North-South Technology Diffusion: How Important Are Trade, FDI and International Telecommunications?

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Abstract

There is an influential literature studying the impact on total factor productivity (TFP) of foreign technology obtained through imports (trade). This paper builds on that literature and is a first attempt to examine the effects on TFP in the South of technology developed in the North that is diffused not only through international trade, but also through foreign direct investment (FDI) and international telecommunications (ITC) measured in call traffic. For developing countries in the South, we construct trade-related, FDI-related and ITC-related North foreign R&D indices, using country specific R&D stocks in the North, and respectively with North-South bilateral trade patterns, FDI patterns and ITC volumes. We find: (i) trade and ITC both significantly promote North-South technology diffusion, while FDI seems to generate North-South technology diffusion, though not always significantly; (ii) the effects on TFP through ITC-related foreign R&D are the largest, followed in order by those through trade-related, and then by those through FDI-related foreign R&D indices; and (iii) the effects on TFP of trade-related North foreign R&D are primarily driven by the growth in developing countries' trade-to-GDP ratios, while the effects from ITC-related North foreign R&D are largely due to the growth in the Northern R&D stocks.

Key Words: Technology Diffusion, Trade, FDI, International telecommunications

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HOW IMPORTANT ARE TRADE, FDI AND INTERNATIONAL TELECOMMUNICATIONS?

1. Introduction

It has been argued that countries can obtain dynamic gains from opening up their economies because it enables them to increase the absorption of technological knowledge developed elsewhere, and that this results in increased productivity growth (The World Bank, 2000). Since developed OECD countries (the North) conduct most of the research and development (R&D) activities, while developing countries (the South) do very little, the benefits of a developing country's openness with developed countries would be potentially greater.[1] This paper explores the effects on total factor productivity (TFP) in developing countries in Asia, Latin America and the Caribbean (LAC) of technology developed in the North that is diffused through international trade, foreign direct investment (FDI), and international telecommunications (ITC) in call traffic.

Developing countries in Asia and LAC have been actively participating in the new wave of globalization, by liberalizing their trade regimes and by enacting favourable regulations aiming at attracting FDI, which makes them natural candidates to study the benefits associated with trade liberalization. During the sample period from 1981 to 2000, trade flows between industrialized countries and developing countries in Asia and LAC increased dramatically, so did FDI flows from industrialized countries to them. Most developing countries in Asia and LAC have experienced fast economic growth in the last 25 years. For example, in Asia, the two most populated countries—China and India—have been embracing open economic policies for quite some time, and both have been

[1] In 1990, 96% of the world's R&D expenditures took place in industrial countries (Coe et al., 1997). In 1995, that share was 94.5% (calculated from the World Bank database by the author).

enjoying impressive economic growth rates.[2] [3] China's continuous high economic growth rates have led Newsweek to claim that the 21st century is "China's century." [4] In LAC, trade liberalization started earlier and a number of countries have also signed an FTA (free trade agreement) with developed countries. See, for example, on January 1st, 1994, Mexico joined the North America Free Trade Agreement (NAFTA); Chile has free trade agreements with the United States, the EU, and Canada respectively. And Central American countries and the Dominican Republic have signed an FTA (CAFTA) with the United States.

Increasing a country's trade volume, and/or attracting more FDI, and/or increasing its ITC all reflect a country's growing openness. This paper aims to investigate the benefits for a developing country's TFP growth from three channels of North-South technology diffusion through trade, FDI and ITC. To our best knowledge, it is the first empirical attempt to examine three channels of North-South technology diffusion simultaneously. Thus, empirical results here are less likely to suffer omitted variable biases, which might be present in some of the previous studies in the literature.

Based on data for 30 developing countries in Asia and in LAC from 1981 to 2000, we find: (i) trade and ITC both significantly promote technology diffusion from the North to the South, while FDI also generates North-south technology diffusion, though not very strong; (ii) the effects on TFP from ITC-related North foreign R&D are the largest,

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[2] In 1978, the Chinese government, under the leadership of Deng Xiaoping, embarked on a series of economic reforms designed to integrate China into the world economy. It gradually liberalized its protective trade regime and enacted favorable regulations to attract foreign investment, as well as privatized many state-owned enterprises to liberalize its market. Now, China has the lowest trade barriers among all developing countries. Its economic reforms are very successful: since 1978, China's economy has an average annual growth rate of about 9%.

[3] In India, government controls have been reduced on foreign trade and investment, and privatization of domestic output has proceeded slowly. The economy has posted an excellent average growth rate of 6% since 1990, reducing poverty by about 10 percentage points.

followed in order by those from trade-related, and then by those from FDI-related North foreign R&D; and (iii) the effects on TFP from trade-related North foreign R&D are primarily driven by the growth in developing countries' trade-to-GDP ratios , while the effects from ITC-related North foreign R&D are largely due to the growth in the Northern R&D stocks. Our results also indicate that the magnitude of North-South technology diffusion through one channel tends to be overestimated without the presence of other channels.

The remainder of the paper is constructed as follows. Section 2 reviews the literature, Section 3 sets forth a brief analytical framework, Section 4 describes the data, Section 5 presents empirical results, and Section 6 concludes.

2. Literature Review

How does the paper relate to the literature? Trade and FDI as channels for international technology diffusion have been studied quite extensively, while the study on the role of ITC in international technology diffusion is very limited.

Trade as a channel for international technology diffusion was first studied by Coe and Helpman (1995), who build a trade-weighted foreign R&D index for a sample of 20 industralized OECD countries plus Israel, and find that a country's TFP increases not only with its own R&D stocks but also with its trade-related foreign R&D stocks. The study was then followed by Engelbrecht (1997), Keller (1998), Lichtenberg et al. (1998), Falvey et al. (2002) and Lumenga-Neso et al. (2005), all of which tend to confirm the

[4] "Special Report: China's Century" was in the issue published on May 9th, 2005.

findings in Coe and Helpman (1995), with the exception of Keller (1998).[5] Coe et al. (1997) extend that approach in the context of North-South trade and examine the impact on TFP in the South of technology developed in the North diffused through trade at the aggregate level. This study stimulated a few works such as Engelbrecht (2002), Falvey et al. (2005), and Savvides and Zachariadis (2005).[6] Industry level studies tend to confirm the findings at the aggregate level using a similar approach in Coe and Helpman (1995), see Keller (2000, 2002) for OECD countries. In the North-South context at the industry level, Lejour and Nahuis (2005) explore the relationship between openness and growth by looking different effects across industry groups of trade-related knowledge spillovers, while Schiff and Wang (2003) show that North-South trade-related technology diffusion has a regional dimension. Subsequent contributions at the industry level of North-South technology diffusion are Schiff and Wang (forthcoming) studying direct and indirect trade-related North-South technology diffusion, and Wang (forthcoming) on the importance of countries' absorptive capacity in improving trade-related North-South technology diffusion. This paper adds to the above literature by also examining technology diffusion through FDI and ITC.

