Determinants of Foreign Direct Investment: Evidence from the Semiconductor Industry

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Abstract

This paper examines the determinants of foreign direct investment (FDI) in semiconductor fabrication plants in 24 countries over the period 1985 to 2002. Semiconductor investment is of interest because semiconductor manufacturing is a large, high technology industry that is economically important in many advanced and developing countries. Using a unique international dataset of semiconductor fabrication plants, combined with macroeconomic data from home and host countries, we compare FDI and domestic investments to understand what factors explain why a firm invests in a given country as opposed to remaining a purely domestic entity. Our empirical estimates are based on a theoretical framework that uses Tobin's *q* theory, which is a significant departure from the knowledge-capital models of multinational enterprises that dominate the existing literature. Our results indicate that labor costs and the real exchange rate are important factors in explaining FDI in the semiconductor industry; we find almost no evidence to support gravity-type variables such as distance or language differences as being motivations for FDI in this industry.

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1. Introduction

An important feature of globalization in the past two decades has been the increasingly important role of multinational enterprises' (MNEs) activities across countries, and consequently, significant increases in foreign direct investment (FDI) flows. As international capital markets became more integrated in the 1990s, global FDI flows grew faster than world output, world trade, or world economic growth. The potential effects of FDI flows on labor markets, particularly their impact on the wages of unskilled home and recipient country workers, have also generated a lot of public and academic debate. This prompted economists to build models of the MNE and to develop empirical frameworks that could help identify the determinants of FDI flows[1]. In terms of distribution, even though developed countries account for a substantial share of both inflows and outflows of FDI (for example, 70% and 94% respectively for 2001), some developing countries such as China and Mexico are now becoming important players in this market[2]. The resource flow implications of FDI, especially for developing countries, provides yet another reason why one should spend some time analyzing the determinants of FDI flows.

This paper examines the determinants of FDI in semiconductor fabrication plants in 24 countries over the period 1985 to 2002. It is important, at the outset, to distinguish foreign portfolio investment (FPI) from FDI, which are two different types of private international capital flows. Current world FPI flows are much larger than world FDI flows, and they refer to the movement of financial capital in search of higher returns,

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[1] Other social scientists, in particular from political science and political economy have also spent a great deal of time looking at the political determinants of FDI flows, namely the role of political regimes and institutions in attracting FDI flows.

which in a world of perfect capital mobility, should lead to the equalization of risk-adjusted returns. FPI flows have contributed to the growth of equity markets but have also been partly held responsible for currency crises (such as in Mexico or East Asia). FDI, on the other hand, refers to a situation where the investor acquires a controlling interest in a foreign enterprise or builds a subsidiary in a foreign country. Hence, FDI implies a long-term relationship, as well as a transfer of resources and management control. The IMF definition, for example, specifies that an investment is considered as FDI if the investor has acquired 10 percent or more of the ordinary shares or voting power of an enterprise abroad.

Our paper contributes to the existing empirical literature in several ways. First, we use a unique database of investment projects at semiconductor fabrication plants. By studying a single industry, the heterogeneity of investment projects is greatly reduced. The semiconductor industry provides a useful case study for several reasons. It is an economically important industry with worldwide shipments of during the 1990s ranging from \$25 billion to \$50 billion per year in 1996 U.S. dollars.[3] Jorgenson (2001) shows that the semiconductor industry is the most important component of the information technology sector because semiconductor product cycles generate the lower prices that drive productivity growth.

Second, we base our empirical estimates on a theoretical framework that uses Tobin's *q* theory, which puts the firm's FDI decision in the context of an intertemporal investment decision, rather than a trade-based framework. This represents something of a departure from the knowledge-capital models of multinational enterprises, which tend to

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[2] This finding thus contradicts the "conventional wisdom" that MNEs are prevalent in developing countries.
[3] Semiconductor Industry Association estimates.

dominate the existing literature, yet is intuitively appealing since it links FDI to investment directly. Third, our data structure allows us to consider bilateral relationships between many countries whereas many studies only consider FDI to or from a single country. Our results are based on panel data estimates over the period 1985 to 2002. The findings indicate that labor costs and the real exchange rate are important factors in explaining FDI in the semiconductor industry. We find almost no evidence to support gravity-type variables such as distance or language differences as being motivations for FDI in this industry. In addition, real exchange rate movements remain significant for the domestic (home country) investments made by multinational firms.

The rest of the paper proceeds as follows. Section 2 briefly reviews the literature pertinent to our analysis. Section 3 presents the theoretical model of FDI based on De Santis *et al* (2004). Section 4 explains the empirical strategy employed to estimate the equations for domestic investment and FDI. Section 5 describes the data set we will be using in our regressions and provides summary statistics. Section 6 discusses the empirical results based on panel data estimation. Section 7 concludes. The Appendix provides further detail on data sources and variable definitions, and the tables of results from our regression analyses.

2. Literature Review

MNEs, by definition, are firms that integrate their activities whether they be production, management, research and development (horizontally, vertically or both) across borders. The question that one should then ask is why would a firm be interested in extending its activities to other countries. After all there are clear risks in doing so such as language and cultural differences, transport costs, different laws and business practices, imperfect information about markets and local conditions, and risks of expropriation among others. Profit-maximizing firms will therefore engage in FDI as long as there are more potential benefits to be realized from integrating activities internationally than there are risks.

Following Dunning (1977, 1981), it is now common to view these advantages as being related to ownership, location and internalization (the so-called *OLI* framework). Ownership advantages are unique features such as a patent, or technological advantage in the form of a better production process and new and better quality products that local firms do not possess, and that can be exploited. The location advantage refers to the characteristics of host countries that make it cost efficient to produce in the latter rather than exporting goods to them. The third element, internalization, has to do with licensing as opposed to exporting. Indeed, firms can sell the technology required to produce a good, and have local firms in another country produce it. However, this poses a few problems. First, it is difficult to determine a priori what price should be charged for the license. Second, if a license is provided, and contracts are not properly enforced (which is significant in countries without proper institutions), the owner of the license can sell the technology to others for a high reward. The internalization advantage, therefore, refers to the case where it is in the interest of a firm to control the exploitation of a good or asset, rather than allow someone else to be in charge of production.

