Technology Spillover from International Flows: Imports, Foreign Direct Investment and Immigration

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Abstract

This paper examines the externalities that accrue to the United States of America when the trading-partner sample of 19 countries increases Research and Development (R&D) expenditures. Three channels of foreign technology transfer analyzed through international inflows include imports, Foreign Direct Investment (FDI) and immigration. Through these channels, foreign technology affects domestic Total Factor Productivity (TFP), calibrated using Newey-West estimation. We examine the effects of domestic expenditures on Basic, Applied and Experimental R&D on TFP. Empirical results reveal that immigration and imports are channels of transfer of foreign technology. It is also found that domestic expenditures in Basic and Experimental research enhance the level of technology. Thus, the type of research expenditures matters in altering the level of technology.

Keywords: Technology Spillover, International R&D, Total Factor Productivity

JEL Classification: F21, F22

1 Introduction

Domestic output depends on investment that improves technology. Foreign transfer of technology is transmitted through international flows of goods, labor and investment represented by imports, immigration and Foreign Direct Investment (FDI), respectively. The process of technology spillover has been explored in previous literature. First, imports of consumption and intermediate goods elicit a learning process by domestic firms and may result in higher levels of technology (Keller and Yeaple 2009). Imports also compete with domestically produced goods and services. Competition leads to innovation in search of least cost methods of production. Low productivity firms will exit the market if they are unable to compete and high productivity firms will remain but become even more productive (Blalock and Veloso 2007). Imported intermediate capital inputs produced with high levels of technology improve production processes for final goods (Keller 2002). Second, subsidiaries of multinational firms may employ technology that is transferred from parent firms (Markusen and Maskus 2001). Interactions with domestic firms may foster flow of methodologies and knowledge from human capital. These subsidiaries may also import a new set of intermediate goods that are produced with high levels of technology (Rodriguez-Clare 1996). Competition between foreign-owned firms and domestic firms reduces cost of production through innovation (Seck 2011). Finally, immigration facilitates direct transfer of human capital if immigrants are highly skilled (Hanson 2011). Immigrants who are less educated than the general population are often crowded in unskilled employment leaving natives to specialize in skilled employment; specialization generates gains that result in increased output (Peri 2009). Immigrants accept lower wages than natives with similar skills due to lower levels of bargaining power. Lower wage cost decreases overall cost of production for firms (Peri

2012) and increases their capacity to hire additional labor units (Ottaviano, Peri and Wright 2010).

The present study addresses problems identified in previous literature on foreign technology spillover and introduces categorization of domestic expenditures on Research and Development (R&D). First, there have been studies that model or estimate the effect of foreign technology through imports only (Coe and Helpman 1995, Edmond 2001, Funk 2001), FDI only (Koizumi and Kopecky 1977, Das 1987, Campos and Kinoshita 2002, Zhao and Zhang 2007), both imports and FDI (Keller and Yeaple 2009) and immigration only (Peri 2009, Peri 2012) but not all three channels. Second, in previous literature, some authors use multi-country models that suggest homogeneity in spillover effects for all countries or firms in samples. However, it has been shown by Luintel and Khan (2003) that estimates from single-country studies suggest heterogeneous spillover effects. Finally, there are differences in measurement of foreign stock of R&D. While Coe and Helpman (1995) use bilateral import share of total imports as weights in the construction of foreign stock of R&D, Edmond (2001) shows that simple sums and random weights yield spillover effects that may even be higher.

This paper considers all three international flows - imports, FDI and immigration - as channels of technology transfer in a single-country model, and domestic technology, measured by Total Factor Productivity (TFP). The country of choice is the United States of America, and its international flows from 19 countries are analyzed. Solow (1957) discovered that residuals derived from determination of output are an important determinant of growth for the United States. TFP is defined by Comin (2006) as variation in output that is not attributable to changes in inputs and is proxied by Solow's residual. The use of TFP as proxy for technology is based on its assumed definition as "…a measure of technical progress," (Ray 1998) and "…a contribution to technical progress" (Acemoglu 2009). R&D stock is measured using the perpetual inventory method (Bitzer and Kerekes 2005; Cato and Suzuki 1989; Hall and Mairesse 1995) and is unweighted following Edmond (2001). Domestic R&D stock is categorized into Basic, Applied and Experimental to assess the impact of different types of domestic R&D on TFP.

Results from Generalized Least Squares (GLS) estimation indicate that imports and immigration add to TFP while FDI does not increase productivity. Second, immigration has a larger spillover effect than imports. Third, domestic expenditures in Basic and Experimental research increase productivity; there is a negative correlation between Applied R&D expenditures and TFP. The type of domestic research expenditure matters in impacting productivity.

The next section presents literature on international technology spillover. Research questions are outlined in Section 3. Section 4 presents the theoretical framework within which the model determining TFP is discussed. In Section 5, we describe the econometric model used in estimation, data and their sources, tests of data, choice of estimation methods and results. Section 6 presents the conclusion of the analysis and section 7 offers recommendations for policy.

2 Literature

There are studies that assess spillover effects of foreign technology on output under the assumption that spillover effects increase output. For instance, Tong (2001) studies how technology is transferred through FDI to Chinese firms using data from a World Bank (WB) survey conducted in 1993. One of the regressands is total output for firms in the sample. Evenson and Singh (1997) analyze the relationship between domestic output and foreign R&D through imports for 11 Asian countries from 1970 to 1993. Other studies that use output as their regressand in estimation are Kolesnikova and Tochitskaya (2008), Campos and Kinoshita (2002), and Hu, Jefferson and Jinchang (2005). Sinani and Meyer (2004) use sales growth as the regressand in empirical analysis of technology transfer to Estonian firms from 1994 to 1999 through FDI.

Other studies investigate spillover effects by modeling or testing the relationship between TFP and foreign technology weighted by international flows. Solow's residual is used as proxy for technology in these papers and it is determined by investment that increases productivity such as domestic and foreign expenditures in R&D. Coe and Helpman (1995) estimate spillover effects of foreign capital on domestic TFP for 22 countries. The authors measure growth of TFP by taking the difference between growth of output and growth of inputs; growth of inputs are weighted by output elasticities of inputs. Edmond (2001) and Luintel and Khan (2003) add to Coe and Helpman's model and thus employ the same regressand in estimation. Luintel and Khan (2003) aver that Coe and Helpman (1995) implicitly assume homogeneity in technology transfer to countries and provide evidence for the alternative hypothesis. Funk (2001) uses cointegration techniques to assess how international R&D affects TFP based on Kao and Chiang (1998) and

Kao (1999). TFP, by definition in literature, is a better proxy for technological progress than domestic output.

Some studies analyze technology spillover with multi-country or multi-firm models. Tong (2001) uses a sample of 500 firms. Coe and Helpman (1995) use a sample of 21 OECD countries and Israel. Edmond (2001) performs panel cointegration tests from Pedroni (1997, 1998) on the same data used by Coe and Helpman (1995). Luintel and Khan (2003) use a sample of 10 OECD countries. However, Luintel and Khan (2003) assert that elasticities of TFP with respect to domestic and foreign stocks of R&D differ in their effect on countries and cannot be analyzed using pooled data. Single-firm or single-country studies relax the assumption of similar technology spillover effects. Such studies include Caves (1974). Caves (1974) estimates positive spillover effects of FDI on productivity using 23 firms in Canada's manufacturing industry in 1966. Blomstrom and Persson (1983) estimate positive spillover effects of FDI on labor productivity in Mexico. Keller and Yeaple (2009) investigate the impact of imports and FDI on productivity of firms in the United States. This study uses a single-country model.