The body of the empirical works on the impact of FDI on host country economies ranges from aggregate to firm level studies. At the aggregate level, studies tend to show that FDI promotes technology spillovers to the host country, such as findings in Borensztein et al. (1998) for a sample of 69 developing countries. At the firm level,

[5] A few influential works have shown that trade raises a country's income, see Frankel and Romer (1999), Wong (2004), and Noguer and Siscart (2005), just to name a few. They are different from Coe and Helpman (1995) in that they do not link the volume of a country's bilateral trade with its trading partner's technology, and thus they only emphasize the role of trade alone in bridging income gaps. Their approach is somewhat similar to the ones used by Dollar and Kraay (2002, 2003, and 2004) which show that trade (and globalization in general) is good to the poor.

[6] Savvides and Zachariadis also look at the effects of FDI.

studies shift from searching for horizontal knowledge spillover effects from FDI to vertical ones. The former studies have mixed results, see, for example, Haddad and Harrison (1993) find significant and positive effects from FDI using Moroccan data, while no significant impacts were found in Aitken and Harrison (1999) using firm data in Venezuela. Studies on FDI's impact through vertical linkages tend to be encouraging: Javorcik (2004) shows strong backward linkages in Poland's firm-level study, while Liveela (2006) presents a positive impact from FDI through vertical linkages on Canadian domestic manufacturing firms.

Turning to the role of ITC in raising a country's income, Wong (2004) uses an approach similar to the one in Frankel and Romer (1999), investigating how a country's trade volume and international telephone call traffic could bridge income gaps. However, Wong does not take into consideration whether technologies from a country's trading (conversation) partners generate international technology diffusion, which is incorporated in our approach.

In principle, our approach is similar to the one in Coe et al. (1997) by emphasizing the impact on TFP not only from trade volume, but also through each trading partner's technology. Besides trade, we also examine the impact of FDI, and of ITC on a developing country's TFP by using a measurement not only highlighting the volume of FDI (ITC), but also taking into account FDI (ITC) source countries' technologies. For each developing country at each year, we build three independent variables of trade-related, FDI-related, and ITC-related North foreign R&D indices, using country-specific R&D stocks in the North, and respectively with North-South bilateral trade patterns, FDI patterns, and incoming and outgoing ITC in minutes.

Unlike Coe et al. (1997), we only include 30 developing countries in Asia and LAC which are relatively more open, and more integrated into the world economy, and thus are more suited to study productivity gains from trade, FDI and ITC. Also, we use more recent data from 1981 to 2000 when FDI to developing countries started taking off, while Borensztein et al. (1998) use a sample from 1970 to 1990 when not a lot of FDI went to the South. Finally, Wong (2004) employs cross-sectional data, while here we use a rich panel data set to examine the impact of ITC-related foreign R&D on a country's TFP growth.

3. Analytical Framework

Technology developed in the North could be diffused to the South possibly via several channels: trade, FDI, ITC and the internet, etc. Grossman and Helpman (1991) argue that a country's productivity increases with its trade volume, as imported products embed the producing countries' technology. Thus, a country obtains access to other countries' technology through trade. Markusen (1995) shows that firms undertaking FDI are characterized by high levels of R&D relative to sales, a large share of professional and technical workers in total employment, new and/or technically complex products and high levels of product differentiation. It has been argued in the literature that FDI could potentially benefit local firms through local contacts, workers' turnover, and participation in business meetings and conferences, etc. International technology diffusion could also take place through ITC, as analyzed in Wong (2004).[7] One unique feature of the ITC-

[7] International technology diffusion could potentially materialize through internet as well, among others. On a related topic, Freund and Weinhold (2004) find that Internet stimulates trade. Evidence from time-series and cross-section regressions shows a significant effect of Internet on trade in recent years. But due to data limitations relating to internet, this paper does not intent to include it as another channel. Excluding

related technology diffusion is that it is invariant to the directions of the calls placed.[8] This makes ITC-related technology diffusion different from trade-related and FDI-related technology diffusion where directions make a difference.

3.1. Conceptual Framework

We assume that for developing country *c*, its total factor productivity at year *t*, TFP_{ct}, is determined mainly by the following factors:

$$TFP_{ct} = (q_{ct})^{y} \, f\left(Openness_{ct}^{N}, q_{Nt}\right) G(X_{ct}), \qquad (1)$$

where q indicates a country's technological level, N indicates North for the moment, $Openness_{ct}^{N}$ captures the openness of developing country c to the North, and y is the elasticity of TFP with respect to a country's own technology. X here is a vector including all other factors affecting a country's TFP. Equation (1) says that a country's TFP depends on its own technology, its openness with respect to the North, the technology in the North, among other factors. Openness to the North is to be proxied by three measures involving a country's trade volume, inward FDI stock, and its bilateral ITC respectively. These are discussed in turn.

Openness measured by trade is defined as the ratio of developing country *c*'s imports of machinery and transportation equipment from country N, $Trade_{c}^{N}$, to its gross domestic product (GDP).[9] Similarly, openness measured by FDI is defined as the ratio of

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the channel of internet is very unlikely to bias our results as people in developing countries started using internet in the late 1990s, and early 2000s, the period which only overlaps a little with our time coverage: 1981 to 2000.

[8] Whether it is professional A in country *i* or professional B in country *j* who placed the call does not affect the knowledge flow from, say for example, B to A.