Several papers in the trade literature build on the *OLI* framework, a number of papers by developing theoretical models that incorporate MNEs into a general equilibrium framework to explain why they would invest overseas. The taxonomy here is the horizontal model, the vertical model, and the knowledge-capital model, the latter being a hybrid of the former two. The horizontal model was first developed by Markusen (1984) and describes firms which carry out the same activities in multiple locations. According to this model, the driving forces for FDI rest on firm-level economies of scale and trade costs. Such multinational firms are more likely to exist when countries are similar in size and factor endowments (Markusen and Venables 1998). By engaging in FDI, the firm benefits from the existence of a plant at home (given that the costs of a new facility abroad are lower than the costs of a new firm). The firm will also face a trade-off between serving the foreign market through exports (which means that it pays trade costs) or producing in the foreign market (which means that it pays fixed costs); hence, high trade costs imply more horizontal FDI. The key in such models is the proximity to consumers.

The vertical model of the multinational firm was first formalized by Helpman (1984) and refers to a situation where there is an incentive for firms to fragment their production process into different stages in order to take advantage of differences in production costs through factor price differences. Hence, such multinational firms are more likely to exist when countries are dissimilar in size and factor endowments. Countries which are identical in size and factor endowments are thus expected not to engage in FDI because of the absence of cost differences. A prediction of the vertical model is that FDI should flow from a skill-abundant country (where the firm's headquarters are located and its nationality determined) to less skilled-abundant countries.

The third type of model for multinational firms is the knowledge-capital model (Markusen 1997), which integrates the horizontal and vertical models. Here, firms have the option of multiple plants or the geographical separation of headquarters and a single plant; they can choose among domestic, horizontal or vertical strategies. Allowance is therefore made for multiplant scale economies and the exploitation of factor price differences. Empirical investigations suggest strong support for the horizontal approach, but little support for the vertical approach (see for example Brainard (1997), Markusen and Maskus (1999b)), suggesting that horizontal FDI is more important than vertical FDI. The hybrid or "knowledge-capital" model has empirical support, but in some cases the evidence does not allow it to be distinguished from the horizontal model (Carr *et al* (2001); Blonigen *et al* (2003)).

De Santis, Anderton and Hijzen (2004) point out that the above models "look at the FDI implications for market structure, welfare, the equilibrium number of national and multinational firms in a static framework, where FDI is generally exogenously specified as a fixed cost to set-up a plant abroad. Similarly, the empirical studies based on these models generally develop predictions about affiliate production." (p. 8). Few papers explicitly consider green field investment decisions as a choice between domestic investment and FDI using standard investment theory, i.e. Tobin's Q. De Santis *et al* (2004) are an exception in that they develop and test a model of investment decision making by the multinational firm that includes both domestic and foreign investment. In their empirical work, however, they focus only on FDI levels. They find that their proxies for Q, stock market prices, are an important explanatory variable in estimating euro-area FDI to the United States.

In the current paper, we also consider FDI as being derived from an intertemporal maximization problem faced by the multinational firm. The theoretical framework (explained in the next section) adopts a standard investment approach based on *q* theory[4] of investment with convex adjustment costs. This framework is appropriate given that adjustment costs for international investment are likely to be higher than for domestic investment. Jovanovic and Rousseau (2002) have shown that the *q* theory of investment can explain why some firms buy other firms.[5] In particular, they find that a firm's merger and acquisition investment responds to its *q* more than its direct investment does because the latter is a high fixed cost and low marginal adjustment cost activity.

3. Theoretical Framework

This section provides some simple extensions to the model developed by De Santis *et al* (2004). Most importantly, we allow for differences in endowments of labour and human capital in the host and home countries. Since our data allows us to compare both domestic and foreign investment using plant-level data, but does not provide information on FDI plants' export or production flows after it is built, De Santis *et al* provide a natural theoretical framework in which to study FDI using our dataset. The model is set up as follows.

Multinational firms have two production functions, one for the home-country production, $G(K_t,L_t,W_t)$, and one for foreign host-country production, $F(K_t,L_t^F,W_t^F)$, where K_t is the firm's capital stock, L_t and L_t^F are labor inputs available in the home and foreign

[4] The Q-Theory of investment posits that a firm's investment rate will increase with its Q, which is the ratio of market value to the replacement cost of capital.
[5] Jovanovic and Rousseau (2002) use US firm level data for the period 1971-2000 to verify the theoretical predictions of their model.

country, and W_t and W_t^F represent the knowledge or human capital stock in each country. The common capital stock component implies that output can be produced using any of the firm's capital stock combined with labor and human capital available in particular countries. One way to think about this is that multinationals can fragment production by shipping partially made products from one plant to another for finishing, even if the second plant is in another country. In the semiconductor industry this can occur if a firm develops a chip design and some prototypes at an R&D plant, say in the home country, but the actual commercial scale production of that product is done at a fabrication plant overseas. The chips may then be sent to another plant in a third country for assembly and packing.