Previous studies make references to one or two channels of international technology spillover possibly allowing for omitted variable bias. Studies that consider imports only as a channel of transmission include Coe and Helpman (1995), Edmond (2001), Funk (2001) and Luintel and Khan (2003). Studies that consider FDI only as a channel of international technology transfer include Koizumi and Kopecky (1977), Das (1987) Campos and Kinoshita (2002), Zhao and Zhang (2007), and Wang and Blomstrom (1992). Keller and Yeaple (2009) consider both imports and incoming FDI as carriers of foreign technology. Mariya and Tritah (2009), Peri (2009) consider immigration only in their analysis of technology transfer. This study uses all three channels.

There is some level of consensus in the use of cumulative expenditures in measuring stocks of foreign and domestic R&D. The perpetual inventory method is utilized by Bitzer and Kerekes (2005), Cato and Suzuki (1989), Hall and Mairesse (1995) and Evenson and Singh (1997) among others to account for the loss in value attributable to depreciation since R&D is considered as investment. Nevertheless, there are different opinions about the measurement of the weights attached to foreign R&D stock. Coe and Helpman (1995) use bilateral import share in total imports as weights to calculate foreign R&D. Edmond (2001) uses alternative weights in addition to that used by Coe and Helpman (1995) and compares the results. The author follows Keller (1998) in utilizing the unweighted sum of R&D stock and then assigns randomized bilateral shares as weights. Using these measures in place of Coe and Helpman's (1995) measure yields parameter estimates that indicate higher spillover effects. This study uses unweighted stocks of foreign R&D expenditures.

While some studies find positive spillover effects through international flows, others find either no effect or negative effects. In the case of imports, Coe and Helpman (1995) find that as the share of imports in output increases, foreign R&D has a higher positive effect. Edmond (2001) confirms results of Coe and Helpman (1995) but asserts that when countries are allowed to differ in effect of foreign R&D, the effect through imports is less robust and unstable using other estimation methods. Luintel and Khan (2003) have mixed results. The authors use R&D without weights and find positive spillover effects for 7 countries. There are negative effects of foreign R&D on productivity in United States, confirming the results of Bernstein and Mohnen (1998) and Blonigen and Slaughter (2001), but insignificant for Denmark and Germany. Using import shares of output as weights for foreign R&D yields positive effects for 7 countries, negative for United States and insignificant for Denmark and Japan. Funk (2001) finds that the definition of weights employed in construction of foreign R&D affects spillover effects, and there is no evidence of spillover effects from imports. Effects of FDI are mixed. Aitken and Harrison (1999) estimate positive spillover effects through FDI for Venezuelan firms. Positive spillover effects accrue to U.S. manufacturing firms (Keller and Yeaple, 2009). Campos and Kinoshita estimate positive effects for 25 transition economies in Europe and the former Soviet Union. However, Kolesnikova and Tochitskaya (2008) investigate spillover effects for 2000 firms in Belarus from 1998 to 2006 and are unable to estimate any spillover effects from FDI. The authors find that firms that receive FDI tend to be more capital intensive and export more than firms that do not receive FDI, but the presence of FDI does not add to technology. Studies of immigration too produce mixed effects. Mariyah and Tritah (2009) categorize immigrants by age and skill level and estimate mixed effects on TFP for 20 OECD economies from 1960 to 2005. They address other regressands which are not described in this paper since the focus is on TFP. Aggregate immigration produces positive spillover effects. By age, those between 15 and 24 years, 25 and 54 years, and 55 and 64 years have a negative effect, no effect and a positive effect, respectively. Results for unskilled individuals in these age groups yield similar results. Among skilled individuals, those between 15 and 24 years, 25 and 54 years have no effect, and those between 55 and 64 years have a negative effect on TFP. Peri (2009) estimate positive spillover effect through immigration for the United States from 1960 to 2006.

We consider issues identified by previous authors and make additions to literature.

3 Research Questions

Assumptions made in this paper and the choice of a model depends on previous literature and an attempt to fill a gap in estimation using all three channels of international flows. First, this paper follows suggestions made in previous literature by using a single-country model to relax the assumption of heterogeneity in effects on countries. Second, while this paper uses TFP to measure domestic technology, it uses imports, incoming FDI and immigration to cover all international inflows. An issue that has not been discussed in previous literature concerns the categorization of domestic R&D and how the different functions of research affect productivity. To uncover the role of international flows in technology transfer to the United States, we ask:

1. Do immigration, incoming FDI and imports transfer technology from source countries to the United States?
2. What are the relative strengths of the technological spillovers enabled by immigration, incoming FDI and imports, if any at all?
3. Does the effect of domestic R&D expenditures depend on the type of R&D considered?

To answer these questions, we derive a proxy for technological progress - TFP - from the standard production function and determine TFP by domestic and foreign sources of technology. The next section discusses the theoretical framework within which TFP is determined.

4 Theoretical Framework and Econometric Model

Assume the existence of an aggregate production function with Hicks-Neutral technological change (Solow 1956) defined as

$$Y(t) = \Gamma(t)F[K(t), L(t)]\ ; t = 1,2,\cdots,T \qquad (1)$$

where *Y*= Output, $\Gamma(t)$ = Technology, *K(t)* = Capital, *L(t)* = Labor and *t* = Time. Hicks-Neutral technology dictates that relative input share remains constant given a particular input ratio; technology is output augmenting (Heijdra and Van der Ploeg 2002). A change in technology shifts the production function independent of any changes that may occur in labor and capital; technology is disembodied. Assume that technology is a public good – non-rival and non-exclusive. All firms have access to technology though in reality, the provision of patents can render technology rivaled and exclusive (Acemoglu 2009). Total differentiation of the production function with respect to time yields

$$\frac{dY(t)}{dt} = F[K(t), L(t)]\frac{d\Gamma(t)}{dt} + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial K(t)}\frac{dK(t)}{dt} + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial L(t)}\frac{dL(t)}{dt} \qquad (2)$$

From Equation 2, growth rates of output (g_Y), capital (g_K), labor (g_L) and technology (g_Γ) are defined as

$$g_Y = \frac{dY(t)}{dt}; g_K = \frac{dK(t)}{dt}; g_L = \frac{dL(t)}{dt}; g_\Gamma = \frac{d\Gamma(t)}{dt} \qquad (3)$$

Divide the left-hand side of Equation 2 by *1/Y(t)* and the three left-hand side terms by $\frac{\Gamma(t)}{Y(t)}$, $\frac{K(t)}{Y(t)}$ and $\frac{L(t)}{Y(t)}$, respectively,

$$\frac{1}{Y(t)}\frac{dY(t)}{dt} = F[K(t), L(t)]\frac{d\Gamma(t)}{dt}\frac{\Gamma(t)}{Y(t)} + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial K(t)}\frac{dK(t)}{dt}\frac{K(t)}{Y(t)} + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial L(t)}\frac{dL(t)}{dt}\frac{L(t)}{Y(t)}$$

(4)

From Equation 4,

$$F[K(t), L(t)]\frac{\Gamma(t)}{Y(t)} = 1 \tag{5}$$

To provide justification for Equation 5, we restate the production function,

$$Y(t) = \Gamma(t)F[K(t), L(t)] \tag{1}$$

Divide both sides of Equation 1 by $\Gamma(t)$ and $Y(t)$,

$$\frac{1}{\Gamma(t)} = \frac{F[K(t),L(t)]}{Y(t)} \tag{6}$$

Make $\Gamma(t)$ the subject of Equation 6 and Substitute in Equation 1,

$$\frac{1}{\Gamma(t)}\Gamma(t) = 1 \tag{7}$$

Since Equation 5 holds, substitution into Equation 4 yields the following function,

$$\frac{1}{Y(t)}\frac{dY(t)}{dt} = \frac{d\Gamma(t)}{dt} + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial K(t)}\frac{dK(t)}{dt}\frac{K(t)}{Y(t)} + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial L(t)}\frac{dL(t)}{dt}\frac{L(t)}{Y(t)} \tag{8}$$

Using Equations 3 and 8, we can state,

$$g_Y = g_\Gamma + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial K(t)}\frac{K(t)}{Y(t)}g_K + \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial L(t)}\frac{L(t)}{Y(t)}g_L \tag{9}$$

