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Foreign Capital, Human Capital, and Efficiency: A Stochastic Frontier Analysis for Developing Countries

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Summary. — We use stochastic Frontier analysis to study which of the three channels of technology diffusion, foreign direct investment (FDI), imports of machinery and equipment, or imports of research and development (R&D) expenditures, affect the total factor productivity of developing countries. We also analyze whether a developing country's openness to technology diffusion is affected by their existing levels of human capital. We find that FDI, imported capital goods, and imported R&D are all important channels for improving efficiency, as is human capital accumulation. However, the positive effect of FDI, imported capital goods, and imported R&D depends crucially on the level of accumulated human capital. In addition, we find that in the process of technology diffusion, the impact of formal education is more important for imported R&D than it is for imported capital and FDI, whereas the opposite is true for learning by doing, which is found to be more important for knowledge diffusion through FDI and imported capital.

Key words — technology diffusion, foreign capital, human capital, stochastic Frontier model

> . . .because knowledge is the quintessential public good, a country that integrates itself into the world economy often can benefit from learning that takes place outside its border. Grossman and Helpman (1994).

1. INTRODUCTION

The debate on whether economies that are open to the rest of the world see faster economic growth goes back to the time of Adam Smith and continues even today. One way that international trade can help in the process of economic growth is by transferring the benefits of technology across borders. Seminal papers by Grossman and Helpman (1991) and Barro and Sala-i-Martin (1995) argued that larger trade implies greater openness which helps in an economy's adoption of more efficient techniques of production. This technology transfer or technology diffusion leads to faster growth of total factor productivity and, hence, faster growth in *per capita* income levels. Moreover, the "new" growth theory of Romer (1990) and Barro (1997) has human capital playing an important role in growth because human capital can help in explaining an economy's capacity to absorb new technologies (Abromovitz, 1986; Cohen & Levinthal, 1989; Kneller, 2005; Kneller & Stevens, 2006).

Recent empirical research by Eaton and Kortum (2001) showed that only a few research and development (R&D) intensive countries produce most of the world's capital; the rest of the world just imports this equipment that embodies new technology. Consequently, a country's productivity "depends on its access to capital goods from around the world and its willingness and ability to use them (p. 1196)." This is also collaborated by Caselli and Coleman (2001) who in their studies show that most countries acquire embodied technologies through capital imports from world technological leaders. In the context of developing countries this is especially important because growth in total factor productivity can be affected by the extent of their adoption and implementation of new technologies that are already in use in developed countries. In addition, how well they use these technologies can be affected by the level of human capital in these countries. [1] For example, Benhabib and Spiegel's (1994) empirical study suggests that human capital plays a role in economic growth by helping in the adoption of technology from abroad and in creating the appropriate domestic technology.

In response to the question of how technology diffusion affects economic growth, there has been an emerging empirical literature examining the nexus between the channels of technology diffusion, openness, and human capital in promoting economic growth. The evidence on this issue is mixed as seen in the differing conclusions of Miller and Upadhyay (2000, 2002), and Olofsdotter (1998). [2] However, a consistent feature of all the empirical studies on this issue is the use of a cross-country regressions framework on a sample of developed and developing countries. Cross-country regressions cannot control for the unobservable heterogeneity which can arise, for example, from the different institutions in the various countries. Furthermore, Rodriguez (2006) argued that policy analysis within the growth-regression framework can carry considerable risks from the misspecification bias that come from using such a specification when it is not valid.

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In order to avoid the pitfalls of these cross-regression studies we use an alternative empirical methodology, stochastic Frontier analysis, to answer our research question of whether a developing country's openness to technology diffusion is affected by their existing levels of human capital. [3] In our empirical framework, technology diffusion can take place through either flows of foreign direct investment, through imports of foreign capital, or through imported R&D. We estimate a stochastic production Frontier for developing countries to determine the three channels through which greater openness diffuses technology—the foreign direct investment (FDI) channel, the imported capital channel, and the imported R&D channel. In addition, by using this empirical methodology we can also study the interaction between these three channels by which greater openness diffuses technology and the existing level of human capital in the country. There have been earlier studies which have looked at the impact of each of these three channels on production efficiency or some combination of these channels. However, to the best of our knowledge, there is no study which has investigated all three channels through which openness diffuses technology for developing countries simultaneously. By investigating the interaction between all three channels of openness (FDI, imported capital goods, and imported R&D) and human capital we can determine what has been a source of growth in total factor productivity in developing countries.