The firm's intertemporal optimization problem is to maximize the present discounted value of its profits by choosing domestic investment I_t and FDI_t, as well as domestic and foreign labour inputs, L_t and L_t^F. FDI may take the form of either mergers and acquisitions or new plant building. Both *FDI* and *I* are subject to convex costs of adjustment, that is, the marginal costs of adjustment are increasing in the rate of investment. The net real profit for an MNE firm *i* operating in both countries at time *t* can be expressed as V_{it},

$$V_{it} = \int_{s=t}^{\infty} e^{-r(s-t)} \left\{ \begin{aligned} &\left(\frac{p_s^F}{e_s} \left(F(K_s, L_s^F, W_s^F) - \frac{\varphi^{FDI}}{2} \frac{FDI_s^2}{K_s} \right) - FDI_s - \frac{w_s^F}{e_s} L_s^F \right. \\ &\left. + \left(p_s \left(G(K_s, L_s, W_s) - \frac{\phi^I}{2} \frac{I_s^2}{K_s} \right) - I_s - w_s L_s \right) \right. \end{aligned} \right\} ds$$

which is maximized subject to the evolution of the capital stock, $\dot{K} = FDI_t + I_t - \delta K_t$. In the expression for V_{it}, the cost of investment goods is assumed to be one and *r* is the real interest rate; p_s and p_s^F are the domestic and foreign good prices; φ parameterizes the cost of adjusting the capital stock either at home or abroad; e_s is the nominal exchange rate (host country currency relative to home country); and δ denotes the depreciation rate. The real interest rate and the depreciation rate are assumed to be constant to simplify the analysis, and costs of adjusting the firm's capital stock are assumed to be greater in the foreign than home country, i.e. $\varphi^{FDI} > \varphi^{I}$. This may be due to language or cultural differences, distance or other factors that raise the cost of adjusting capital stock abroad. The current-value Hamiltonian for this problem is

$$H_t\left\{I_t, FDI_t, L_t, L_t^F\right\} = \left(\frac{p_t^F}{e_t}\left(F(K_t, L_t^F, W_t^F\right) - \frac{\varphi^{FDI}}{2}\frac{FDI_t^2}{K_t}\right) - FDI_t - \frac{w_t^F}{e_t}L_t^F$$
$$+\left(p_t\left(G(K_t, L_t, W_t\right) - \frac{\phi^I}{2}\frac{I_t^2}{K_t}\right) - I_t - w_t L_t + q_t[I_t + FDI_t - \delta K_t]$$

where q is the shadow value of an additional unit of capital obtained in time t. The first order conditions with respect to the control variables I_t and FDI_t generate the familiar condition that the firm invests up to the point where the cost of acquiring a unit of capital equals its shadow value, q_t. Here, this condition applies to both domestic and foreign investment as shown by equations 1 and 2.

(1) $$1 + \frac{p_t^F}{e_t}\varphi^{FDI}\frac{FDI_t}{K_t} = q_t$$

(2) $$1 + p_t\varphi^I\frac{I_t}{K_t} = q_t$$

The first order conditions with respect to labor inputs equate the wage with the marginal product of labor in each country.

(3) $$p_t^F F_L = w_t^F$$

(4) $$p_t G_L = w_t$$

The derivative of H_t with respect to the state variable K_t yields an expression that equates the marginal revenue product of capital with the opportunity cost of a unit of capital,

(5) $$\frac{p_t^F}{e_t} F_K(K_t, L_t^F, W_t^F) + p_t G_K\left(K_t, L_t, W_t\right) = (r+\delta) q_t - \dot{q}_t$$

We assume that the value of the capital stock must approach zero, and that there are no permanent bubbles in q_t.[6] These assumptions allow us to solve (5) and find marginal q, the discounted stream of future marginal products of a unit of capital,

(6) $$q_t = (r+\delta)^{-1}\left[\frac{p_t^F}{e_t} F_K(K_t, L_t^F, W_t^F) + p_t G_K\left(K_t, L_t, W_t\right)\right]$$

Substituting q_t into (1) and (2) we can obtain expressions for FDI_t and I_t as shares of K_t:

(7) $$\frac{FDI_t}{K_t} = \frac{1}{\varphi^{FDI}} \frac{e_t}{p_t^F}\left\{(r+\delta)^{-1}\left[\frac{p_t^F}{e_t} F_K(K_t, L_t^F, W_t^F) + p_t G_K\left(K_t, L_t, W_t\right)\right] - 1\right\}$$

(8) $$\frac{I_t}{K_t} = \frac{1}{\varphi^I p_t}\left\{(r+\delta)^{-1}\left[\frac{p_t^F}{e_t} F_K(K_t, L_t^F, W_t^F) + p_t G_K\left(K_t, L_t, W_t\right)\right] - 1\right\}$$

Assuming Cobb-Douglas production functions for home and foreign operations, we get $F(K_t, L_t^F, W_t^F) = K_t^{1-\alpha} L_t^{F\alpha} W_t^F$ and $G(K_t, L_t, W_t) = K_t^{1-\alpha} L_t^{\alpha} W_t$, with $0<\alpha<1$. The respective marginal products of capital (MPK) will be $F_K = (1-\alpha) K_t^{-\alpha} L_t^{F\alpha} W_t^F$ and $G_K = (1-\alpha) K_t^{-\alpha} L_t^{\alpha} W_t$. Therefore the MPK in the foreign country can be written as a function of home country MPK and the relative stocks of labor and knowledge in each country,

(9) $$F_K = G_K \left(\frac{L_t^F}{L_t}\right)^{\alpha} \frac{W_t^F}{W_t}$$

Substituting F_K and G_K into equations 8 and 9 we obtain

(10) $$\frac{FDI_t}{K_t} = \frac{1}{\varphi^{FDI}} \frac{RER_t}{p_t^F}\left[\frac{p_t G_K}{(r+\delta)}\left(1 + RER_t \left(\frac{L_t^F}{L_t}\right)^{\alpha} \frac{W_t^F}{W_t}\right) - 1\right]$$

$$(11)\ \frac{I_t}{K_t} = \frac{1}{\varphi^I p_t}\left[\frac{p_t G_K}{(r+\delta)}\left(1 + RER_t \left(\frac{L_t^F}{L_t}\right)^{\alpha} \frac{W_t^F}{W_t}\right) - 1\right]$$

where $RER_t = p_t^F / e_t p_t$ is the real exchange rate expressed in terms of home currency.