[9] Imports of machinery and transportation equipments are chosen to measure a country's openness, rather than the total imports of manufacturing goods, solely because of the purpose of the paper. Machinery and

the inward FDI stocks from country N, FDI_c^N, to country c's GDP.[10] Finally, openness measured by ITC is defined as the ratio of bilateral telephone call traffic (in minutes) between countries c and N (the sum of the incoming and outgoing calling traffic), ITC_c^N, over country c's population (Pop).[11]

With the above definitions, equation (1) can be rewritten as:

$$TFP_{ct} = (q_{ct})^y \ f\left(\frac{Trade_{ct}^N}{GDP_{ct}}, \frac{FDI_{ct}^N}{GDP_{ct}}, \frac{ITC_{ct}^N}{Pop_{ct}}, q_{Nt}\right) G(X_{ct})$$

$$\equiv (q_{ct})^y \left[g_1\left(\frac{Trade_{ct}^N}{GDP_{ct}} q_{Nt}\right)\right]^a \left[g_2\left(\frac{FDI_{ct}^N}{GDP_{ct}} q_{Nt}\right)\right]^b \left[g_3\left(\frac{ITC_{ct}^N}{Pop_{ct}} q_{Nt}\right)\right]^g G(X_{ct}), \quad (2)$$

There are two implicit assumptions in equation (2). First, foreign technology becomes a productive force only through trade, FDI, and ITC, their products called trade-related, FDI-related, and ITC-related North foreign R&D indices respectively. Second, trade-related, FDI-related and ITC-related North foreign R&D indices are independent of each other. a, ß and ? measure the elasticity of TFP with respect to trade-related, FDI-related, and ITC-related North R&D respectively.

Taking logs of equation (2) leads to the following:

$$ln\,TFP_{ct} = y \ ln q_{ct} + a \ ln\, g_1\left(\frac{Trade_{ct}^N}{GDP_{ct}} q_{Nt}\right) + b \ ln\, g_2\left(\frac{FDI_{ct}^N}{GDP_{ct}} q_{Nt}\right)$$

$$+ g \ ln\, g_3\left(\frac{ITC_{ct}^N}{Pop_{ct}} q_{Nt}\right) + ln\, G(X_{ct}) \quad (3)$$

transportation equipments are the natural candidates to indicate the producing country's technology, as analyzed in and also chosen by Coe et al. (1997).

[10] FDI stocks do not fluctuate as much as FDI flows, and thus empirical analysis are less likely to be negatively affected by the short-term fluctuations.

[11] Ideally, we would prefer the usage of international calling spent on business. However, data on bilateral calling do not differentiate between business and non-business purposes. Also, the empirical results stay about the same when the denominator is changed to population aged 15 to 65.

3.2. Measurement of the Trade-, FDI- and ITC-Related North R&D Indices

A country's technology is proxied by its R&D stocks.[12] We follow the literature by assuming that for developing country *c*, total foreign R&D diffused from the North through each channel is the sum of the knowledge diffused to country *c* from each of the 20 countries in the North (Coe and Helpman, 1995).

Accordingly, trade-related North foreign R&D is defined as:

$$g_1\left(\frac{Trade_{ct}^{N}}{GDP_{ct}}q_{Nt}\right) \equiv TradeRD_{ct} = \sum_{n}\left(\frac{Trade_{ct}^{n}}{GDP_{ct}}\right)RD_{nt}, \tag{4}$$

Equation (4) says that trade-related North foreign R&D, $TradeRD_{ct}$, is a weighted sum of RD_{nt}—R&D stocks in OECD country *n*—over the 20 industralized OECD countries, with the weights equal to $Trade_{ct}^{n} / GDP_{ct}$, country *c*'s trade-openness towards country *n*.[13]

Similarly, FDI-related Northern R&D Stocks is defined as:

$$g_2\left(\frac{FDI_{ct}^{N}}{GDP_{ct}}q_{Nt}\right) \equiv FDIRD_{ct} = \sum_{n}\left(\frac{FDI_{ct}^{n}}{GDP_{ct}}\right)RD_{nt}, \tag{5}$$

Finally, we turn to the measurement of ITC-related North R&D index. The flows of ITC bring in flows of foreign knowledge—not embedded in any physical forms like trade, but rather in people's minds (so called disembodied technology diffusion in Wong 2004). It might be potentially problematic to argue that knowledge obtained in the current

[12] This is a common assumption in the literature, as was done in Coe and Helpman (1995), Coe et al. (1997), and Schiff and Wang (forthcoming), for example.
[13] In the literature, there are variations in choosing the weights for trade-related foreign R&D. Coe and Helpman (1995) use bilateral weights as ratios of bilateral imports over total imports, while Lumenga-Neso et al. (2005) argue that the weights in Coe and Helpman could not properly reflect the fact more imports associated with more embedded technology, and instead propose to use weights as imports over GDP ratios. This paper follows Lumenga-Neso et al. and is also similar to Wang (forthcoming) for North-South trade-related technology diffusion at the industry level.

period through ITC either becomes obsolete in the next period (such as trade-related North foreign R&D), or does not depreciate (such as FDI stocks). The first argument tends to underestimate ITC-related North foreign R&D index, while the second tends to overestimate it. Accordingly, we adopt a two-step procedure involving the perpetual inventory method to convert the flows of the knowledge diffused through ITC, $ITCRD^F$, to the "stock" of that knowledge, $ITCRD^S$, which is our measurement of ITC-related North R&D index. They are defined as follows:

$$ITCRD_{ct}^{F} \equiv \sum_{n}\left(\frac{ITC_{ct}^{n}}{Pop_{ct}}\right)RD_{nt}, \tag{6}$$

$$ITCRD_{c,0}^{S} = \frac{ITCRD_{c,0}^{F}}{d + g_{c}}, \tag{7}$$

$$ITCRD_{c,t+1}^{S} = (1-d)ITCRD_{c,t}^{S} + ITCRD_{c,t+1}^{F}, \tag{8}$$

where d is depreciate rate, set as .10, and g_c is the average annual growth rate of $ITCRD_{ct}^{F}$, the annual flow of ITC-related North R&D for country *c*. Superscripts F and S denote flows and stocks respectively. Equation (6) measures the annual flows of ITC-related Northern technology for country *c*, equation (7) sets its initial stock level, and equation (8) calculates the stocks for each year.