These are elasticities of output with respect to capital and labor from the second and third terms in Equation 8, respectively,

$$\theta_K = \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial K(t)}\frac{K(t)}{Y(t)}\,;\, \theta_L = \Gamma(t)\frac{\partial F[K(t),L(t)]}{\partial L(t)}\frac{L(t)}{Y(t)} \tag{10}$$

Substitution of factor share into Equation 10 provides the following relation,

$$g_Y = g_\Gamma + \theta_K g_K + \theta_L g_L \tag{11}$$

Branson, (1989) defines the growth rate of TFP as the difference in growth rates between output and factors of production, where factors of production are weighted by elasticities of output with respect to inputs,

$$g_\Gamma = g_Y - \theta_K g_K - \theta_L g_L = \Psi \tag{12}$$

The stock of TFP is derived by taking anti-logarithm of g_Γ,

$$TFP_t = e^{g_{\Gamma(t)}} \tag{13}$$

In previous literature, TFP is often defined in theory as technology, and in estimation, is determined by cumulative R&D expenditures (Luintel and Khan 2003; Funk 2001; Edmond 2001). In previous literature, authors posit that while domestic investments in R&D affect TFP, foreign R&D expenditures may affect TFP through international flows (Coe and Helpman 2005, Keller and Yeaple 2009, Peri 2009). In estimation, elasticities are measured by estimation of Equation 11, extraction of residuals using Equation 12 and application Equation 13 to the result. TFP is an index and does not lend itself to comparison. Multi-country models use growth of TFP. This paper does not compare TFP levels across countries and uses the level of TFP for the USA only.

In Figure 1, domestic and foreign technology stocks are measured by expenditures on research and development. Domestic R&D expenditures (Ω_{it}) are categorized into Basic, Applied and Experimental. The effect of imports (*M*) depends on the share of imports in domestic output. The spillover effect through FDI inflows (Λ) depends on FDI inflow's share in domestic investment (I). The strength of immigration (Ξ) as a channel of transfer of foreign technology depends on the share of immigrants in total population (*P*). For all three channels, increases in relative shares may increase the impact of foreign technology on domestic technology.

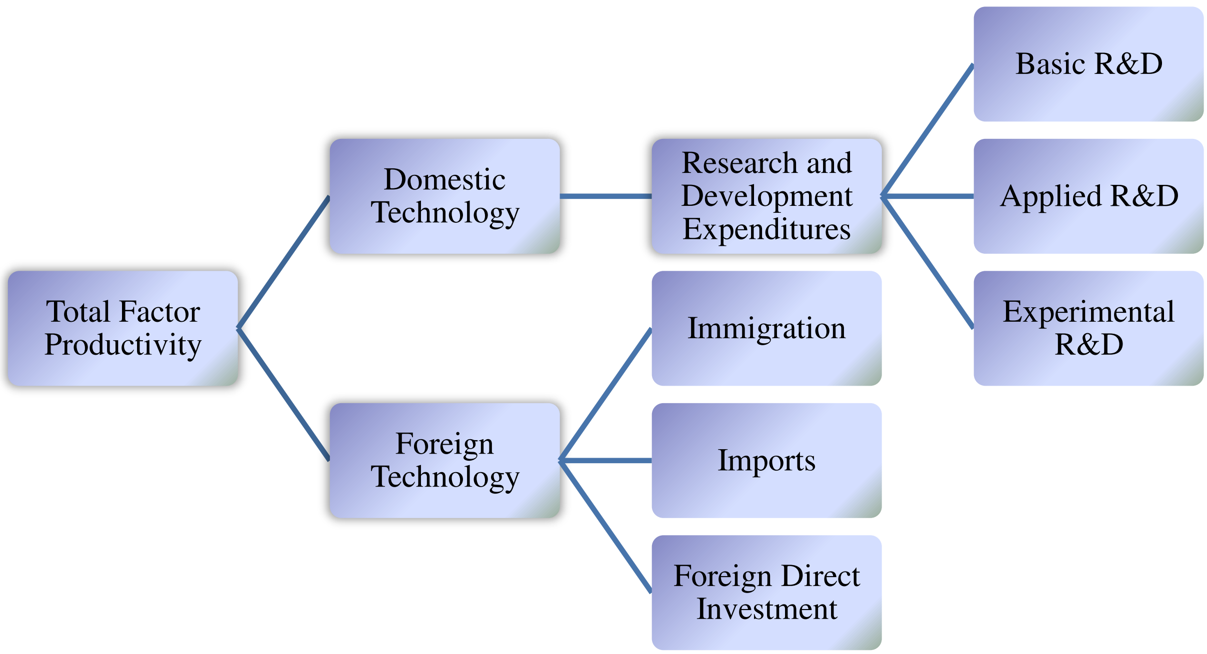

Figure 1: Map of Determinants of Total Factor Productivity

Determination of the effect through these channels is presented in the econometric model below as interactions between relative shares and foreign stock of R&D (Ω_{jt}),

$$\Psi_{it} = \varphi_0 + \varphi_1 \frac{M_{jt}}{Y_{it}} \Omega_{jt} + \varphi_2 \frac{\Xi_{jt}}{P_{it}} \Omega_{jt} + \varphi_3 \frac{\Lambda_{jt}}{I_{it}} \Omega_{jt} + \varphi_4 \frac{M_{jt}}{Y_{it}} + \varphi_5 \frac{\Xi_{jt}}{P_{it}} + \varphi_6 \frac{\Lambda_{jt}}{I_{it}} + \varphi_7 \Omega_{jt} + \varphi_8 \Omega_{it} + \varepsilon_t \quad (14)$$

where i = home country, j = foreign country. We test the following hypotheses:

$$H_0: \frac{\partial \Psi_{it}}{\partial \Omega_{it}} = \varphi_8 = 0 \quad (15)$$

$$H_A: \frac{\partial \Psi_{it}}{\partial \Omega_{it}} = \varphi_8 \neq 0$$

$$\text{H}_0\text{: } \frac{\partial \Psi_{it}}{\partial \frac{M_{jt}}{Y_{it}} \Omega_{jt}} = \varphi_1 = 0 \quad (16)$$

$$\text{H}_\text{A}\text{: } \frac{\partial \Psi_{it}}{\partial \frac{M_{jt}}{Y_{it}} \Omega_{jt}} = \varphi_1 \neq 0$$

$$\text{H}_0\text{: } \frac{\partial \Psi_{it}}{\partial \frac{\Xi_{jt}}{P_{it}} \Omega_{jt}} = \varphi_2 = 0 \quad (17)$$

$$\text{H}_\text{A}\text{: } \frac{\partial \Psi_{it}}{\partial \frac{\Xi_{jt}}{P_{it}} \Omega_{jt}} = \varphi_2 \neq 0$$

$$\text{H}_0\text{: } \frac{\partial \Psi_{it}}{\partial \frac{\Lambda_{jt}}{I_{it}} \Omega_{jt}} = \varphi_3 = 0 \quad (18)$$

$$\text{H}_\text{A}\text{: } \frac{\partial \Psi_{it}}{\partial \frac{\Lambda_{jt}}{I_{it}} \Omega_{jt}} = \varphi_3 \neq 0$$

We calculate stocks of R&D using the Perpetual Inventory Method. The first year used in analysis represents initial investment in R&D. Previous expenditures depreciate at a rate, δ. There are R&D expenditures accumulated in the current year which are a proportion, α, of the previous period's R&D expenditures. Taking into account the rate at which R&D expenditures depreciate, we calculate R&D stock as

$$\Omega_t = \Omega_{t-1} + \alpha\Omega_{t-1} - \delta\Omega_{t-1} \quad (19)$$

$$\Omega_t = (1 + \alpha - \delta)\Omega_{t-1} \quad (20)$$

The next section presents summary statistics, tests of models to be estimated and results from estimation.