Since G_K is the marginal product of capital in the home country, equations 10 and 11 tell us that *FDI* and *I* for a multinational firm depend on costs of adjustment, demand conditions (price of goods), the discounted stream of MPK in the home country, real exchange rates, and the relative sizes of labor and human capital stocks in the two countries. This model therefore also incorporates factor endowment differences (and hence price differences) that are widely believed to be a motivation for FDI. A purely domestic firm's optimal investment equation would be the same as equation 11 but the foreign component would be zero.

4. Estimation Strategy

In this section, we develop an empirical strategy to estimate foreign and home investment in the semiconductor industry based on equations (10) and (11). The two equations are estimated separately. The dataset consists of a three-dimensional panel of *N* firms denoted *i*=1,2,…*N* which own one or more fabrication plants denoted *j*, where *j*=1, 2,..*J*. The investment in a given plant occurs at time *t*, the year the investment project begins. In the panel, firms are the group variable, and plants are the specific observational unit belonging to a particular firm.[7]

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[6] That is, the transversality condition $\lim_{t\to\infty} e^{-rt} q_t K_t = 0$ holds, and $q_t \to 0$ as $t\to\infty$.

[7] This is slightly different from most panels where the cross-sectional unit is the group and the specific observations occur for that unit over time, usually denoted with subscripts *it*. Here we have firm *i* and plant *j*, because the different locations of plants belonging to the same firm is the focus of the analysis. The time dimension is controlled for with time dummies in the regression, but is not the focus.

Estimation of FDI

We first estimate the equation for a firm's rate of FDI, in which *FDI/K* is a function of adjustment costs in the foreign country, demand conditions in the foreign country, home country *q*, real exchange rate and the relative size of labor and human capital stocks in foreign versus home country. We can write a linear regression model in log form, closely related to equation 10 as follows,

(12)

$$\ln FDI_{ijt} - \ln K_{it} = \beta_0 - \beta_1 \ln \varphi_{ij}^{FDI} + \beta_2 \Delta \ln RER_t + \beta_3 \Delta \ln GDP_t^F + \beta_4 \Delta \ln q_t + \beta_5 (r_t^F - r_t)$$
$$+ \beta_6 \ln \frac{L_t^F}{L_t} + \beta_7 \ln \frac{W_t^F}{W_t} + \beta_8 FOUNDRY_{ij} + \mu_i + \varepsilon_{ijt}$$

The firm-specific fixed effect μ_i is assumed to include adjustment costs common to both domestic and foreign investment. The FDI adjustment costs are proxied by the log of distance in kilometers, and a dummy variable for different language. These adjustment cost measures are expected to decrease the rate of FDI investment. By incorporating distance into the foreign plant adjustment costs in the *q* theory framework, we are able to control for the type of transaction costs emphasized in gravity model frameworks common in the FDI literature. The third term is the real exchange rate measured by the ratio of GDP deflators and nominal bilateral exchange rates. The exchange rate is measured in units of foreign country currency per U.S. dollar. Therefore an increase in ln*RER* corresponds to a depreciation of the host country currency, which is expected to raise *FDI/K*. Host country GDP is included to reflect demand conditions in the foreign country. Since log of GDP is likely to be nonstationary, we take its first difference.

Under the assumption of Cobb-Douglas production, we can write discounted foreign MPK as a function of home MPK and relative factor supplies. Thus in our regression model, we include home country *q*, proxied by the log of the main stock price index in the country.[8] To control for possible nonstationarity, we take the change in log of *q*.[9] We expect that home country investment conditions measured by *q* would have a positive effect on FDI. Although *q* already incorporates the user cost of capital, however, the theoretical model assumes that *r* is constant and equal between countries. Therefore the regressions include the real interest rate differential, specifically foreign less home country interest rate. An increase (r^F-r) is expected to decrease the rate of FDI, since it implies foreign cost of capital has increased relative to the home country.

Labor stocks are proxied by population. The stock of knowledge or human capital is approximated by the total number of commercial R&D semiconductor fabrication plants existing in each country in period *t-1*. This measure was chosen to reflect relative endowments of knowledge and human capital specific to this industry. Depending on the motive for FDI, the signs on these two terms could be either positive or negative. Heckscher-Ohlin models of trade suggest that firms would locate where factors are more abundant and less expensive. If labor costs are a primary driver, we expect $\ln L^F/L$ will have a positive sign. New growth theories suggest that human capital or technical knowledge is an important factor in firm decision-making. FDI for technology or knowledge seeking purposes would mean *FDI/K* is increasing in $\ln W^F/W$. A dummy

[8] Barro (1990) indicates that stock market prices provide a good proxy for discounted MPK. Marginal *q* is actually stock market capitalization divided by the replacement cost of capital under constant returns to scale, however, DeSantis et al (2004) show that it is highly correlated with stock price movements.

[9] The standard panel unit root tests that require a balanced panel, so we could not formally test for non-stationarity. Instead we plotted the mean and median values for each series over time. q and GDP appeared potentially nonstationary, so we use the first difference for those variables. The other variables did not appear to have any time trends for our sample, however, year dummy variables are also included.

variable indicating if the plant is a foundry plant to control for vertically structured MNEs is included. Foundry plants produce chips but do not usually design them, requiring less skilled labor. If FDI is done to obtain skills this would likely have a negative sign in the regression. If FDI is done to take advantage of an abundance of less skilled labor, we expect a positive sign on the *FOUNDRY* dummy.