3.3. Main Estimation Equation

To sum up, we analyze the effect on TFP in the South of three potential channels for North-South technology diffusion: trade, FDI and ITC. The effects of each of these channels can be compared, either individually, or, preferably, in a nested model. We choose to estimate the main equation by a moving five-year first difference (1981-1986, 1982-1987, …, 1995-2000). The purpose of doing so is three-fold. It avoids spurious regression results due to possible unit root problems, while at the same time maximizes the number of observations, and also takes account of the argument that North R&D on TFP in the South could be better captured in a long-run growth model—as argued in Coe et al. (1997). A country's human capital is one of the control variables, by assuming for now that $G(X_{ct}) = HC_{ct}^{s}$. Human capital is proxied by the average total years of schooling over its population aged 25 and above.

From equations (3) to (8), and by taking a five-year first difference, we obtain:

$$\Delta \ln TFP_{ct} = y \Delta \ln q_{ct} + a \Delta \ln TradeRD_{ct} + b \Delta \ln FDIRD_{ct} + g \Delta \ln ITCRD_{ct}^{S} + s \Delta HC_{ct} \tag{9}$$

It should be noticed that cross-country regressions presented above might be subject to possible endogeneity problems. Taking trade as example, countries with higher productivities for reasons other than trade may have more imports. We therefore estimate the main regressions by implementing two-stage least squares with instrumental variables (IV). Given that there are only 17 out of the 30 countries have data on FDI, in order to maximize the observations, we choose to use IV for $\Delta \ln TradeRD$ and $\Delta \ln ITCRD^{S}$ based on their lagged terms, the square terms of their lagged terms, and the cross-product (5 terms). While for $\Delta \ln FDIRD$, besides the above mentioned IV, we also added the lagged terms of $\Delta \ln FDIRD$, its square term, and its cross-product with the lagged terms of $\Delta \ln TradeRD$ and $\Delta \ln ITCRD^{S}$ (9 terms in total). We use the predicted values of $\Delta \ln Tr\hat{a}deRD$, $\Delta \ln \hat{F}DIRD$ and $\Delta \ln IT\hat{C}RD^{S}$ from the first stage for $\Delta \ln TradeRD$, $\Delta \ln ITCRD^{S}$ and $\Delta \ln FDIRD$ respectively in the main estimation equation.

The panel nature of our data set also gives us further freedom to control for other things which could affect a country's TFP growth. We add country dummies to control for heterogeneous country effects, such as government policies, shocks, and other country specific features that might also be correlated with a country's TFP growth. Domestic R&D data are either not available for most developing countries. We instead assume that the log first difference of domestic R&D stocks, $\Delta ln\, q_{ct} = h_{ct}$, follows a random walk, which goes to the error term. The main estimation equation thus becomes:

$$\Delta \ln TFP_{ct} = a + b_T \Delta \ln \hat{TradeRD}_{ct} + b_F \Delta \ln \hat{FDIRD}_{ct} + b_{ITC} \Delta \ln \hat{ITCRD}^S_{ct}$$

$$+ b_E \Delta HC_{ct} + \sum_c l_c D_c + e_{ct} , \qquad (10)$$

where D_c is country dummy, and e_{it} is the error term, capturing all of the other factors not included in the model affecting TFP. The error term is assumed to be independently distributed with zero mean across countries.

4. Data Sources

Our sample consists of 13 developing countries in Asia and 17 developing countries in LAC.[14] The sample covers the period of 1981 to 2000. Due to missing observations, the sample is unbalanced, especially for data on FDI. There are 20 industrialized OECD partners in the North serving as technology sources.[15]

[14] The 13 countries in Asia are: Bangladesh, China, Hong Kong-China, Indonesia, India, Korea, Rep., Sri Lanka, Macao-China, Malaysia, Pakistan, the Philippines, Singapore, and Thailand. The 17 countries in LAC are: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, Paraguay, Uruguay, and Venezuela.

[15] The 20 developed OECD countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Switzerland, the United Kingdom, and the United States.

The log of TFP index is calculated as the log difference between value-added and the primary factor use, with the inputs weighted by their income shares, i.e., $ln\,TFP = ln\,Y - a\,ln\,L - (1-a)ln\,K$. a is country-specific labor share, which is defined as the mean of the ratio of wage bill divided by value added, *Y*, *L* and *K* stand for value added, labor and capital stocks respectively. The use of time-invariant, country specific labor share combined with a country dummy in the econometric analysis will make the empirical results invariant to the unit of the measurement of capital (in unit or in thousands, etc). Capital stocks are derived from the fixed capital formation series using the perpetual inventory method with a 10% depreciation rate. Value-added, fixed capital formation, labor and wages are all taken from the United Nations National Accounts. Value-added and gross fixed capital formation series are reported in current US dollars, and both are deflated by US GDP deflator (1990 = 100) before being used to construct the TFP index.

R&D expenditures for each of the 20 developed OECD countries are taken from the OECD's database "Main Science and Technology Indicators". These expenditure series are first converted to nominal US dollars using official annual average exchange rates, and then are deflated using US GDP deflator (1990=100). The perpetual inventory method is used to convert the real R&D flows to R&D stocks for each of the 20 countries in the North.

Bilateral FDI stocks from each of the 20 industralized OECD countries to each of the 30 developing countries are taken from the OECD's FDI database. Only 17 out of the

30 developing countries in the sample are covered in that database, however, they are the major FDI recipients among the developing countries.[16]

Bilateral imports of machinery and transportation equipment are taken from the World Integrated Trading System (WITS) database. They are available from 1981 to 2000 with few missing observations for some country pairs.

Data on bilateral international telecommunications (call traffic) in minutes start from 1983, the earliest year with such data. For 1983-1995, they are taken from TeleGeography, International Telecommunication; and for 1996-2000, they are from TeleGeography, International Traffic Database. Incoming and outgoing minutes are reported in both databases, and the sum of incoming and outgoing minutes are used to calculate ITC minutes per capita.

Data on GDP and population are taken from the World Development Indicators, maintained by the World Bank. Finally average total years of schooling in the population aged 25 and above are taken from Barro-Lee Dataset, annualized here.[17]

Table 1 provides summary statistics of R&D stocks in the North. During the sample period, all of the 20 industralized OECD countries have experienced positive growth rates of their R&D stocks. The average annual growth rate is 4.8% for the North.

