MULTINATIONALS, ENDOGENOUS GROWTH AND TECHNOLOGICAL SPILLOVERS: THEORY AND EVIDENCE

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ABSTRACT

FDI has received surprisingly little attention in theoretical and empirical work on openness and growth. This paper presents a theoretical growth model where MNCs directly affect the endogenous growth rate via technological spillovers. This is novel since other endogenous growth models with MNCs, e.g. the Grossman-Helpman model, assume away the knowledge-spillovers aspect of FDI. We also present econometric evidence (using industry-level data from seven OECD nations) that broadly supports the model. Specifically, we find industry-level scale effects and international knowledge spillovers that are unrelated to FDI, but we also find that bilateral spillovers are boosted by bilateral FDI.

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1 Introduction

After decades of empirical research, the positive association between openness and growth is now widely recognised by policymakers and economists alike.* Yet despite this impressive body of empirical work, the exact channels through which openness encourages growth are not well understood.

Among the many possible openness and growth links, the leading contender is surely technological transfers and spillovers. We have direct evidence that domestic technological progress is aided by foreign progress. Eaton and Kortum (1997), for example, find that domestic productivity growth is mainly related to foreign innovation, rather than domestic

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* See Edwards (1997) and Harrison (1996) for surveys of the empirical literature.

innovation. Moreover, virtually all growth regressions include a catch-up term that is generally rationalised as capturing international technology transfers.

International technology transfer is promoted by many channels: trade in goods, trade in services, migration, international licensing, joint ventures and the like. Of the various technological transfers/spillovers channels, the most plausible is probably that of multinational corporations (MNCs) and foreign direct investment (FDI). Just at a mechanical level, it is easy to understand how FDI fosters international technology spillovers. As Todaro (1985 p. 438) writes, multinationals "supply a 'package' of needed resources including management experience, entrepreneurial abilities, and technology skills which can then be transferred to their local counterparts by means of training programs and the process of 'learning by doing'". More importantly, economists have marshalled an impressive body of empirical evidence on the role of MNCs as transferors of technology (see the survey by Blomström and Kokko 1998).

Given all this, it is surprising that FDI is almost entirely absent from theoretical and empirical work on the link between overall openness and economic growth. This omission is serious for two reasons. First, without formal modelling of FDI and growth links, it is not possible to know what sorts and forms of FDI-linked spillovers are logically consistent with steady-state growth. Second, policymakers strongly believe that FDI is good for growth and act on these beliefs, granting tax holidays, signing international agreements and relaxing competition policy in order to encourage FDI. For instance the head of the OECD, Donald Johnston, stressed the importance of the (soon-to-fail) Multilateral Agreement on Investment in the Financial Times (24 February 1998) by claiming: "For years, international investment has made an important contribution to economic growth. … The benefits are numerous. Host countries receive fresh capital, technology and know-how. Source countries get access to new markets." Given that policy is being made based on these beliefs, it would seem essential to have a variety of direct tests of growth and FDI links.

The neglect of FDI in empirical trade and growth studies is matched by--and perhaps explained by--a neglect of MNCs in the theoretical trade and endogenous growth literature. The seminal trade and endogenous growth literature consists of Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991a, b). This mainly ignores MNCs, although Grossman and Helpman (1991) do introduce MNCs into one variant of their basic growth model. However, the MNCs are of the Helpman (1984) type and as such merely serve to expand the factor-price-equalisation set (just as in the static trade and MNC model of Helpman and Krugman 1985).[*] In particular, MNCs in the Grossman-Helpman model do not affect the internationalisation of learning externalities so MNCs play no direct role in determining the endogenous growth rate between, for example, two symmetric nations. Keller (1998) presents a theoretical, non-scale growth model in which exogenous labour force expansion drives long-run growth. MNCs raise this long-run growth rate since it is assumed that FDI increases the extent of global technological spillovers in the innovation sector. The particular assumption is that the spillovers from any innovation (home or foreign) rises as the nation purchases a larger share of its intermediate goods from abroad or from locally based foreign subsidiaries. Thus both trade and FDI boost global spillovers.

This paper focuses on the pro-growth role of MNCs. We first present a simple theoretical model in which MNCs play a critical role in determining the endogenous long-run growth rate via technological spillovers. We then present an empirical test (using industry-

[*] Caves (1996 p179) makes this point.

level data from seven OECD nations) that broadly supports our model.

The rest of this paper is organised in four sections. The next section, section 2, introduces the basic MNC model in a static framework. Our static MNC model is related to the Brainard (1993) restatement of the seminal Horstmann and Markusen (1987) model. That is, firms choose between supplying foreign markets via exports or local production (i.e. FDI) in order to exploit the trade-off between production-scale and proximity to markets. Our static MNC model focuses heavily on knowledge capital. Motivations of the Horstmann-Markusen-Brainard model also stress the role of knowledge-based assets, but knowledge is omitted from the formal models, including recent extensions by Markusen, Venables, Konan and Zhang (1998). We redress this by explicitly introducing knowledge capital as a productivity factor and explicitly defining its properties. We should also note that the similarities between our static MNC model and the aptly named ‘knowledge-capital model’ that was independently developed by Carr, Markusen and Maskus (1998).