Estimation of Domestic Investment

In a final set of regressions, we estimate domestic investment for domestic and multinational firms. Recall that equations 8 and 11 describe the domestic investment rate for multinational firms with both domestic and foreign plants. Most importantly, the theoretical model predicts that a multinational firm's domestic investments depend not only on the MPK of domestic investment, G_K, but also on the MPK of the firm's foreign investments in capital stock, F_K, since the q term includes both. The *I/K* equations also indicate that domestic investment by MNEs also depends on the real exchange rate and relative endowments of labour and human capital. To empirically estimate these relationships for *I/K* we use equation 13, which includes both home country and foreign country variables.

$$\ln I_{ijt} - \ln K_{it} = \beta_0 + \beta_1 \Delta \ln GDP_t + \beta_2 \Delta \ln q_t + \beta_3 r_t + \beta_4 \Delta \ln GDP_t^F + \beta_5 \ln \varphi_{ij}^{FDI} + \beta_6 \ln \frac{L_t^F}{L_t} + \beta_7 \ln \frac{W_t^F}{W_t} + \beta_8 \Delta \ln RER_t^F + \beta_9 FOUNDRY_{ij} + \mu_i + \varepsilon_{ijt} \quad (13)$$

The first three variables are home country GDP growth, q and real interest rates, which reflect home country demand conditions, MPK and cost of capital. The next four terms are the foreign components: foreign country demand (GDP growth), adjustment costs (distance and different language dummy), and relative factor differences. To operationalize the foreign term we take the average across all the foreign countries or plants that the firm is doing FDI in for that year. For example, suppose we observe a new domestic investment by a US based multinational in 1995, and this company also built FDI plants in Ireland and Japan that year. We calculate the foreign components by taking the average of stock market price changes (*q* proxy), distance, ΔlnGDP and ΔlnRER relative to the US, and differences in labour and human capital endowments compared to the US, for both Ireland and Japan for 1995. Since we also have many firms that are not MNEs in the sample, the foreign variables for those firms are set to zero.

The regressions all include a time-trend variable as an additional control for possible nonstationarity. Because we have a small number of observations, we use a year variable as a time trend rather than time dummies. The next section provides summary statistics for the regression variables and describes the data. The appendix contains further details on data sources and variable definitions.

5. Data Description and Summary Statistics

We use data on semiconductor fabrication plants ("fabs") from a commercial database called World Fab Watch (WFW) produced by Strategic Marketing Associates, a semiconductor industry research firm based in Santa Cruz, California. WFW contains data on semiconductor firms' investments in semiconductor fabrication plants. Strategic Marketing Associates estimate that the database covers more than 95% of the commercial semiconductor fabrication plants in the world. The database includes detailed data on each plant, including the company, location, country of ownership, beginning and ending dates for construction or upgrade of the plant, production technology, and total fixed costs of the project. We select a sample from the WFW database by first removing plants owned by governments, universities or other not-for-profit organizations. In some cases where dates or costs of the project were missing, we could obtain the missing data from the industry and business news in the Lexis Nexis news database, or from industry newspapers. There are 23 plants for which some data is obtained from news sources.

In total, we have data on 431 plants built from 1985 to 2002, and these plants are owned by 229 firms. Of these, 82 plants are FDI plants and 349 are domestic investment plants. Annual macroeconomic data for the home and host countries on inflation, exchange rates, GDP, and factor endowments was collected from the IMF and other sources and matched to the plant data based on the year the investment in a given plant was begun. The appendix describes the macro data sources and variable construction.

Table 1a summarizes the distribution of observations (semiconductor plants) by country for both FDI plants and domestic plants. In total there are 19 countries that host FDI plants, that is where a multinational firm has built a semiconductor fab. Only 10 countries are the home countries for multinational semiconductor firms. An average FDI plant in the sample costs $646 million (2000 US$) to build. Domestic plants have been built in 17 countries, with an average cost of $335 million, roughly half the cost of the larger FDI plants that tend to be built by multinationals. Japan and the United States account for most of the investment in this industry over the sample period, 1985 to 2002.

Table 1b provides summary statistics for the variables used in the regression analyses. The statistics are for two sets of variables namely for the FDI regressions (Tables 2 and 3 in the appendix), and for the domestic investment regressions (Table 4 in the appendix). As one can see, we have more than four times as many observations for domestic investment as we have for FDI. The dependent variable, *fdik* (the regression shortname for ln*FDI*-ln*K*) is larger on average than the domestic investment equivalent *ik* (short for ln*I*-ln*K*). This indicates that FDI plants tend to be larger investments relative to the firm's existing capital stock than domestic plants. The median values of both *fdik* and *ik* are both negative which tells us that the median plant is smaller in value than the existing capital stock of the firm. Nevertheless, it is interesting to note that the mean and median values are not too different for most variables; the standard deviations (and the standard deviation to mean ratios), however, can be quite large in some cases. In the case of the real exchange rate variable, for example, the mean is -0.35 while the standard deviation is 11.14.

6. Estimation Results

We estimate three different sets of regressions based on the empirical model specified in section 4 of the paper: two sets of regressions for FDI (with and without factor endowments respectively) and one set of regressions for domestic investment. The standard errors reported take into account clustering at the firm level, and are robust to serial correlation. Table 2 shows the results of our estimation for models based on the general case in equation (7) but with no factor endowments and where the dependent variable is the firm's rate of FDI (*FDI/K*). Some of the regressions that test equation (7) include foreign q, or use the difference between the two countries' q since both G_K and F_K enter that equation. The adjustment cost variables (distance and language differences), which are emphasized in gravity models, are not significant even though distance shows up with the right sign. The real exchange rate variable is positive and significant in some of the regressions and this confirms the prediction of the model, namely that a depreciation of the host country's currency raises *FDI/K*. Host and foreign country demand conditions (proxied by the first difference of the log of GDP for the host and foreign country) are not significant, which may be due to the fact that they are too broadly defined (macro data) and are not picking up effects at the firm level. The *q* and real interest rate variables are also not significant in all of the regressions.[10]

A key contribution of our paper is to extend the q-theory model of FDI developed by De Santis *et al* to include relative factor endowments. Table 3 shows the results of our estimation for models based on equation 12 but with factor endowments and where the dependent variable is once again the firm's rate of FDI (*FDI/K*). The real exchange rate variable is again significant with the expected sign in all of the regressions. The *q* and real interest rate variables are not significant but as far as factor endowments are concerned, it seems that labor costs are a primary driver of FDI since ln*(LF/L)* is positive and significant in almost all of the regressions. This is consistent with the predictions of Heckscher-Ohlin models of trade whereby firms locate where factors of production are abundant and less expensive. The human capital variable is, however, not significant.