Table 2 reports summary statistics of the relevant data for the 30 developing countries. A few observations are described in turn. First, comparing FDI with trade (imports of machinery and transportation equipment), it clearly indicates that the majority of the developing countries attracted relatively more FDI than imported equipments: 15

[16] They are: Argentina, Brazil, Chile, China, Colombia, Costa Rica, Hong Kong—SAR China, India, Indonesia, Korea, Mexico, Malaysia, Panama, the Philippines, Singapore, Thailand, and Venezuela. Eight of them are in Asia, and nine of them are in LAC.

out of the 17 countries with both trade and FDI data have a larger ratio of FDI-to-GDP than that of imports-to-GDP. Second, accumulated FDI stocks-to-GDP ratio is still very small for almost all developing countries, except for Costa Rica, and Panama.[18] And third, all of the developing countries experience a positive growth rate of trade-related, FDI-related and ITC-related North foreign R&D indices, except Argentina, which has a negative growth rate of FDI-related North foreign R&D, possibly due to the financial crisis during that time period which deterred some potential FDI inflows.[19]

5. Empirical Results

5.1. Main Results

Tables 3 presents main results of the paper. Before describing the results, we would like to point out two tests. Take column (i) as example. The first is the test of overidentification. Basmann's test suggests that the instruments are valid with a t-statistics of 6.543 and a P-value of .162. In fact, Figures 1 to 3 scatter plot the actual and predicted values of $\Delta \ln TradeRD$, $\Delta \ln ITCRD^S$ and $\Delta \ln FDIRD$. The figures show that all plots are scattered around the trend line, indicating that IVs are valid.

We also tested whether the error terms are homoskedastic, and the test statistics indicated that we fail to reject the null hypothesis that the error terms are homoskedastic

[17] Education data for Macao-China are not reported in Barro-Lee dataset. Here, we assume that Macao's educational attainment is the same as Hong Kong's, given that the two regions are very similar in development stages, in culture and in political systems.

[18] In Costa Rica, though agriculture is still important in its economy, it developed a strong electronics industry, largely funded by foreign investment. Foreign investors remain attracted by the country's political stability and high education levels. In Panama, the enormous foreign investment on the Panama Canal reconstruction certainly takes its toll.

[19] The numbers reported here indicate the observed facts well. First, for example, in the past decade, China, together with Chile and Mexico, have been popular destinations for FDI, which are clearly evidenced by their high growth rates of FDI-related North foreign R&D: 0.209 for China, 0.211 for Chile and 0.106 for Mexico, all of which are larger than the average growth rate of the Northern R&D stocks (.048). Second,

(t = 80.03 and P-value=1.000). Hence, simple OLS in the second stage will lead to efficient estimates. Similar results are found in other columns as well.

Columns (i) to (iii) present the effects on TFP from each of the three channels, columns (iv) to (vi) with effects from two of the three channels, and column (vii) with effects from all three channels. What are the results? Firstly, trade, and ITC both significantly promote North-South technology diffusion, while FDI also generates North-South technology diffusion, which is not always significant. All columns suggest a positive and significant elasticity of TFP with respect to either trade-related or ITC-related foreign R&D, while FDI-related North foreign R&D only generates positive effects on TFP growth without the presence of trade-related North foreign R&D.

Secondly, a closer look shows that ITC-related foreign North R&D has the largest effects on TFP growth, followed in order by trade-related, and then by FDI-related North R&D. Column (vii) (with results less likely to suffer omitted variables biases) shows that the elasticity of TFP with respect to ITC-related, trade-related, and FDI-related technology diffusion is .357, .114 and .010 respectively, the former two are significantly different from zero at the 1% level, where the last one is not significant. Or in other words, the effects from FDI are at the most 3% of those from ITC, and 9% of those from trade. The effects of trade are about one third of those from ITC. F-tests show that those elasticities are statistically different from each other. The results imply that a one percentage point increase in ITC-related, trade-related, and FDI-related North foreign R&D will increase TFP in the South by about .36%, .1%, and .11% respectively. Further, given an equal increase of 1% in the R&D stock of each of the 20 industralized OECD

the growth rate of FDI-related North R&D is larger than that of trade-related R&D, which mirrors the fact that FDI outgrows trade flows in the last decade.

countries, TFP growth rate in developing countries will increase by about .48% (=.36% + .01% +.11%) , which is tested to be significantly less than 1%.

Thirdly, the results suggest that the effects on the growth of TFP of trade-related, of ITC-related and of FDI-related technology diffusion are biased upward without the presence of the other channels. Let's look at the effects from trade-related foreign R&D first. Not including other channels leads to about .16 of the elasticity of TFP with respect to trade-related foreign R&D. However, that elasticity is decreased to .11 (columns, v and vii) with the presence of ITC-related foreign R&D. Or, the effects of trade-related foreign R&D index are biased upward by about 36% [= (.155-.114)/.114]. Similarly, the effects of ITC-related foreign R&D index are biased upward by 36% [= (.484-.357)/.357]. For the impact on TFP from FDI-related foreign R&D, it is significant when trade channel is not included, and insignificant once trade channel is included, a result suggesting that FDI tends to pick up the effects mostly from trade.

Turning to human capital, it is significant across all specifications, indicating that the bigger the increase in human capital, the faster the TFP growth.[20]

5.2. Comparison with the Literature

How do our results compare with those in the literature? First, on the channel of trade-related technology diffusion, Coe et al. (1997) is the closest to our analysis. They report that the elasticity of TFP with respect to North-South trade-related R&D is about

[20] We also examined whether a country's human capital has additional impact on TFP growth through increasing the North-South technology diffusion by also including the cross product of human capital with each of the three channels of North foreign R&D indices—one way to measure the host country's absorptive capacity. We did not get any significant additional impacts, a similar finding also reported in Falvey et al. (2005). These findings suggest that more research is needed in understanding the host country's absorptive capacity. As pointed out by Abramowtiz (1986) that absorptive capacity is

0.06, much smaller than what is found here (about .300). The difference is probably due to the fact that Coe et al. include 77 developing countries, many of which did not import many machinery and transportation equipments (less trade in general), implying a weaker North-South economic link, which tends to reduce the measured effect of North-South trade-related technology diffusion.