We apply stochastic Frontier analysis in a macroeconomics context, where countries are producers of output (i.e., GDP) given inputs (e.g., capital, labor, and technology), to empirically examine the role of foreign capital in the process of technology diffusion in developing countries. This closely matches the concept of Frontier technology and the innovation of technology found in growth theory (Acemoglu, Aghion, & Zilibotti, 2006; Aghion, Harris, Howitt, & Vickers, 2001, 1997). In this context, countries can be thought of as operating either on or within the Frontier, with the distance from the Frontier reflecting inefficiency. Over time, a country can reduce its inefficiencies and reach the Frontier or the Frontier itself can shift outwards over time, indicating technical progress. [4] Moreover, a country can move along the Frontier by changing inputs. Thus, output growth can be seen as being made up of three components: efficiency change, technical change, and input change with the first two components being the "productivity change" (Koop, Osiewalski, & Steel, 2000a).

We find two important results. First, we find that FDI, imported capital goods, and imported R&D are important channels for improving efficiency, as is human capital accumulation. However, there is an important difference between the three channels in that knowledge diffused through human capital is more general, or disembodied, than knowledge diffused from FDI and imported R&D, which tend to be more embodied. Second, we find that the positive effects of FDI, imported capital goods, and imported R&D depend crucially on the level of accumulated human capital. Moreover, we find that in the process of technology diffusion the impact of human capital in the form of accumulated formal education is more important for imported R&D than it is for imported capital and FDI. However, human capital that is more specific, like learning by doing, is more important for knowledge diffusion through imported capital and FDI.

The remainder of the paper is organized as follows: In Section 2, we discuss the role of technology diffusion, openness, and human capital in developing countries. We then construct the empirical model in Section 3 and present the estimation strategy in Section 4. In Section 5, we discuss the empirical results. We conclude in Section 6.

2. PREVIOUS RESEARCH ON TECHNOLOGY DIFFUSION, HUMAN CAPITAL AND OPENNESS

(a) *Channels of technology diffusion*

The diffusion of technology is a continuous and slow process. A recent World Bank publication (Hoekman & Javorcik, 2006) suggested that countries which are more open to the rest of the world facilitate the diffusion of knowledge since "undistorted access to capital equipment and imported inputs that embody foreign knowledge allow firms to acquire know-how." Besides imported inputs, an open developing economy can have several channels through which technology diffusion can take place in developing countries. First, there is foreign direct investment when a foreign multinational company with more advanced technology invests in the economy. The second channel is *via* imports of high-technology capital goods. The third channel of technology diffusion is *via* the adoption of foreign technology through technology licensing or technology purchase. The final channel is through the transfer of human capital through other means like international labor immigration (Chou & Wong, 2001). These different channels are reflected in the varied theoretical frameworks that show technology diffusion. For example, Borensztein, De Gregorio, and Lee (1998) developed a model where long-run economic growth is determined by technological progress that takes place *via* a process of "capital deepening" as new varieties of capital goods are introduced.

Some of the early empirical studies that have emphasized the role of openness are by Coe and Helpman (1995), Coe, Helpman, and Hoffmeister (1997), and Keller (1998), where imports are considered to be a means of introducing foreign technology into domestic production and raising total factor productivity. They show that countries that have imported more machinery and equipment from world technology leaders have seen faster growth in total factor productivity. The role of human capital in hastening economic growth is seen in Benhabib and Spiegel's (1994) empirical study which suggested that human capital plays a role in economic growth by helping in the adoption of technology from abroad and in creating the appropriate domestic technology.

(b) *Mixed evidence*

The empirical results of studies that have looked at the interrelationships between the various channels of technology diffusion, openness, and human capital in promoting economic growth have been mixed. Borensztein *et al.* (1998) looked at the role of foreign direct investment (FDI) in the process of technology diffusion and economic growth in 69 developing countries and find that the impact of FDI on *per capita* growth depends upon the accumulated threshold level of human capital in the host economy. This threshold effect is also demonstrated by Xu's (2000) study of 40 countries, which uses US multinational enterprises as the channel of international technology diffusion. He also found that a country needs to reach a minimum level of human capital to benefit from this technology transfer. Navaretti and Tarr (2000) found that inflows of technology are more beneficial, the faster importers are able to master new knowledge. Similarly, Miller and Upadhyay (2000) found that open economies benefit from higher total factor productivity. In particular, the negative effect of human capital on the total factor productivity of low-income countries changes to a positive effect as a country moves from a low to a higher level of openness. Mayers (2001) using a cross-country growth-accounting framework investigated the