The main result from the regressions on *FDI/K* is that the rate of foreign investment depends most on the real exchange rate and population differences. We find a consistent positive effect from the real exchange rate variable, which supports the theoretical prediction of our model. This is in line with previous research on the relationship between exchange rates and foreign direct investment; for example, both Froot and Stein (1991) and Blonigen (1997) find that the real exchange rate movements significantly affect FDI flows into the United States. Note, however, that the real

[10] It is important to note that empirical investigations of investment and *q* have yielded different results regarding *q*'s significance. Our finding that *q* is not significant is, therefore, not too surprising.

exchange rate variable could be significant for reasons other than *q* theory, namely simply cheaper production costs. Also, as the difference between the population in the host country and home country increases, the rate of FDI also increases. This suggests that FDI in the semiconductor industry is seeking lower cost labor, since higher population is associated with a larger labor force and lower wages. This finding is also consistent with the proximity hypothesis regarding FDI that firms locate closer to large markets.[11]

Our final set of regressions in Table 4 considers the rate of domestic investment (*ik*) as the dependent variable. All the observations in that table are for domestic plants only and *ik* is the total cost of the domestic plant observed relative to the firm's whole capital stock. Some of the plants are owned by multinationals and some are not. Since equation 11 says that a multinational firm's domestic investment depends on the marginal productivity of capital of all of their plants (both domestic and foreign), some of the regressions for domestic investment also include characteristics of the firm's foreign investments when the firm has FDI. The 'foreign' variables are calculated as averages for all the foreign plants that the firm invested in that year. Recall that if the firm did not do any FDI in a particular year, or if they are a domestic-only firm, the foreign variables are zero. Another way to think about this is that in any given year, a firm is deciding how much total investment it will do; if it does FDI, then its domestic investment will be affected by the latter, and we take this into account by including 'foreign' variables.

Columns 1 and 2 consider cases where no foreign investments do not affect the rate of domestic investment, i.e. we initially omit the foreign variables shown in equation

[11] Since labor endowment is measured by relative population sizes, it is possible that this is a large market proximity motive rather than low cost labor. Since the GDP variable should have controlled for size, the

13. The additional controls for the effects of foreign country MPK (such as foreign *q*, distance, demand conditions in the foreign country), and foreign/domestic factor endowment ratios are included in the latter columns. As usual, *FOUNDRY* and time trend are included to control for vertically structured MNEs and possible nonstationarity respectively. The interesting observation is that the real exchange rate variable for the foreign country is significant with the expected sign. There is no indication that relative factor endowments play a significant role in the domestic investment case. Interestingly, foreign *q* is nearly significant at 10% and is in fact significant at the 15% level, which implies the MPK of foreign plants may affect an MNE's domestic investment flows, consistent with the theoretical prediction. However, our small sample does not allow us to see this effect very clearly.

7. Conclusion

This paper has attempted to explain the reasons for FDI in the semiconductor industry by using a unique database of investment projects at semiconductor fabrication plants in 24 countries over the period 1985 to 2002, together with macroeconomic data for home and host countries. In so doing, it has also compared FDI with domestic investments to try to obtain a better understanding of why a firm would invest in a particular country. This is in our view an important contribution since a large number of empirical studies rely only on macro data and cannot explain FDI as a microeconomic decision process at the firm level, and more importantly the choice faced by the firm in deciding whether to invest domestically or abroad. The uniqueness of this paper is also the fact that it uses Tobin's *q* theory as the theoretical basis for its empirical estimates,

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labor story is probably correct.

thus departing from the more commonly used knowledge-capital models of the multinational enterprise.

Our results show that labor costs and the real exchange rate are important factors in explaining FDI, which in our view provides some (albeit weak) support for q theory. In terms of future work, obtaining better proxies for q using firm-specific stock price data for publicly traded firms, or just the country index for private companies or companies where we cannot get data, is a possibility. In fact, empirical investigations between investment and q have in recent years focused on obtaining better measures of q. It would also be interesting to see how our results differ when other competing models of FDI are tested using the dataset in this paper.

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Appendix: Variable Definitions and Data Sources

All dollar values are expressed in constant 1996 U.S. dollars, calculated with the BEA's U.S. GDP deflator.

Dependent Variable Components:

I_{ijt} Investment by firm i in plant j is measured by the total fixed costs to build the plant. I_{ij} measures the sum of investments plants built at time t, located in firm i's home country. Source: World Fab Watch (WFW) commercial database on semiconductor fabrication plants, constructed in June 2002.

FDI_{ijt} The investments by firm i in foreign country plant j at time t. As for I_{ij}, FDI_{ij}, is measured by total fixed costs for that plant. Source: World Fab Watch (WFW) commercial database on semiconductor fabrication plants, constructed in June 2002.

K_{it} The value of firm i's stock of fabrication plants in existence at the beginning of year t. This is constructed by summing the total fixed cost of existing plants depreciated at a rate of 10% per year, consistent with the 9.2% to 10.4% range shown in ICE (1997, p.2-2). The initial capital stock for each firm is just the depreciated value of plants constructed between 1980 and 1985. If the total cost data were unavailable for a plant, it was assumed to be equal to the average total cost of plants built by that firm in other years, (done for construction of K_i only).

Explanatory Variables:

φ^I The adjustment cost for domestic investments is assumed to be constant and contained in the firm-specific fixed effect, as in Gilchrist and Himmelberg (1995).