Second, on the effectiveness of FDI-related international technology diffusion, Borensztein et al. (1998) show that on average, an increase of .005 in the FDI-to-GDP ratio (equivalent to one standard deviation in their sample) ratio raises the growth rate of the host economy by .3 percentage points per year. In our case, given an average of FDI-to-GDP ratio of .0414 (Table 2), an increase of .005 in the FDI-to-GDP ratio implies roughly a 12.08% increase in the FDI-related North foreign R&D, which implies an increase in the growth rate of TFP in the South is about .38 (12%*.032, the elasticity is from column ii in table 3, as Borensztein et al. only focus on FDI-related technology diffusion) percentage points per year, a bigger impact than that in Borensztein et al. The bigger impact here is probably due to the fact that we build a FDI-related foreign R&D, which also takes into account the FDI source countries' technology besides the FDI-to-GDP ratios.

Turning to ITC-related technology diffusion, the closest one is Wong (2004). Wong uses a cross-section study and concludes that international call traffic is better in bridging countries' income gaps than trade, which are consistent with our findings that the effects from ITC-related technology diffusion are statistically larger than those from trade-related. However, we believe our measurement of ITC-related technology diffusion

multidimensional, with education being one dimension. Due to data problems, it is not feasible to have an index of absorptive capacity compiled from several dimensions.

(also trade-related technology diffusion) is an improvement over Wong's. As we will see a little later in the robustness checks, failing to account for the technology levels from a country's conversation partners leads to a much smaller impact from ITC (section 5.4).

5.3. Sensitivity Analysis

The unbalanced dataset implies an open question on how sensitive the empirical results on the sample size, as FDI data are only available for 17 out of the 30 countries in the sample. Further, for the 17 countries, they have higher ratios of trade-to-GDP and higher ITC per capita than those for the whole sample: the average ratio of imports of machinery and transportation equipment to GDP is .439%, verse .365%; and the average ratio of ITC per capita is 322.34 minutes, verse 290.73 minutes. The above numbers suggest that those countries with FDI data are relatively more open, which might make people wonder how sensitive our results are to countries with/without FDI data. However, what matters is the growth of the trade-related, and ITC-related foreign R&D. As long as the average growth rates of the trade-, FDI-, and ITC-related foreign R&D for the 17 countries are not different from those for the whole sample, we do not expect to see statistically different results. A check on the average growth rates of the 17 countries verse the whole sample indicates that they are about the same. Nonetheless, we limit ourselves with only the 17 countries, and use same instruments of the lagged values of all three independent variables together with their square terms, as well as cross products to predict the growth rates of trade-related and ITC-related foreign R&D (9 items). We re-estimate the regressions in Table 3 with the newly predicted values of $\Delta \ln \widehat{TradeRD}$ and $\Delta \ln \widehat{ITCRD}^{S}$. The new results are presented in Table 4.

A simple comparison of the results in Tables 3 and 4 reveals that the impact from trade-related foreign R&D is similar for the 17 countries as those for the 30 countries, with similar findings for ITC-related foreign R&D indices. This implies that our results are not sensitive to the samples. All of the other earlier findings hold here.

5.4. How Important Are the Volume of Trade, FDI and ITC in TFP Growth?

Given our measurement of trade-related, FDI-related and ITC-related North foreign R&D indices, people might argue that the significant impact from trade- and ITC-related foreign R&D indices are not primarily driven from the growth in trade or in ITC per se, but rather from the growth in their Northern partners' R&D stocks. To show the importance of the growth of volume of trade, FDI and ITC respectively, we constructed another set of trade-related, FDI-related, and ITC-related North foreign R&D indices holding each Northern country's R&D stocks fixed at its initial levels (year 1981). This implies that the growth rates of trade-related, FDI-related, and ITC-related North foreign R&D indices are entirely driven by the growth in the ratios of imports-to-GDP, FDI-to-GDP, and ITC in minutes per capita respectively. Here, we choose to use the 17 countries with data on trade, FDI and ITC in order to be able to use the full set of the lagged terms as IV. We would expect that the magnitudes of the elasticities of TFP with respect to trade-related, FDI-related, and ITC-related North foreign R&D indices are not bigger than those reported in Table 4 respectively.

Following the same procedure of the IV estimation, Table 5 presents the second stage empirical results. A comparison between results in Table 5 and those in Table 4 reveals the following. Firstly, the elasticity of TFP with respect to trade is statistically similar to those in Table 4, the elasticity of TFP with respect to ITC ceases to be statistically significant, while the elasticity of TFP with respect to FDI either becomes smaller (column, ii) or remains nonsignificant (column, vii).

Secondly, contrary to what we have found earlier, the effects on TFP from trade are now the largest, followed by those from ITC, and then by those from FDI, with the latter two not significant. The elasticity of TFP with respect to trade, ITC and FDI are .155, .011 and .134 respectively. F-tests showed that the impact of trade is significantly different from that of ITC, or from that of FDI, while the impacts of the latter two are not statistically different from each other.[21]

Thirdly, the results imply that the effects on TFP growth of trade-related foreign R&D are primarily driven by the growth in imports-to-GDP, while the effects of ITC-related North foreign R&D index is largely driven by the growth in North's R&D stocks. The huge drop in the impact from ITC tends to emphasize the argument made in the paper that not only the volume of the ITC matters, but also the conversation partners' technology.

6. Concluding Remarks

There is a growing literature examining international technology diffusion. This paper analyzes the effects on TFP in developing countries in Asia, Latin America and the Caribbean (LAC) of technology developed in the North that is diffused through international telecommunications in call traffic, trade, and FDI. Our sample consists of 30 developing countries (13 in Asia and 17 in LAC) from 1981 to 2000, with 20

[21] The new measurements of trade-related and ITC-related foreign R&D indices are in essence similar to the ones in Wong (2004), though Wong (2004) does not take into account partner country's technology.

industralized OECD countries as technology sources. For each developing country, we build three independent variables of trade-related, FDI-related, and international telecommunications-related North foreign R&D indices, using country-specific R&D stocks in the North, and respectively with its bilateral trade patterns, FDI patterns and ITC volumes with each country in the North. We explicitly control for endogeneity problems associated with trade, FDI and international telecommunications by using instrumental variables.

The main findings are: (i) trade and international telecommunications significantly promote technology diffusion from the North to the South in terms of improving developing countries' TFP growth; while FDI also generates some positive and significant diffusion, though statistically weak; (ii) the effects on TFP growth are the largest from international telecommunications-related North foreign R&D index, and the effects from FDI-related North foreign R&D are the smallest, with those from trade-related North foreign R&D index in between; and (iii) the effects on TFP from trade-related North foreign R&D indices are primarily driven by the growth in developing countries' imports-to-GDP ratios and FDI-to-GDP ratios respectively, while the effects from international telecommunications-related North foreign R&D are largely due to the growth in industrialized technology.