5 Data and Results

5.1 Data

The focus of our analysis is the United States We use 19 countries from which imports, FDI and migrants originate. The channels of transmission are bilateral flows from 1997 to 2006 totaling 190 observations in the sample. Table 1 presents summary statistics on data used to calibrate and estimate TFP. Data used in calibrating TFP for the United States are growth of real output (GDP), real capital (Gross Capital Formation) and labor (Number of people Employed) from 1949 to 2009. Statistics for growth of output, capital and labor are provided by the Bureau of Economic Analysis (BEA), the United Nations (UN) and the Bureau of Labor Statistics (BLS), respectively. Output grows at a faster rate than capital and at a slower rate than labor. The rest of the variables described in Table 1 are available from 1997 to 2006. Domestic R&D expenditures (for the United States) are categorized as Basic, Applied or Experimental by the United Nations Educational and Scientific Organization (UNESCO) drawing on definitions provided by the Organization of Economic Co-operation and Development (OECD) and are discounted by the Consumer Price Index (CPI) for the United States with 2005 as the base year. Basic R&D expenditures are those expenditures that are made to assist in acquisition of novel knowledge without definition of a particular goal. Applied R&D expenditures are also applied to acquire new knowledge but towards the attainment of a defined goal. Experimental R&D expenditures utilize existing knowledge to develop or improve goods, services and processes (OECD 2002). The three categories are discounted by the Consumer Price Index of the United States to obtain real values.

Table 1: Summary Statistics

Variables	Mean	Standard Deviation	Minimum	Maximum
Output Growth (%)	3.2393	2.5140	-3.5	8.7
Capital Growth (%)	6.6508	6.2254	-15.1336	20.3554
Labor Growth (%)	1.7902	2.1201	-4.4	5.8
Real Applied $R\&D^D$ Stock (Trillions)	1,170,000	236,000	568,000	1,390,000
Real Basic $R\&D^D$ Stock (Trillions)	951,000	204,000	451,000	1,120,000
Real Experimental $R\&D^D$ Stock (Trillions)	3,320,000	605,000	1,570,000	3,820,000
Real Foreign R&D Stock (Trillions)	3,540	5,340	134	26,900
Imports/Output	0.0047	0.0061	0.0001	0.0236
Immigrants/Population	0.0031	0.0073	0.0001	0.0359
FDI/Investment	0.0033	0.0072	-0.0023%	0.0574

The United States invests more in Experimental R&D than Basic and Applied R&D. Data on foreign R&D expenditures are obtained from the World Development Indicators (WDI) created by the World Bank (WB) are discounted by each country's CPI with 2005 as the base year. Imports are bilateral in nature, weighted by the CPI and obtained from the Correlates of War

Project Trade Data Set (COW). Bilateral migration data are compiled every decade by the World Bank and recorded in the Global Bilateral Migration Database. Using data from 1990, 2000 and 2010, we interpolate values and extract data from 1997 to 2006. Data on population of the United States are obtained from the WDI. The OECD provides data on bilateral FDI flows from the 19 countries to the United States. Inflow of FDI measures "net increases in liabilities" according to the United Nations Conference on Trade and Development (UNCTAD); therefore, negative FDI inflows indicate that either "equity capital, reinvested earnings or intra-company loans" is negative, representing disinvestment.

Figure 2 shows the trends of the components of real domestic stocks of R&D. Real Experimental R&D stock is quite stable other than the initial rise from 1997 to 1998 and is higher than other forms of R&D stocks.

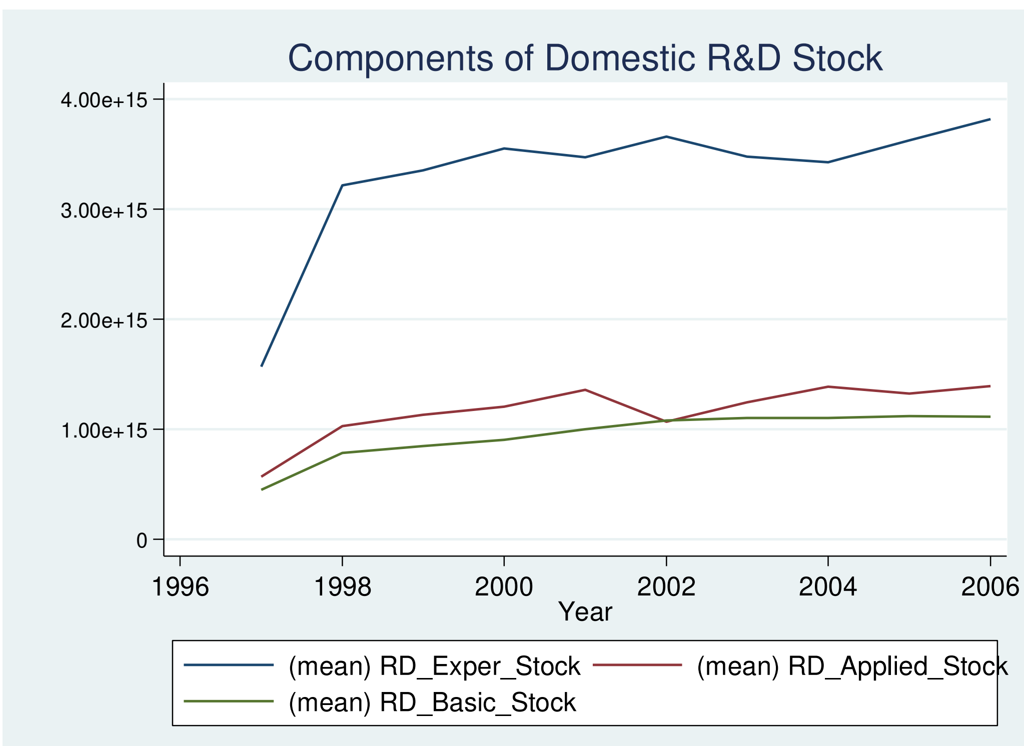

Figure 2: Components of Real Domestic Stocks of R&D

Real Applied and Experimental R&D stocks are lower and quite stable over the period under consideration. In Figure 3, share of bilateral imports in domestic output and share of immigration in domestic population are more stable than share of real inward FDI in real domestic investment. Share of real inward FDI in real investment rises from 1997 to 1999, stays somewhat stable in 2000, decreases sharply in 2001, reaches a trough in 2003 and climbs unsteadily from 2003 to 2006.

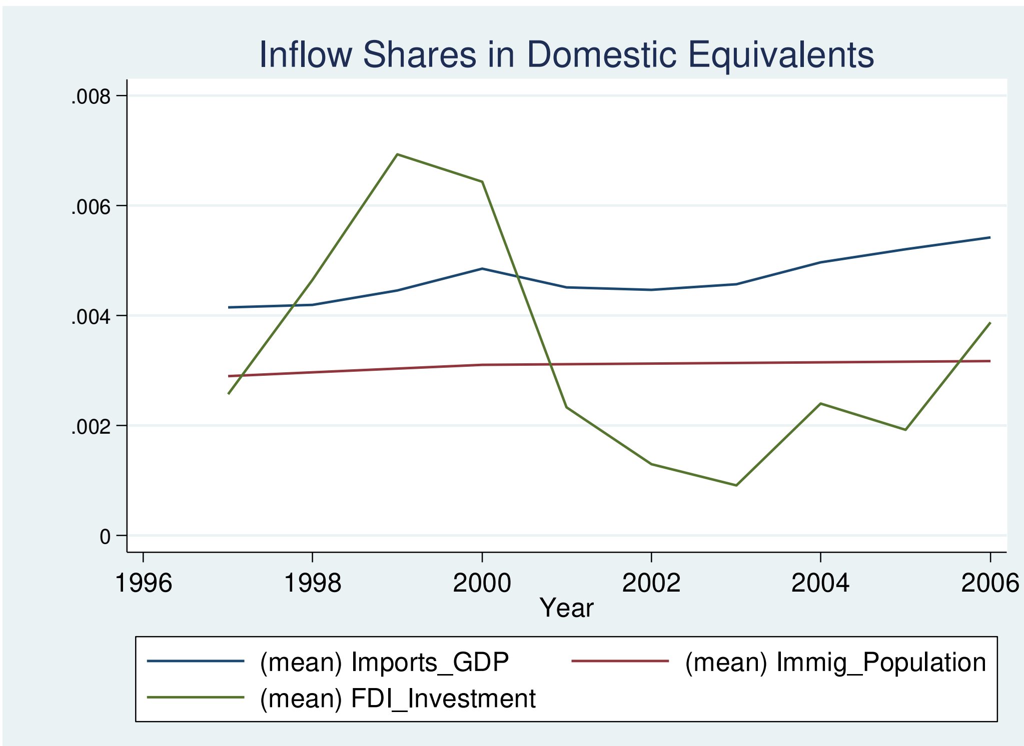

Figure 3: Imports/Output, Immigrants/Population and FDI/Investment

5.2 Calibration of TFP

To calibrate TFP, we start with estimation of Equation 11 restated:

$$g_Y = g_\Gamma + \theta_K g_K + \theta_L g_L \quad (11)$$

We apply Ordinary Least Squares (OLS) to data on the United States from 1949 to 2009. All coefficients are valid at a level of significance of 5% with a coefficient of determination of 74.66%. Based on the OLS estimation, we conduct tests of multicollinearity, heteroscedasticity and autocorrelation in addition to unit root tests to ensure that the estimated parameters are the Best Linear Unbiased Estimates (BLUE) obtainable.

Multicollinearity refers to exact or high linear relationships between explanatory variables. Its existence may result in high variances of estimates and wide confidence intervals resulting in highly inaccurate predictions (Greene 2003). To test for multicollinearity, we derive variance inflation factors (VIF) from STATA. VIFs are defined as $\frac{1}{1-R_{LC}^2}$, where R_{LC}^2 is the coefficient of correlation between growth of capital and growth of labor. There is no set rule concerning the cutoff point in determining the presence of serious multicollinearity, we choose a cutoff value of 10. Based on an average VIF of 3.08, we reject the null hypothesis of existence of multicollinearity in the model.

Heteroscedasticity refers to non-constant variance across residuals. The presence of heteroscedasticity in a model may result in biased parameter estimates and hence, over- or under-estimation of the fitted regressand. To test for heteroscedasticity, we use the Breusch-Pagan test under the null hypothesis that the variance of growth in output is constant. The obtained Chi-square statistic is not significant; we conclude that there is no evidence of heteroscedasticity in the model.

Breusch-Godfrey's test for autocorrelation shows a χ^2 (=5.681) that is valid at a level of significance of 5%. Serial correlation exists in the model. However, there is no evidence of Autoregressive Conditional Heteroscedasticity (ARCH) from a Lagrange Multiplier (LM) test. In addition, there are no unit roots, indicating stationarity of stochastic processes based on Dickey fuller tests for unit roots for each variable.

To correct for autocorrelation, we use Prais-Winsten and Newey-West methods of estimation and compare the power of the regression models using the resulting F-statistic. Growth of output is estimated using Newey-West method with one lag with results tabulated in Table 2. Growth of TFP is calculated as the difference between fitted values of the regressand and growth of inputs weighted by estimated factor shares. TFP is defined as the antilogarithm of growth of TFP.

Table 2: Estimation of Production Function (Prais-Winsten)

	Newey West (AR(1)
Capital growth	0.1525***
	(0.0523)
Labor growth	0.6305***
	(0.1151)
Constant	1.0968***
	(0.2071)
F-stat	120.63

"***", "**" and "*" represent 1%, 5% and 10% level of significance, respectively.

Figure 4 charts the trend of TFP over time. It is quite until 2001 when it plunges. There is a sharp growth between 2001 and 2002 and a sharp decline between 2002 and 2005.

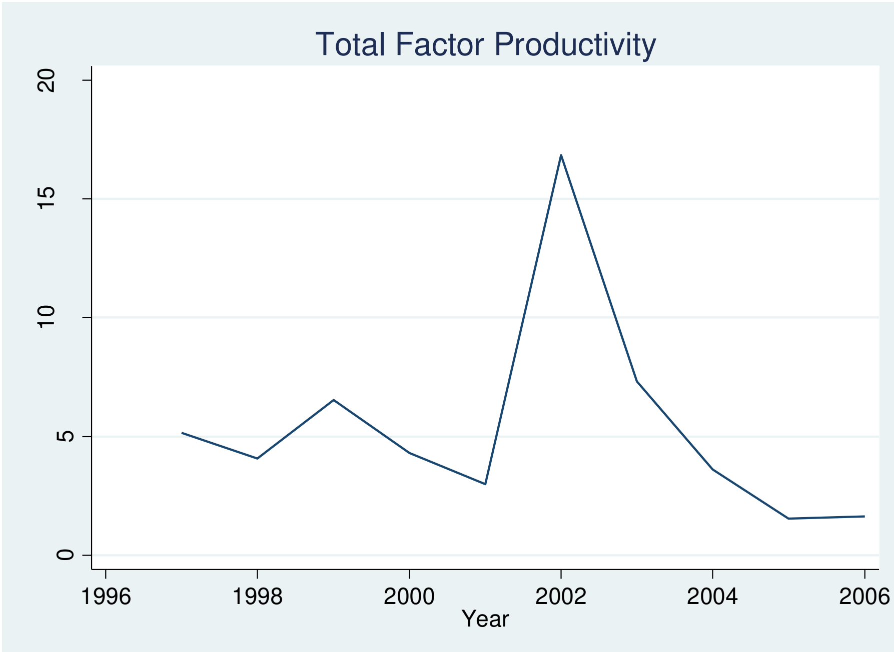

Figure 4: Trend of Total Factor Productivity

5.3 Estimation of TFP

Based on Figure 1, TFP is determined by both foreign and domestic R&D stocks. In Table 3, domestic R&D stocks are categorized as Basic, Applied and Experimental. Foreign stock of R&D expenditures are interacted with bilateral import share of domestic output, inward FDI share in domestic investment and immigration share of domestic population to represent the strengths of imports, inward FDI and immigration as transmitters of foreign technology. The use of fixed effects estimation is to provide a platform for tests (panel autocorrelation and contemporaneous correlation) of the model.

Fixed effects estimates indicate that Experimental and Basic R&D stocks improve TFP while expenditures in applied R&D decrease TFP. Foreign R&D positively affects TFP but not through any of the channels defined. Wooldridge's test suggests the presence of autocorrelation since the F-statistic of a regression of residuals on lagged residuals is statistically significant.

There is also evidence of contemporaneous correlation using Pesaran's test. To correct for panel autocorrelation and contemporaneous correlation, we use GLS with a single lag of OLS residuals allowing for cross-sectional dependence. Results are presented in Table 3. The coefficients on stocks of R&D are small because R&D stocks are very large while TFP figures are quite small. TFP has a mean of 5.3974 and ranges between 1.5411 and 16.8417. Average Experimental, Applied and Basic R&D stocks are 3,320,000, 1,170,000 and 951,000, respectively, all in *trillions*. The first panel in Table 3 presents changes in the explanatory variables required to increase TFP by one unit.

While some authors have estimated positive effects of domestic R&D stock on TFP, the results presented in Table 3 show that the effect of domestic R&D depends on the purpose of investment in R&D. Experimental R&D stock positively affects TFP. Using existing knowledge to develop or improve goods, services and processes increases productivity of inputs more than any other kind of R&D expenditures. Basic R&D stock also adds to TFP but has a lower effect than experimental R&D. Basic R&D expenditures aim at acquiring new knowledge, in general. Applied R&D expenditures do not improve TFP. OECD (1994) states, "[T]he results of applied research are intended primarily to be valid for a single or limited number of products, operations, methods, or systems. Applied research develops ideas into operational form. The knowledge or information derived from it is often patented but may also be kept secret." A plausible explanation for the non-positive estimated coefficient based on OECD's (1994) definition is that the effect of expenditures in Applied R&D may be limited to a few firms with low positive externalities to other firms eased by protection of intellectual property through patents. Basic and Experimental R&D knowledge processes are quasi-public (OECD 1994) and generate positive externalities.