Endogenous growth is introduced into our theoretical model in section 3. This permits us to formally study how FDI-linked technology spillovers encourage long-run growth. The growth in our model stems from cease-less product innovation, which is, in the spirit of Romer (1990) and Grossman and Helpman (1991 Chapter 3), driven by learning externalities in the innovation sector. We consider within-sector and between-sector learning externalities that are called Marshall-Arrow-Romer spillovers and Jacobian spillovers respectively. The international spillovers promoted by FDI in our model are of the Jacobian type.

The fact that knowledge capital is a natural way of simultaneously explaining why MNCs exist and how they promote growth has long been recognised in the literature. A recent example is Caves (1996 p.162):

> The MNE’s rationale, according to the transaction-cost model, lies in the administered international deployment of its proprietary assets so as to evade the failures of certain arm’s-length markets. Premier among those assets is the knowledge embodied in new products, processes, proprietary technology, and the like. Therefore, the MNE plays a role in the production and dissemination of new productive knowledge that is central if not exclusive.

The fourth section presents our estimating equation, which is guided by the theoretical model. It also discusses data sources and the construction of the explanatory variables. Finally, it presents our results. These broadly confirm the role of FDI in encouraging long-run growth via technology spillovers. Interestingly, our results find so-called ‘scale effects’ contrary to the time series evidence presented by Jones (1995). The final section contains our concluding comments.

2 The Static Model of MNCs and FDI

To fix ideas and notation, we solve the static MNC model before introducing endogenous growth. The MNC model is based on Horstmann and Markusen (1987). Although some modelling details differ (to make room for growth aspect in the next section), horizontal MNCs and intra-industry FDI arise for Horstmann-Markusen motives that Brainard (1993) aptly describes as scale versus proximity.[*]

[*] Brainard actually uses the terms proximity versus concentration, where by "concentration" she meant exploiting scale economies. Since "concentration" has a specific meaning in the theory of imperfect competition (related to the degree of competition), "scale" is probably a less confusing label.

2.1 The Basic MNC Model

Consider a world with two symmetric countries (home and foreign) each with two factors (labour L and knowledge capital K) and two traded-goods sectors (X and Z). The Z sector is Walrasian (perfect competition and constant returns), producing a homogeneous good with L as the only factor; by choice of units, the unit input coefficient a_Z equals unity. The X-sector (manufacturing), which consists of differentiated goods, is marked by monopolistic competition. Manufacturing an X-variety requires a_X units of labour per unit of output. It also requires a one-time investment in one unit of variety-specific knowledge capital, K. However, K is not a primary factor. A unit of K is produced with a_I units of labour under perfect competition (so capital is priced at marginal cost). Taking labour as numeraire implies that the X-sector fixed cost, denoted as F, equals a_I.

The nature of knowledge capital is essential to the existence of MNCs. We presume that the know-how embodied in each variety-specific unit of knowledge capital cannot be patented since it involves tacit knowledge that is embodied in workers, or that the value of the knowledge could be exploited by others by slight variations that would not formally violate a patent (e.g. Coke's formula). Due to this "industrial secrets" aspect of knowledge, K cannot be internationally traded at arm's-length. If an X-firm wishes to exploit its K abroad, it must export finished goods, or produce abroad, i.e. become an MNC.

Setting up production abroad, however, entails various natural and man-made barriers, implying somewhat higher fixed costs. Specifically, firms that produce locally and abroad require $(1+\Gamma)$ units of capital as a fixed cost, where the parameter Γ (a mnemonic for general costs) reflects barriers to FDI. We can interpret Γ as the extra knowledge that the firm needs to operate abroad and/or the extra knowledge necessary to bring the firm's product into conformity with foreign production standards. In short, the fixed cost of being a multinational firm is $(1+\Gamma)F$, while that of a pure domestic firm is F.

X-firms that decide to enter face two types of decisions: location and pricing. The firm first decides whether to produce its variety in only one factory and export to the other market, or to produce in two factories (one in each nation) and supply both markets by local production. After this decision is taken, the firm sets its price in both markets. X-firms take as given the location and pricing decisions of all other firms when deciding their own location and pricing.

X and Z are both traded. X-trade is impeded by frictional (iceberg) import barriers, so $\tau=1+t\geq 1$ units of an X-variety must be shipped to sell one unit abroad (t is the barrier's tariff equivalent). These may be thought of as representing transport costs and so-called technical barriers to trade (idiosyncratic industrial, safety or health regulations and standards that raise production costs but generate no rents or tax revenue). Alternatively, they may be thought of as tariffs where tariff revenue has an ignorable impact on the equilibrium. For modelling convenience, we assume that Z-trade occurs costlessly.

National L-stocks are fixed and factors are non-traded. That is, L is internationally immobile and K must be used in the nation in which it is created (K *services* can be employed abroad, but only via FDI).