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Table 1. Summary Statistics for Northern R&D Stocks: 1981-2000

Country	Average yearly R&D stocks (US$ Billion)	Average Annual Growth Rate (%)
Australia	31.6	4.8
Austria	1.12	7.6
Belgium-Luxemburg	0.54	6.8
Canada	66.4	4.1
Denmark	13.5	8.8
Finland	2.35	8.5
France	30.5	4.6
Germany	152	5.0
Iceland	0.45	10.1
Ireland	3.81	10.3
Italy	0.04	6.0
Japan	617	8.2
Netherlands	20.6	4.4
Norway	13.3	5.5
Portugal	10.4	12.4
Spain	0.12	10.6
Sweden	45.3	5.2
Switzerland	40.3	4.8
United Kingdom	178	2.0
United States	1300	3.7
All Countries	2520	4.8

Table 2: Summary Statistics in Developing Countries: 1981-2000

Countries	Average ratios of			Average Annual Growth Rate of		
	FDI/GDP (%)	Imports of MT/GDP (%)	ITC/Pop. (in Minutes)	FDIRD	TradeRD	$ITCRD^S$
Argentina	0.57	0.07	68.01	8.7	-0.2	13.5
Bangladesh	--	0.08	8.75	--	5.2	14.8
Bolivia	--	0.32	85.36	--	8.7	9.5
Brazil	0.75	0.07	25.85	7.1	13.0	15.6
Chile	1.21	0.26	134.21	21.1	9.6	15.8
China	0.17	0.25	5.27	20.9	5.7	30.4
Colombia	0.80	0.18	149.82	5.4	5.0	9.5
Costa Rica	6.36	0.36	418.49	19.5	13.7	9.4
Ecuador	--	0.31	215.08	--	3.7	7.6
El Salvador	--	0.27	821.70	--	10.1	11.0
Guatemala	--	0.26	391.15	--	13.7	4.6
Honduras	--	0.51	558.15	--	11.3	3.9
Hong Kong	2.35	0.75	1557.51	8.1	10.6	17.3
India	0.10	0.08	5.28	7.6	2.0	24.7
Indonesia	1.67	0.30	9.09	1.4	1.1	15.8
Korea	0.28	0.31	177.81	8.7	7.3	16.8
Macao	--	0.20	441.34	--	7.8	21.6
Malaysia	1.48	1.08	105.52	6.6	8.6	17.8
Mexico	0.76	0.48	438.47	10.6	19.4	13.4
Nicaragua	--	0.57	326.00	--	23.3	4.4
Pakistan	--	0.21	37.80	--	1.2	18.6
Panama	47.58	0.31	606.91	81.7	11.1	5.2
Paraguay	--	0.23	48.41	--	11.5	5.2
Peru	--	0.14	86.20	--	8.3	13.7
Philippines	0.99	0.36	102.76	6.3	16.3	14.5
Singapore	3.75	1.83	1496.64	9.5	6.5	17.7
Sri Lanka	--	0.29	82.00	--	2.9	13.9
Thailand	0.86	0.44	41.69	8.9	10.5	19.3
Uruguay	--	0.10	140.17	--	15.2	15.6
Venezuela	0.73	0.33	136.41	51.9	2.3	6.8
All Countries	4.14	0.37	290.72	17.4	8.2	15.7

MT: machinery and transportation equipment. *ITC:* international telephone call traffic. *FDIRD*, *TradeRD*, and $ITCRD^S$ are FDI-related, trade-related, and international telecommunications-related North foreign R&D indices, described in Section 3.

Table 3: The Determinants of TFP

(Dependent variable: DlnTFP)

Variables	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
DlnTradeRD	**.155*****			**.159*****	**.110*****		**.114*****
	(6.79)			***(5.71)***	***(4.93)***		***(4.31)***
DlnFDIRD		**.032****		**.012**		**.023***	**.010**
		(2.00)		***(0.83)***		***(1.65)***	***(0.79)***
DlnITCRD^{S}			**.484*****		**.368*****	**.453*****	**.357*****
			(7.32)		***(5.56)***	***(6.46)***	***(5.18)***
?HC	**0.127*****	**0.173*****	**0.118*****	**0.116*****	**0.093*****	**0.103*****	**0.077****
	(3.53)	***(4.11)***	***(3.32)***	***(3.00)***	***(2.76)***	***(2.73)***	***(2.15)***
Total effects on TFP: Smaller than 1?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
F-stat of joint Significance	**37.00**	**10.42**	**41.23**	**19.71**	**39.50**	**23.31**	**24.81**
P-value	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Observations	**190**	**135**	**190**	**135**	**190**	**135**	**135**

Note: There are 30 countries in the sample. All variables are five-year moving first differences. Data are unbalanced due to missing observations. Figures in parentheses are t-statistics. Regression results on constant and country dummies are not reported. ***, ** and * denote significance level of 1%, 5% and 10% respectively. *HC* is human capital, measured in average total schooling years of population aged 25 and above. *TradeRD*, *FDIRD*, and *ITCRD*^{S} are trade-related, FDI-related and international telecommunications -related North R&D, defined in Section 3. ?ln*TradeRD*, ?ln*ITCRD*^{S} and ?ln*FDIRD* are instrumented variables. All variables are in five-year first differences.

Table 4: Sensitivity Analysis on the Determinants of TFP:

(Dependent variable: DlnTFP)

Variables	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
DlnTradeRD	**.163***** ***(6.15)***			**.157***** ***(5.85)***	**.122***** ***(4.76)***		**.116***** ***(4.48)***
DlnFDIRD		**.032**** ***(2.00)***		**.017** ***(1.20)***		**.027**** ***(1.98)***	**.017** ***(1.35)***
DlnITCRD^S			**.429***** ***(6.26)***		**.325***** ***(4.88)***	**.422***** ***(6.23)***	**.326***** ***(4.91)***
DHC	***.114******* ***(2.98)***	***.173******* ***(4.11)***	***.110******* ***(2.87)***	***.116******* ***(3.04)***	***.082****** ***(2.29)***	***.111******* ***(2.94)***	***.084****** ***(2.35)***
Total Growth Effects from Northern R&D: Smaller than one?	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***
F-stat of Joint Significance	**29.71**	**10.42**	**30.48**	**20.36**	**31.66**	**22.14**	**24.37**
P-value	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Observations	**135**	135	135	135	135	135	135

Note: This table is parallel to Table 3, except that the sample here is limited to the 17 countries which have data on FDI, and have on average higher ratios of imports-to-GDP and higher ITC per capita. Figures in parentheses are t-statistics. Regression results on constant and country dummies are not reported. *** and ** denote significance level of 1%, 5% respectively. *HC* is human capital, measured in average total years of schooling of population aged 25 and above. *TradeRD*, *FDIRD*, and *ITCRD^S* are trade-related, FDI-related and international telecommunications -related North R&D, defined in Section 3. ?ln *TradeRD*, ?ln*ITCRD^S* and ?ln*FDIRD* are instrumented variables. All variables are in five-year first differences.

Table 5: Robustness Check on the Determinants of TFP: Fixed Initial RD Stock of each Partner in the North

(Dependent variable: ΔlnTFP)

Variables	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
ΔlnTradeRD	**.195******			**0.186******	**0.179******		**0.155******
	(5.77)			***(5.29)***	***(4.26)***		***(3.33)***
ΔlnFDIRD		**0.021****		**0.008**		**0.025******	**0.011**
		(2.20)		***(0.89)***		***(2.80)***	***(1.20)***
ΔlnITCRD^{S}					**0.078**	**0.414******	**0.134**
					(0.65)	***(4.06)***	***(1.04)***
ΔHC	***0.056***	***0.115*******	***0.061***	***0.058***	***0.049***	***0.050***	***0.046***
	(1.35)	***(2.56)***	***(1.31)***	***(1.30)***	***(1.14)***	***(1.11)***	***(1.07)***
F-stat of Joint Significance	**21.05**	**5.96**	**10.47**	**14.27**	**14.10**	**10.03**	**10.98**
P-value	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Observations	**129**	**129**	**129**	**129**	**129**	**129**	**129**

Note: This table is parallel to Table 4, except that *TradeRD*, *FDIRD*, and *ITCRD*^{S} are defined with fixed RD stocks for each partner in the North at the first year of the period. Figures in parentheses are t-statistics. Regression results on constant and country dummies are not reported. *** and ** denote significance level of 1% and 5% respectively. *HC* is human capital, measured in average total years of schooling of population aged 25 and above. *TradeRD*, *FDIRD,* and *ITCRD*^{S} are trade-related, FDI-related and international telecommunications -related North R&D, defined in Section 3. ?ln*TradeRD*, ?ln*ITCRD*^{S} and ?ln*FDIRD* are instrumented variables. All variables are in five-year first differences.

Figure1: Scatter Plot of $\Delta \ln TradeRD$ and its Predicted Values

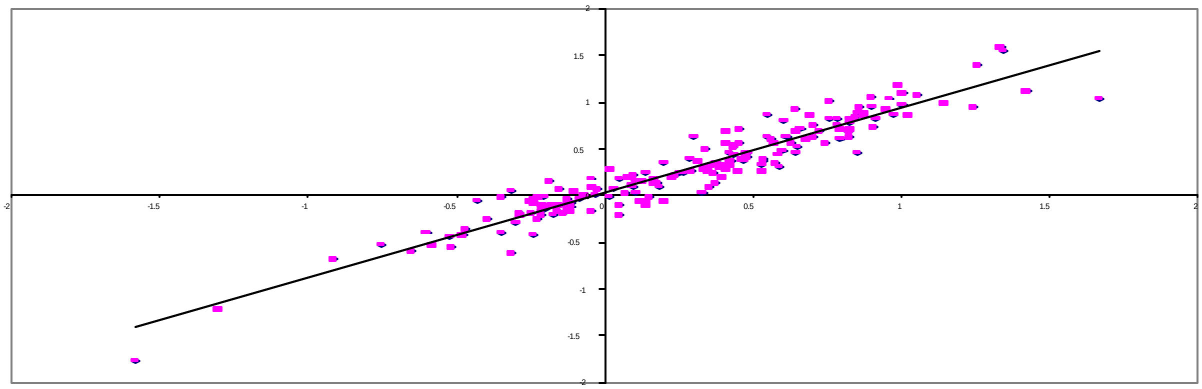

Figure2: Scatter Plot of $\Delta \ln ITCRD^S$ and its Predicted Values

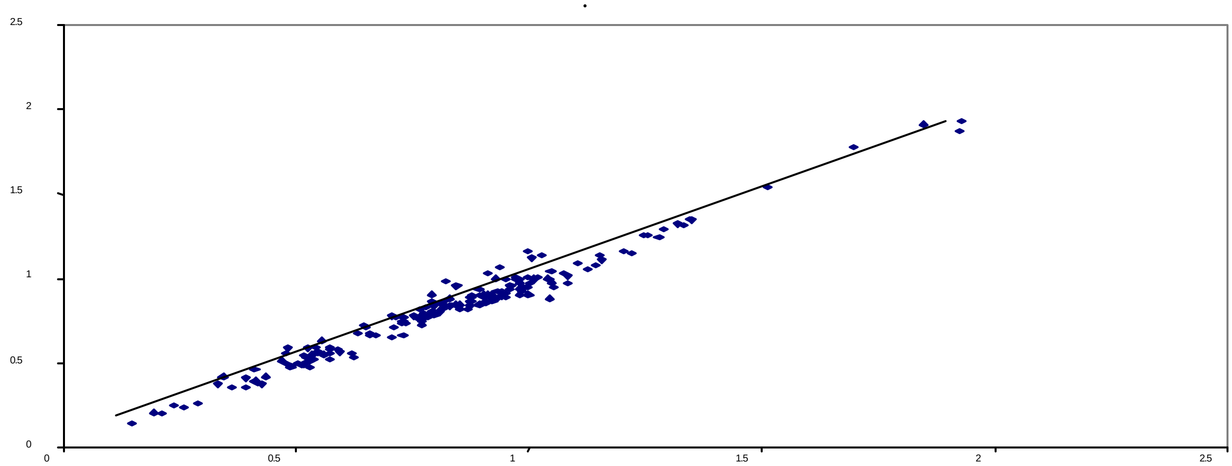

Figure3: Scatter Plot of $\Delta \ln FDIRD$ and its Predicted Values