Table 3: GLS Single Lag of Residuals

TFP Summary Statistics			
Mean = 5.3974	St. Dev = 2.8799	Min = 1.5411	Max = 16.8417
From Model (5), to change TFP by one unit, Increase Experimental R&D *stock* by 177,305 trillion Decrease Applied R&D *stock* by 26,455 trillion Increase Basic R&D *stock* by 39,216 trillion Decrease Foreign R&D *stock* by 872 trillion			

Regression Results: Dependent Variable - TFP

Variable	(1)	(2)	(3)	(4)	(5)
Experimental	5.63e-15**	6.11e-15***	5.57e-15***	5.90e-15***	5.64e-15***
$R\&D^D$	(2.86e-15)	(4.42e-16)	(8.85e-16)	(5.11e-16)	(2.66e-16)
Applied	-3.76e-14***	-3.96e-14***	-3.64e-14***	-3.81e-14***	-3.78e-14***
$R\&D^D$	(7.13e-15)	(1.18r-15)	(2.38e-15)	(1.41e-15)	(7.10e-16)
Basic $R\&D^D$	2.50e-14***	2.72e-14***	2.54e-14***	2.54e-14***	2.55e-14***
	(9.28e-15)	(1.23e-15)	(2.47e-15)	(1.25e-15)	(8.93e-16)
Import		3.24e-12***			7.37e-12***
share*$R\&D^f$		(1.96e-13)			(1.33e-12)
FDI share*			-4.98e-12***		-1.19e-11***
$R\&D^f$			(6.96e-13)		(3.82e-13)
Immigrant				5.99e-12***	2.46e-11***
share* $R\&D^f$				(3.94e-13)	(4.39e-12)
Import share		-10.8299***			-46.3739***
		(0.9518)			(6.4437)
Investment			29.0970***		72.6279***
share			(4.2213)		(2.7499)
Immigrant				-4.6932***	1.7524
share				(0.3311)	(22.0488)
$R\&D^f$		-4.95e014***	6.35e-15**	-3.03e-14***	-8.51e-14***
		(3.19e-15)	(2.69e-15)	(2.05e-15)	(1.47e-14)
Constant	6.9681*	6.1223***	6.2231***	6.4190***	7.1252***
	(3.8811)	(0.5825)	(1.1897)	(0.6171)	(0.5467)
Wald Chi^2		129.47	47.51	200.94	712.02

"***", "**" and "*" represent 1%, 5% and 10% level of significance, respectively.

Imports serve as a channel of technology transfer. Consumption and intermediate goods imports produced with high levels of technology have the tendency to trigger a learning process by firms, and consumption imports increase the level of domestic competition. A profile of the level of technology per capita, proxied by average number of patents per person between 1997 and 2006 shows that Japan, the Republic of Korea, Singapore and Canada have 294.27%, 217.25%, 173.83% and 108.10% more patents per capita, respectively, than the United States. Bilateral imports from these 4 countries constitute 44.23% of total exports from the 19 countries; slightly less than half of real bilateral imports are from countries with an average of 198.36% more patents per capita filed per year. The main imports from these 4 countries are a mixture of consumption and intermediate goods including passenger cars, computer accessories, industrial machinery, semi-conductors, engines, television receivers, household and kitchen appliances, natural gas, telecommunications equipment, and medicinal, dental and pharmaceutical preparations among others; the common factor is that they are all high technology goods.

Incoming FDI does not impact TFP positively. There are different arguments proposed by authors for non-positive spillover effects through FDI. Ajaga and Nunnenkamp (2008) state, "…the assumption that foreign-owned firms possess superior technology is less compelling when the host country is among the world's technological leaders." However, the sample comprises countries that are equally technologically advanced. Highest levels of FDI come from the United Kingdom, Germany, France, Netherlands, Canada and Japan, in order of magnitude. Chung (2001) provides some insight into spillover effects through FDI using firm-level data for the United States from 1987 to 1991. The author finds that productivity growth occurs only in firms that have lower levels of competition or high markup of price over cost. Firms with low markups experience a negative effect on productivity. The average level of competition could partially explain the non-positive effect of foreign technology through FDI on TFP.

Immigration is a channel of transfer of foreign technology to the United States. First, 77.62% of immigrants come from countries that spend, on average, 171.24% more of GDP per capita on tertiary education than the United States based on the sample used in this paper. There are some immigrants who have resided in the United States for a while and have gained education provided by the United States. Based on data from the Office of Immigration Statistics (OIS) (2011), between 2001 and 2010, an annual average of 2.42% of non-immigrant visas were granted to students (academic and vocational) and their families, while 5.10% of non-immigrant visas were issued to temporary workers and their families. Those who apply for and are granted permanent residency through employment comprise temporary workers who decide to stay, students who complete their studies, find jobs and file for permanent residency through their employers, refugees and families of immigrants among others. While the number of people who are granted employment based permanent residency is recorded, the OIS does not specify the percentage that comprises either temporary workers or students who convert their temporary visas into permanent ones. It is interesting to note that employment-based temporary admissions are more than twice the admissions for students. The United States has immigration programs that attract individuals with high levels of human capital from all over the world. Individuals satisfying skill, education and experience requirements are given the opportunity to work in the United States. Out of 20 visa subcategories for employment, one makes provision for migration of unskilled labor and one caters to immigration of families of immigrants and 18 require moderate to high skill levels (Department of Homeland Security (DHS)).

The total effect of foreign R&D stock on TFP is the partial derivative of TFP with respect to foreign stock of R&D:

$$\frac{\partial \Psi_{it}}{\partial \Omega_{jt}} = \varphi_1 \frac{\overline{M_{jt}}}{Y_{it}} + \varphi_2 \frac{\overline{\Xi_{jt}}}{P_{it}} + \varphi_3 \frac{\overline{\Lambda_{jt}}}{I_{it}} + \varphi_7 \tag{21}$$

In Equation 21, variables with bars on them represent averages. The first, second and third terms on the right-had side represent the effect of foreign R&D through imports, immigration and FDI, respectively. The sum of all the terms on the right-hand side provides the full effect of foreign R&D stock. The total effect of foreign technology by country and through time is described in Figure 5. While effects of technology from France, Germany, Netherlands and the United Kingdom fluctuate, the effects of technology from the rest of the countries in the sample are relatively stable.

6 Conclusion

Expenditures in R&D do not benefit only those who make the expenditures but economies that are related through flows of factors, goods and money. This essay has considered how foreign technology is unintentionally transferred through imports, immigrants and FDI assuming that there is technology embedded in these channels. We estimate the relationship between TFP of the United States foreign technology through three channels. Second, we estimate the relationship between different categories of domestic R&D expenditures and TFP of the United States. Using a sample of 19 partner countries from 1997 to 2006, we find that, first, the type of R&D expenditures matters. Domestic Basic and Experimental R&D stocks improve

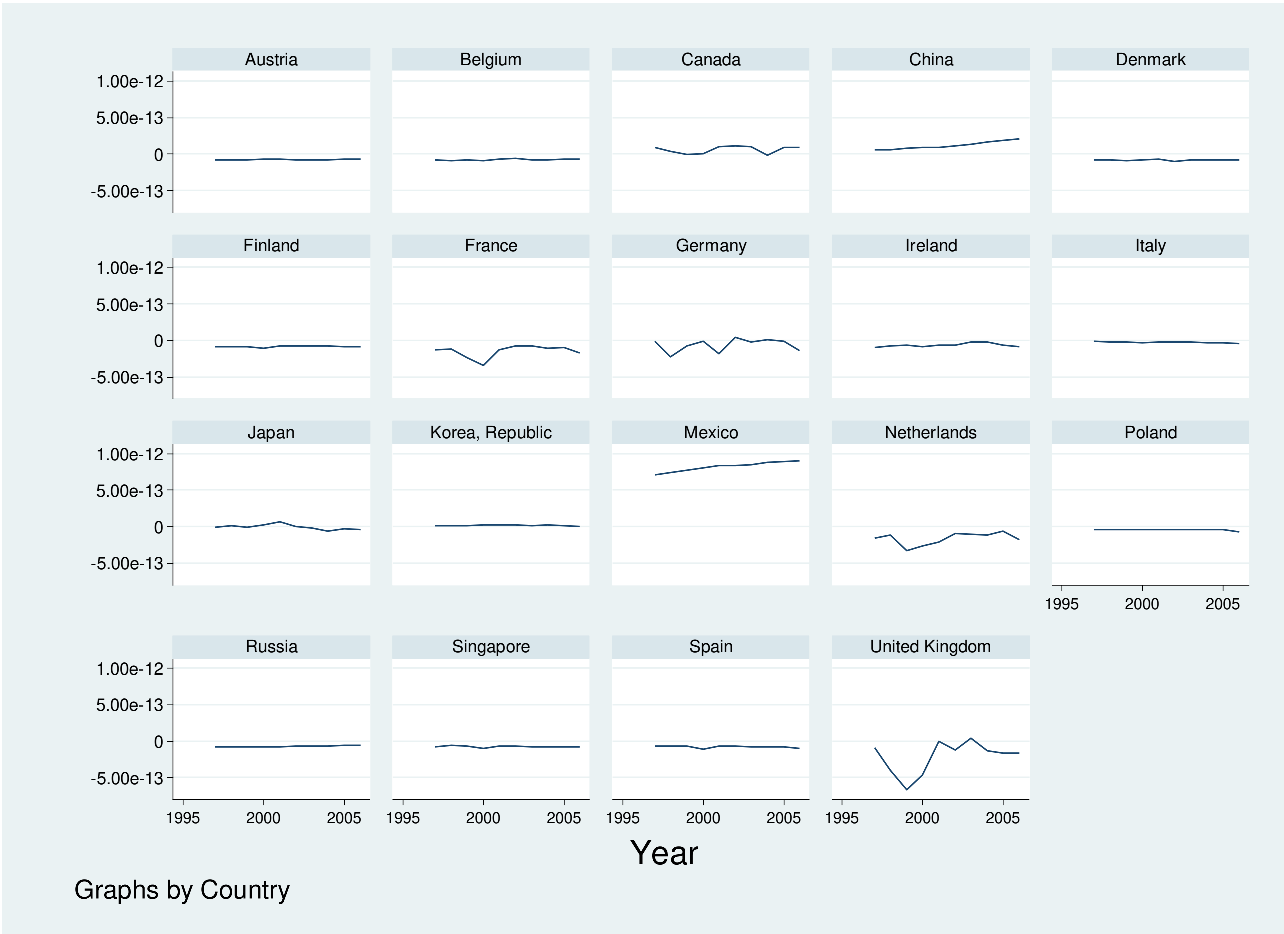

Figure 5: Trends of Effects of Foreign R&D on TFP by Country

TFP; the effect of Experimental R&D expenditures is higher than the effect of Basic R&D expenditures. Investment in Applied R&D does not improve productivity of factors. Second, foreign technology is transmitted through imports and immigration; immigration produces a larger spillover effect than imports. Incoming FDI does not improve TFP. Third, there are differences in estimated effects due to differences in immigration, imports and FDI from source countries.

7 Policy Recommendations

1. *Preference for high technology imports, and imports that are likely to spur domestic competition without unnecessarily hurting domestic firms*.

The United States may benefit from increases in imports that may be classified as being high-technology goods or goods that use cheaper technology than domestic producers are able to procure. Data presented in this paper show that the highest levels of imports (based on the sample used) come from countries with high levels of technology and while the goods are a mixture of consumption and intermediate goods, they are undoubtedly high technology goods. Preference for these goods will generate spillover effects, based on the results estimated.

2. *Admittance of immigrants from countries with high levels of technology or immigrants who have high levels of human capital irrespective of technology level in source country.* The United States, through its visa programs, reveals its preference for highly-skilled immigrants. Even if immigrants are from countries with low levels of R&D expenditures, if those immigrants build their human capital, their residence may produce a similar effect on productivity.[1]

3. *Screen FDI through requirements for investment*

Incoming FDI does not enhance productivity but it is possible that discrimination in FDI to assign greater preference to those that may transfer technology may be optimal. This may be done by strengthening the conditions for eligibility to invest directly in the United States.

[1] This policy does not provide support for discrimination against people with lower levels of education and work experience but prescribed as a policy that may enhance Total Factor Productivity of the United States and for that purpose only

APPENDIX

TFP Calibration and Estimation and Country Comparison

Table A.1: Estimation of Production Function using Ordinary Least Squares

GDP growth	Coefficient	Standard Error	t-value	P>|t|
Capital growth	0.1525***	0.0460	3.31	0.002
Labor growth	0.6305***	0.1352	4.66	~0.000
Constant	1.0968***	0.2383	4.60	~0.000
		F-statistic = 89.39		
		R-square = 0.7466		

"***", "**" and "*" represent 1%, 5% and 10% level of significance, respectively. Data on the United States from 1949 to 2009.

Table A.2: Variance Inflation Factors from Estimation of Production Function

Variable	VIF	1/VIF
Capital growth	3.08	0.3250
Labor growth	3.08	0.3250
Mean VIF	3.08	

Based on results from Table C.1.

Table A.3: Breusch-Godfrey LM Test for Autocorrelation (H_0: No Serial Correlation)

Lags(p)	Chi-square	Degrees of Freedom	Prob>χ^2
1	5.681	1	0.0171

Based on results from Table C.1.

Table A.4: LM test for Autoregressive Conditional Heteroscedasticity (ARCH)

Lags(p)	Chi-square	Degrees of Freedom	Prob>Chi-square
1	0.175	1	0.6753

Based on results from Table C.1.

Table A.5: Dickey-Fuller Test for Unit Roots (60 observations)

	Z(t) Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
GDP growth	-6.379***	-3.566	-2.922	-2.596
Capital growth	-4.475***	-3.566	-2.922	-2.596
Labor growth	-5.547***	-3.566	-2.922	-2.596

"***", "**" and "*" represent 1%, 5% and 10% level of significance, respectively. Based on results from Table C.1.

Table A.6: Estimation of Production Function Using Prais-Winsten and Newey-West

	Prais-winsten AR(1)	Newey West (AR(1)	Newey West AR(2)
Capital growth	0.2521***	0.1525***	0.1525***
	(0.0536)	(0.0523)	(0.0561)
Labor growth	0.4474***	0.6305***	0.6305***
	(0.1338)	(0.1151)	(0.1217)
Constant	0.7806**	1.0968***	1.0968***
	(0.3012)	(0.2071)	(0.2146)
F-stat	89.35	120.63	113.81

"***", "**" and "*" represent 1%, 5% and 10% level of significance, respectively.