Preferences of the representative consumer (in both countries) are modelled as a Cobb-Douglas nest of Z consumption and a CES composite of X-varieties. Specifically:

$$U = \ln\left(C_{Xt}^{\alpha} C_{Zt}^{1-\alpha}\right), \quad C_X \equiv \left(\int_{i=0}^{N+N^*} c_i^{1-1/\sigma}\, di\right)^{\frac{1}{1-1/\sigma}}, \quad \sigma > 1 \qquad (1)$$

where C_Z and C_X are Z-good consumption and the CES composite of manufactured goods (N and N* are the number of home and foreign varieties resepectively), c_i is consumption of X-variety i, and σ is the constant elasticity of substitution between any two varieties. The representative consumer owns all the nation's L and K, so her income equals wL plus payments to capital, πK; w and π are rewards to L and K (K's reward is the Ricardian surplus due to variety-specificity).

2.2 Key Intermediate Results

Utility optimisation implies that a constant fraction α of consumption expenditure E falls on X-varieties with the rest spent on Z. It also yields a unitary-elastic demand for Z and standard CES demand functions for X-varieties. The latter may be written as:

$$c_j = s_j \frac{\alpha E}{p_j}; \quad s_j \equiv \frac{p_j c_j}{\alpha E} = \left(\frac{p_j}{P_X}\right)^{1-\sigma}; \quad P_X \equiv \left(\int_{i=1}^{N+N^*} p_i^{1-\sigma}\, di\right)^{\frac{1}{1-\sigma}}; \quad \sigma > 1 \qquad (2)$$

Here s_j is variety j's share of expenditure on X, the p's are consumer prices, and P_X is the X-sector's perfect price index. Foreign demand functions are isomorphic.

Free trade in Z equalises nominal wage rates since by symmetry both countries produce some Z.[1] (Numbered notes refer to entries in the attached 'Supplemental Guide to Calculations'). Thus p_Z=w=w*=1 in equilibrium.

FDI or No FDI? To characterise the parameter constellation that produces equilibrium FDI, consider the location and pricing decision of a single home firm. For this purpose, we need to keep track of the nationality and production location of each variety. First, some varieties may be produced only in home or only in foreign and we call these n-type (national) firms. The number of home and foreign n-type firms are denoted as n and n* respectively. Other home and foreign varieties may be produced in both home and foreign. We denote the number of these m-type (multinational) firms as m and m*. The total number of varieties is therefore n+n*+m+m*; by symmetry N≡n+m is the number produced in each nation.

Consider first the second-stage pricing decision. The derivation of monopolistic pricing (so-called mill pricing) is well known, so we merely state results. Regardless of its FDI decision, the optimising firm charges domestic consumers a price of $wa_x/(1-1/\sigma)$. Choosing units such that $a_x=(1-1/\sigma)$, the domestic consumer price equals 1. If the firm is an n-type, the optimal consumer price for its variety in the foreign market is τ. By contrast, if it is an m-type, its optimal consumer price in the foreign market is 1.[2]

Next, consider the first-stage location decision of an individual X-sector firm. Regardless of the location decision, the first order conditions for optimal pricing tell us that operating profit is $(1/\sigma)$ times the value of sales.[3] Using (2), symmetry and the optimal pricing rules, the Ricardian surpluses (what is left over to reward K) for an n-type firm and an m-type firm are, respectively[4]:

$$\pi^{n}=\frac{(1+\phi)(\alpha E/\sigma N)}{2s_{m}+(1-s_{m})(1+\phi)},\quad \pi^{m}=\frac{2(\alpha E/\sigma N)}{2s_{m}+(1-s_{m})(1+\phi)};\quad s_{m}\equiv\frac{m}{N},\ N\equiv n+m,\ \phi\equiv\tau^{1-\sigma} \tag{3}$$

where N is the total number of varieties per nation, s_m is the share of firms that are m-types and $\phi\equiv\tau^{1-\sigma}$ is a mnemonic for free-ness (phi-ness) of trade (ϕ=0 corresponds to prohibitive barriers and ϕ=1 corresponds to costless trade).

Becoming an m-type firm entails a larger capital outlay than becoming an n-type, so the firm must compare the m-type and n-type Ricardian surpluses per unit of fixed cost. In equilibrium, the s_m's and π's must satisfy (with complementary slackness):

$$0 \;=\; s_{m}(1-s_{m})\left[\frac{\pi^{n}}{F} \;-\; \frac{\pi^{m}}{F(1+\Gamma)}\right] \tag{4}$$

That is, all firms are m-types (so $1-s_m$ is zero and the bracketed term is negative) or all are n-types (so s_m is zero and the bracketed term is positive) or all are indifferent between types (so $0< s_m<1$ and the bracketed term is zero). We ignore knife-edge cases where two of the three terms are zero. As usual, Dixit-Stiglitz firms are atomistic and thus ignore the impact of their individual location decisions on price indices and expenditures, E and E*. From (3) and (4), FDI occurs for levels of trade free-ness ϕ and FDI barriers Γ satisfying:

$$\Gamma \;\le\; \frac{1-\phi}{1+\phi} \tag{5}$$

This condition exactly captures the essence of the scale versus proximity trade-off. