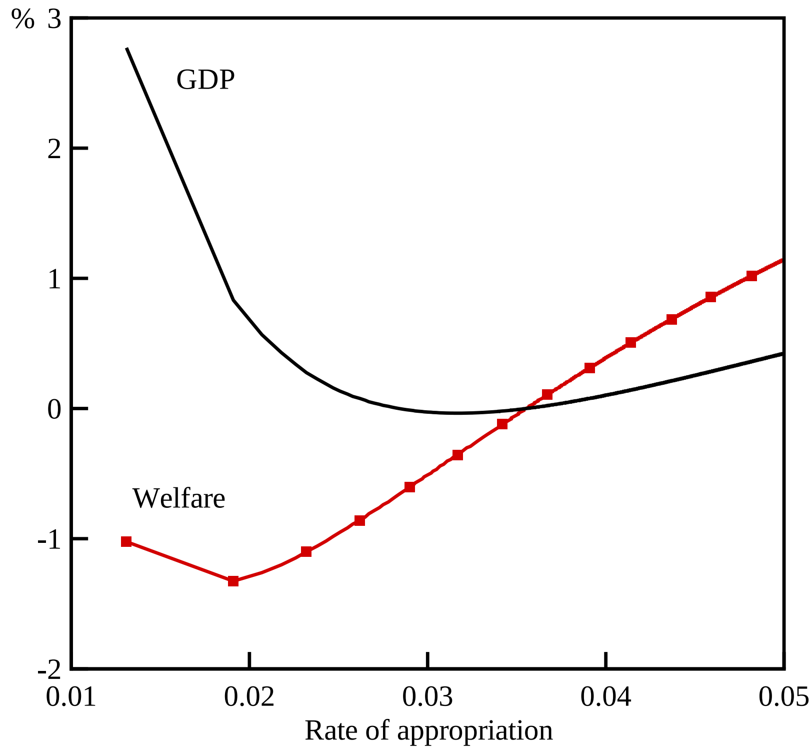

Figure 6D. Steady-state Welfare and GDP, Varying Appropriation Rate

Table 1. Model Parameters Common Across Countries

Parameter	Expression	Value
Preferences		
Discount factor	β	.98
Leisure weight	ψ	1.32
Growth Rates (%)		
Population	γ_N	1.0
Technology	γ_A	1.2
Income Shares (%)		
Technology capital	ϕ	7.0
Tangible capital	$(1-\phi)\alpha_T$	21.4
Plant-specific intangible capital	$(1-\phi)\alpha_I$	6.5
Labor	$(1-\phi)(1-\alpha_T-\alpha_I)$	65.1
Nonbusiness sector (%)		
Fraction of time at work	$\bar{L}_{nb}$	6
Investment share	$\bar{X}_{nb}/\text{GDP}$	15
Value-added share	$\bar{Y}_{nb}/\text{GDP}$	31
Depreciation Rates (%)		
Technology capital	δ_M	8.0
Tangible capital	δ_T	6.0
Plant-specific intangible capital	δ_I	0
Tax Rates (%)		
Labor wedge	τ_l	34
Dividends	τ_d	28

[a] These parameters are taken from McGrattan and Prescott's (2010) analysis of the U.S. current account.

Table 2. Cross-Country Data Used to Parameterize TFP, Openness

	Total Population (US=100)	Profits Tax Rate (Percent)	Inward FDI to GDP[a] (Percent)	Real GDP per capita[b] (US=100)
		1990		
United States	100.0	38.7	0.85	100.0
European Union	150.9	43.6	0.53	71.1
Japan	49.5	50.0	0.06	81.0
China & provinces	465.1	[c]39.0	0.87	7.2
Brazil-Russia-India	459.7	[c]39.0	0.08	11.3
Rest of World[d]	172.5	[c]25.0	1.57	23.4
		2007		
United States	100.0	39.3	1.58	100.0
European Union	134.4	31.8	1.46	54.4
Japan	42.4	39.5	0.45	72.0
China & provinces	447.0	15.0	1.55	19.2
Brazil-Russia-India	483.0	[c]25.0	2.07	12.1
Rest of World[d]	182.9	[c]25.0	2.90	27.4

[a] Excludes FDI from Caribbean islands.

[b] Reported in 1990 U.S. dollars, converted at Geary-Khamis PPPs.

[c] Authors' estimates.

[d] Includes non-Caribbean countries not elsewhere listed with FDI into China in excess of 0.1 billion U.S. dollars, namely, Australia, Bahrain, Canada, Macao, Indonesia, Korea, Malaysia, Mauritius, Philippines, Samoa, Saudi Arabia, Singapore, and Thailand.

Table 3. TFP (A) and Openness (σ) in Three Versions of the Model[a]

	No Transfers		Only Appropriation		Spillovers & Appropriation	
	A	σ	A	σ	A	σ
				1990		
United States	1.00	0.84	1.00	0.86	1.00	0.86
European Union	0.79	0.83	0.79	0.85	0.79	0.85
Japan	0.95	0.66	0.95	0.68	0.95	0.68
China & Provinces	0.16	0.77	0.15	0.89	0.15	0.89
Brazil-Russia-India	0.22	0.68	0.21	0.74	0.22	0.74
Rest of World	0.36	0.81	0.35	0.83	0.36	0.82
				2007		
United States	1.00	0.90	1.00	0.92	1.00	0.92
European Union	0.65	0.87	0.65	0.89	0.65	0.89
Japan	0.88	0.77	0.88	0.79	0.88	0.78
China & Provinces	0.30	0.87	0.29	0.93	0.29	0.93
Brazil-Russia-India	0.22	0.86	0.21	0.97	0.21	0.97
Rest of World	0.39	0.87	0.38	0.96	0.38	0.97

[a] Inputs chosen to align inward FDI to GDP and real GDP per capita in the model with values in Table 1.

Table 4A. Inward FDI Relative to GDP (in Percent), by Country, 1990

	FDI Hosts			
Source of FDI[a]	United States	European Union	Japan	China & Provinces
Data				
US+EU+JP	0.70	0.31	0.05	0.62
CHT+BRI	0.01	0.00	0.00	0.00
ROW	0.13	0.22	0.01	0.25
Total	0.85	0.53	0.06	0.87
Model without Transfers				
US+EU+JP	0.48	0.28	0.04	0.63
CHT+BRI	0.28	0.19	0.02	0.16
ROW	0.08	0.06	0.01	0.07
Total	0.85	0.53	0.06	0.87
Model with Appropriation[b]				
US+EU+JP	0.71	0.44	0.05	0.61
CHT+BRI	0.01	0.01	0.00	0.01
ROW	0.13	0.09	0.01	0.25
Total	0.85	0.53	0.06	0.87
Model with Spillovers and Appropriation[b]				
US+EU+JP	0.72	0.44	0.05	0.62
CHT+BRI	0.00	0.00	0.00	0.00
ROW	0.12	0.09	0.01	0.25
Total	0.85	0.53	0.06	0.87

[a] US+EU+JP combines FDI from United States, the European Union and Japan; CHT+BRI combines FDI from China and its provinces, Brazil, Russia, and India; and ROW is FDI from rest of world as defined in Table 1 footnotes.

[b] The additional parameter introduced in the models with appropriation is chosen to match the actual inward FDI from ROW to China relative to GDP in China, which is equal to 0.25 percent. The parameter is held fixed when spillovers are turned off.

Table 4B. Inward FDI Relative to GDP (in Percent), by Country, 2007

	FDI Hosts			
Source of FDI[a]	United States	European Union	Japan	China & Provinces
Data				
US+EU+JP	0.97	1.08	0.34	0.55
CHT+BRI	0.01	0.01	0.01	0.00
ROW	0.59	0.37	0.10	1.00
Total	1.58	1.46	0.45	1.55
Model without Transfers				
US+EU+JP	0.78	0.77	0.25	1.22
CHT+BRI	0.68	0.59	0.17	0.23
ROW	0.11	0.10	0.03	0.11
Total	1.58	1.46	0.45	1.55
Model with Appropriation[b]				
US+EU+JP	1.07	1.02	0.32	0.58
CHT+BRI	0.00	0.00	0.00	0.00
ROW	0.51	0.44	0.13	0.97
Total	1.58	1.46	0.45	1.55
Model with Spillovers and Appropriation[b]				
US+EU+JP	1.03	1.00	0.31	0.56
CHT+BRI	0.00	0.00	0.00	0.00
ROW	0.55	0.46	0.13	1.00
Total	1.58	1.46	0.45	1.55

[a] US+EU+JP combines FDI from United States, the European Union and Japan; CHT+BRI combines FDI from China and its provinces, Brazil, Russia, and India; and ROW is FDI from rest of world as defined in Table 1 footnotes.

[b] The additional parameter introduced in the models with appropriation is chosen to match the actual inward FDI from ROW to China relative to GDP in China, which is equal to 1.0 percent. The parameter is held fixed when spillovers are turned off.

Table 5. Patent Counts in the Automobile Industry

	Chinese Patent Count, 2000-10	Worldwide Counts in WIPO Database
Multinational firms		
Toyota	4,869	20,623
Honda	2,643	10,991
General Motors	1,858	3,991
Nissan	1,371	6,991
Hyundai	1,167	
Ford	942	3,317
Volkswagen	328	3,854
Mazda	286	1,425
Daimler	155	5,291
Suzuki	98	244
BMW	4	307
Total	13,721	55,258
Joint-Venture Chinese firms		
China Chana	540	7
Dongfeng	182	5
First Auto Work	176	1
Shanghai Auto	160	4
Brilliance	11	0
Beijing Auto	7	0
Total	1,076	17
Independent Chinese firms		
BYD	2,031	458
Chery	1,385	90
Geely	163	25
Great Wall	12	4
Anhui Jac	11	0
Total	3,602	577
Grand Total	26,829	55,852

[a] Chinese patent counts include only invention patents.

[b] WIPO patent counts include patents filed as part of the Patent Cooperation Treaty (PCT) over the period 1978-2011. A particular PCT patent would typically have coverage in numerous countries, but only shows up once in the above count. The WIPO data also includes data from the European Patent Office and twenty-five additional countries. It does not include data from the United States or Japan.

Table 6. Predictions of Model with Spillovers and Appropriation

	Investment (%, Rel. to US)	Investment (%, Rel. to GDP)	Technology Capital: Own Stock (Rel. to GDP)	Technology Capital: Appropriated (Rel. to GDP)	Technology Capital: In Economy (Rel. to GDP)
1990					
United States	100.0	4.7	0.57	0.00	0.72
European Union	125.5	5.4	0.67	0.00	0.78
Japan	63.6	7.4	0.87	0.00	0.88
China & provinces	0.0	0.0	0.00	1.11	1.46
Brazil-Russia-India	0.2	0.0	0.00	0.72	0.74
Rest of World	33.9	3.9	0.45	0.00	0.71
2007					
United States	100.0	5.1	0.63	0.00	1.05
European Union	80.6	5.6	0.68	0.00	1.05
Japan	65.2	10.8	1.28	0.00	1.44
China & provinces	0.0	0.0	0.00	0.54	0.85
Brazil-Russia-India	0.0	0.0	0.00	0.79	1.61
Rest of World	74.0	7.5	0.94	0.00	2.78