Table A.7: Tests for TFP Estimation Panel, Fixed Effects

Fixed-effects	(within)			Number	of obs =	190
Group variable	Panel_ID			Number	of groups =	19
R-sq: within	= 0.7638			Obs per	group:min =	10
between	= 0				avg =	10
overall	= 0.3002				max =	10
					F(10,161) =	52.07
corr(u_i, Xb)	= -0.7791				Prob>F =	0

TFP	Coef.	Std. Err.	t	P>|t|	[95% Conf	Interval]
Experimental Research Stock	5.54E-15	7.13E-16	7.78	~0	4.14E-15	6.95E-15
Applied Research Stock	-3.73E-14	1.76E-15	-21.21	~0	-4.07E-14	-3.38E-14
Basic Research Stock	2.72E-14	2.33E-15	11.7	~0	2.26E-14	3.18E-14
(Imports/GDP)* Foreign RD Stock	3.44E-11	2.41E-11	1.43	0.155	-1.31E-11	8.19E-11
(FDI/Inv)* Foreign RD Stock	-1.09E-11	1.07E-11	-1.02	0.308	-3.21E-11	1.02E-11
(Immig/Pop)* Foreign RD Stock	1.89E-10	1.29E-10	1.47	0.145	-6.58E-11	4.44E-10
Foreign RD Stock	-1.01E-12	3.06E-13	-3.3	0.001	-1.61E-12	-4.04E-13
Imports/GDP	-631.639	233.2967	-2.71	0.008	-1092.36	-170.923
Immigration/Pop	-253.725	414.9771	-0.61	0.542	-1073.23	565.7749
FDI/Investment	71.6746	70.6969	1.01	0.312	-67.9382	211.2874
Constant	9.52508	1.60768	5.92	~0	6.350221	12.69994
sigma_u	4.695831		sigma_e	2.221531		
rho	0.81712					
F test that	u_i=0:	F(18, 161)	= 0.94		Prob>	F = 0.5313

Table A.8: Employment Based Immigration

Class of Employment-Based Immigration	Requirements
First Preference EB-1	Extraordinary Ability OR
	Outstanding Professors and Researchers OR
	Multinational manager or executive
Second Preference EB-2	Advanced Degree OR
	Exceptional Ability OR
	National Interest Waiver
Thrid Preference EB-3	Skilled Workers OR
	Professionals OR
	Unskilled Workers
Fourth Preference EB-4	Religious Workers OR
	Broadcasters OR
	Iraqi/Afghan Translators OR
	Iraqis Who Have Assisted the United States OR
	International Organization Employees OR
	Physicians OR
	Armed Forces Members OR
	Panama Canal Zone Employees OR
	Retired NATO-6 employees OR
	Spouses and Children of Deceased NATO-6 employees
Fifth Preference EB-5	Immigrant Investors

Source: United States Citizenship and Immigration Services.

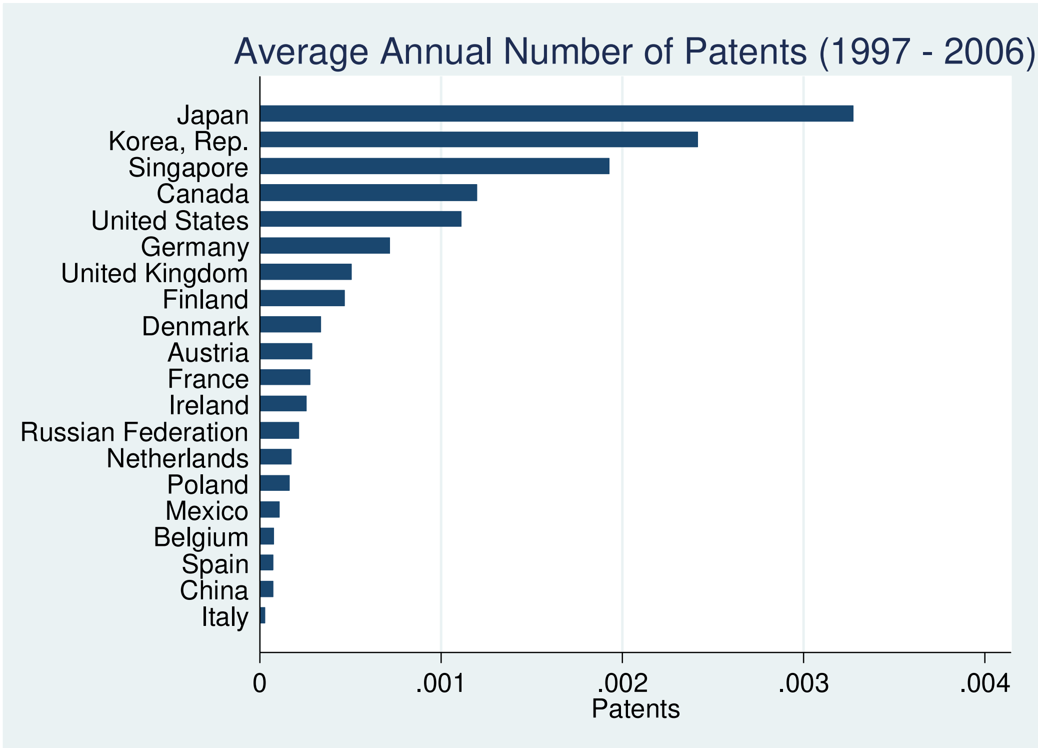

Figure B.1: Average Annual Number of Patents per Capita from 1997 to 2006

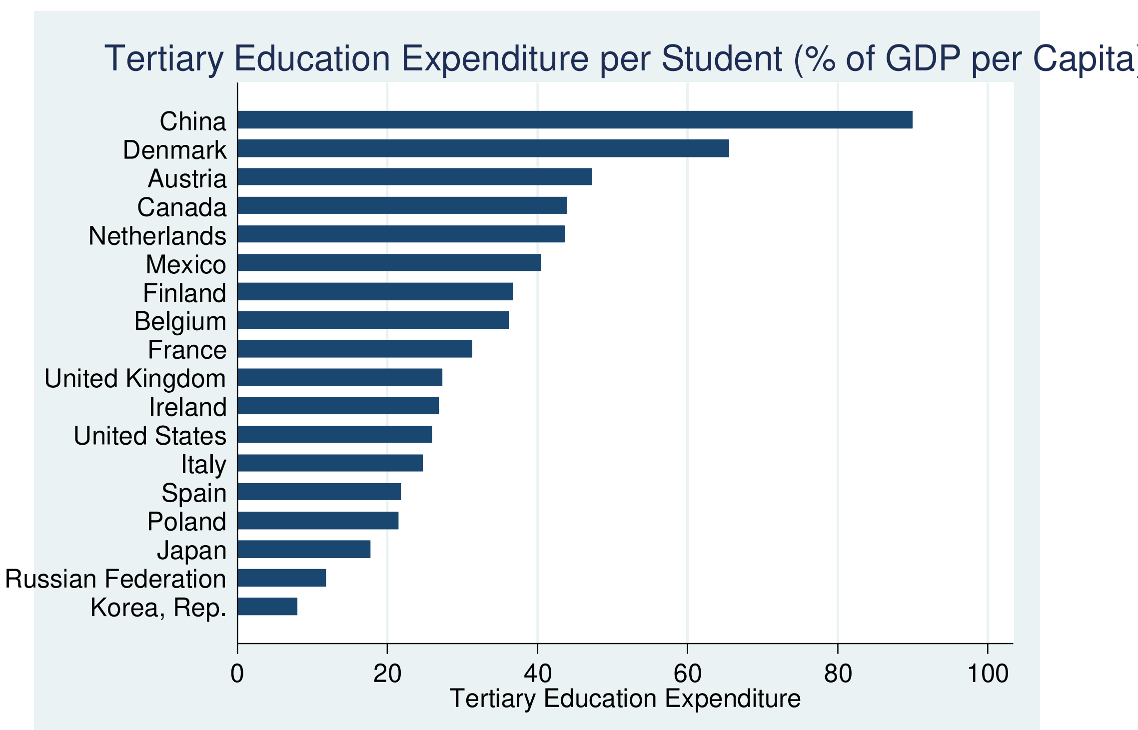

Figure B.2: Percentage of GDP per Capita Spent on Tertiary Education

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

H_0: Constant variance

Variables: fitted values of GDP growth

$\chi^2(1) = 2.51$

Prob > χ^2 = 0.1134

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 18) = 181.448

Prob > F = 0.0000

Pesaran's test of cross sectional independence = 37.141, Pr = 0.0000

Average absolute value of the off-diagonal elements = 0.898

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