φ^{FDI} The adjustment cost for foreign investments are assumed to be equal to $\varphi^I+\gamma$, the domestic adjustment cost, plus an additional component γ_{ij} which relates to the distance between countries i and j. This is proxied by geographic distance in kilometers in some regressions, and a dummy variable for different language in other regressions. Distance data are from Geobytes Inc.'s internet-based City Distance Calculator. The CIA World Factbook 2004 website is the source of information on official and widely used languages.

RER_t The real bilateral exchange rate in home country currency, calculated as the bilateral nominal exchange rate multiplied by the ratio of GDP deflators. Source: Nominal exchange rates data come from IMF International Financial Statistics, except for 1980 to 1998 Taiwanese exchange rate data which comes from Penn World Tables National Accounts data. After 1999, exchange rates are euro/$ for euro area countries in the sample. The GDP deflator data comes from IMF World Economic Outlook.

p_t CPI-based inflation rate. Source: IMF World Economic Outlook.

r_t The real prime lending rate on short term loans (nominal interest rate less CPI-based inflation rate). Source: IMF International Financial Statistics.

GDP_t Real GDP of country *i* in year *t*, measured in 1996 US dollars. Source: IMF World Economic Outlook.

$SIZE_t$ The sum of real GDP of both home and host countries in year *t*.

q_t The average value of the firm *i*'s home country's major stock price index in year *t*. Sources vary by country. Most come from the IMF International Financial Statistics, but some stock price index data were obtained from the OECD or the Bureau of International Settlements. Data for Taiwan come from the Taiwan Stock Exchange.

W_t The number of existing semiconductor fabs in a country that were in existence at the beginning of year *t*. This is constructed from World Fab Watch data.

L_t The size of the labor force in a country in year *t* is proxied by its population. Population data come from the IMF International Financial Statistics.

r_t The real private lending interest rate for the country in year *t*. Source: IMF International Financial Statistics, and the Bank of China Taipei for Taiwan.

Appendix: Tables

Table 1a: Distribution of Sample Plants by Home and Host Countries, Mean of Investments 1985 to 2002, millions of 2000 US$

Country	FDI Host		FDI Home		Domestic I	
	N	Mean $	N	Mean $	N	Mean $
Australia	1	71.0			2	216.0
Austria	1	409.6				
Belgium	1	108.6				
Canada			1	21.0	2	29.0
China	5	625			12	364.1
France	6	854.7	3	160.0	2	310.1
Germany	10	426.3	7	903.8	9	580.5
Hungary	1	72.2				
Ireland	4	1156.2				
India					1	40.0
Italy	1	1113.9			4	478.9
Japan	13	661.4	12	662.6	115	429.0
Malaysia	1	63.4			4	921.3
Netherlands	1	20.7	6	333.4	2	684.3
S.Korea	1	80.0	2	1334.6	28	991.9
Singapore	8	769.3			6	1426.5
Slovakia	1	93.3				
Sweden					1	339.5
Switzerland	1	20.9	6	601.8	2	48.5
Taiwan	5	1118.6	1	1385.2	43	798.8
UK	8	330.6			7	23.2
US	13	830.5	41	659.2	109	392.3
Total Plants	82	646.2	82	646.2	349	335.1
Total Countries	19		10		17	

Table 1b: Summary Statistics for Variables used in Regression Analysis

Variable Name*	N	Mean	Median	Std. Dev.
		FDI Regressions		
fdik (lnFDI – lnK)	82	0.65	-0.35	3.29
lndist (km)	82	8.42	9.03	1.29
d*lnRERF* (%)	82	-0.35	0.00	11.14
d*lnqH* (%)	82	10.47	12.41	17.69
d*lnqF* (%)	80	8.48	6.07	18.04
d*lnqH*-d*lnqF* (%)	80	-2.41	-3.04	21.33
dlnGDPH (%)	82	0.72	2.42	7.29
dlnGDPF (%)	82	3.54	3.03	10.15
ln(LF/L)	82	-0.67	-0.76	2.02
ln(WF/W)	82	-1.43	-1.84	2.88
rF-rH (%)	82	0.18	0.37	2.83
		Domestic Investment Regressions		
ik (lnI-lnK)	349	0.48	-0.40	2.84
dlnqH (%)	349	10.86	8.30	23.44
dlnGDPH (%)	349	4.42	3.24	9.28
rH (%)	349	4.64	4.50	1.85
LH (millions)	349	182.33	125.12	230.16
wH (plants)	349	16.13	15.00	13.81
lnDISTF (km)	349	0.40	0.00	1.82
dlnqF (%)	349	0.38	0.00	2.87
dlnGDPF (%)	349	0.109	0.00	1.77
dlnRERF (%)	349	0.16	0.00	2.58
ln(WF/W)	349	-0.11	0.00	0.88
ln(LF/L)	349	-0.06	0.00	0.57

* The dependent variables, fdik and ik, are the logs of the ratio as in equations 12 and 13. Lndist is log of distance; "d" refers to the first difference, while F and H indicate foreign (host) country or home country.

Table 2: Panel Data Estimates for Equation 7 (No Factor Endowments) – Dependent Variable ln(*FDI/K)*

Explanatory Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
lnDIST	-0.29	-0.29	-0.29	-0.30	-0.30	-0.38	
	[0.87]	[0.88]	[0.82]	[0.86]	[0.87]	[1.37]	
DIFFLANG						1.21	0.79
						[0.52]	[0.40]
dlnRER	0.06	0.06	0.06	0.06	0.06	0.07	0.06
	[1.78]*	[1.81]*	[1.05]	[1.49]	[1.17]	[1.74]*	[1.56]
dlnGDP	-0.01	-0.01	-0.03	-0.03	-0.02	-0.01	-0.03
	[0.08]	[0.06]	[0.25]	[0.27]	[0.16]	[0.11]	[0.23]
dlnGDPF	0.07	0.07	0.06	0.06	0.06	0.07	0.06
	[0.93]	[0.96]	[0.71]	[0.82]	[0.82]	[0.93]	[0.81]
dlnq	0.01		0.01	0.01		-0.01	0.01
	[0.23]		[0.13]	[0.16]		[0.00]	[0.05]
dlnqF	-0.01		-0.02	-0.02		-0.01	-0.01
	[0.28]		[0.34]	[0.34]		[0.29]	[0.33]
dlnq-dlnqF		-0.01			-0.01		
		[0.40]			[0.38]		
r			0.07		0.06		
			[0.19]		[0.18]		
rF			-0.13		-0.11		
			[0.48]		[0.41]		
rF-r				-0.10			
				[0.57]			
FOUNDRY	1.67	1.69	1.69	1.72	1.75	1.56	1.63
	[0.81]	[0.84]	[0.78]	[0.81]	[0.82]	[0.77]	[0.75]
YR	-0.24	-0.24	-0.26	-0.26	-0.25	-0.26	-0.27
	[1.61]	[1.62]	[1.46]	[1.59]	[1.42]	[1.58]	[1.69]
Constant	487.64	484.40	520.81	511.08	505.75	511.06	538.57
	[1.62]	[1.63]	[1.46]	[1.60]	[1.43]	[1.59]	[1.70]*
Number of firms	43	43	41	41	41	41	41
Observations	80	80	80	80	80	80	80
Adj. R-squared	0.56	0.57	0.54	0.55	0.55	0.56	0.56

Note: Robust t-statistics are shown in square brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3: Panel Data Estimates for Equation 12 (with Factor Endowments) - Dependent Variable *FDI/K*

Explanatory Variables	(1)	(2)	(3)	(4)	(5)	(6)
lnDIST	-0.37	-0.28	-0.27	-0.27	-0.26	-0.27
	[2.34]**	[0.98]	[1.03]	[1.17]	[1.08]	[1.18]
dlnRER	0.06	0.06	0.05	0.05	0.05	0.06
	[2.35]**	[1.98]*	[1.76]*	[1.69]	[1.73]*	[1.87]*
dlnGDP	0.07	0.07	0.06	0.06	0.06	0.06
	[1.10]	[0.99]	[0.91]	[0.96]	[0.86]	[0.93]
dlnq	0.01	0.01	0.01	0.01		
	[0.13]	[0.21]	[0.17]	[0.34]		
dlnqF				-0.02		
				[0.38]		
dlnq-dlnqF					-0.01	
					[0.53]	
rF-r			-0.04			
			[0.20]			
ln(LF/L)	0.36		0.57	0.62	0.61	0.55
	[0.88]		[1.99]*	[2.36]**	[1.97]*	[1.79]*
ln(WF/W)		-0.04	-0.24	-0.21	-0.22	-0.24
		[0.15]	[0.75]	[0.63]	[0.67]	[0.76
FOUNDRY	1.31	1.71	1.53	1.45	1.57	1.51
	[0.63]	[0.87]	[0.80]	[0.79]	[0.99]	[1.01]
YR	-0.25	-0.23	-0.26	-0.27	-0.27	-0.29
	[1.69]	[1.81]*	[1.83]*	[2.12]**	[2.17]**	[3.08]**
Constant	494.35	465.45	524.20	548.27	551.05	579.70
	[1.70]*	[1.82]*	[1.84]*	[2.13]**	[2.17]**	[3.09]**
Number of firms	43	43	43	41	42	46
Observations	82	82	82	80	81	87
Adj. R-squared	0.58	0.57	0.57	0.57	0.53	0.59

Note: Robust t-statistics are shown in square brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4: Panel Data Estimates for Domestic Investment – Dependent Variable I/K

Explanatory Variables	(1)	(2)	(3)	(4)	(5)	(6)
	NO FDI		FDI and Domestic Investment			
dlnGDPH	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	[0.14]	[0.10]	[0.22]	[0.22]	[0.20]	[0.20]
dlnqH	0.01	0.01	0.01	0.01	0.01	0.01
	[1.14]	[0.98]	[0.98]	[0.98]	[0.95]	[0.95]
rH	0.10	0.13	0.12	0.12	0.10	0.10
	[0.79]	[0.90]	[0.85]	[0.85]	[0.80]	[0.80]
LH		-0.01	0.01	0.01		
		[0.44]	[0.06]	[0.06]		
WH		0.03	0.01	0.0131		
		[0.52]	[0.22]	[0.22]		
lnDISTF			0.07	0.07	0.02	0.02
			[0.83]	[0.83]	[0.31]	[0.31]
dlnqF			0.09	0.09	0.11	0.11
			[1.53]	[1.53]	[1.64]	[1.64]
dlnGDPF			-0.01	-0.01	-0.04	-0.04
			[0.01]	[0.01]	[0.49]	[0.49]
dlnRERF			-0.05	-0.05	-0.11	-0.11
			[1.20]	[1.20]	[2.25]**	[2.25]**
ln(WF/W)					-0.14	-0.14
					[0.31]	[0.31]
ln(LF/L)					-0.23	-0.23
					[0.40]	[0.40]
FOUNDRY	-0.33	-0.32	-0.27	-0.27	-0.32	-0.32
	[0.56]	[0.57]	[0.43]	[0.43]	[0.52]	[0.52]
YEAR	-0.19	-0.23	-0.22	-0.22	-0.20	-0.20
	[3.29]***	[2.31]**	[2.33]**	[2.33]**	[3.62]***	[3.62]***
Constant	373.80	449.27	432.29	432.29	407.13	407.13
	[3.29]***	[2.30]**	[2.32]**	[2.32]**	[3.62]***	[3.62]***
Number of firms	136	136	136	136	136	136
Observations	349	349	349	349	349	349
Adj. R-squared	0.77	0.77	0.78	0.78	0.78	0.78

Note: Robust t-statistics are shown in square brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.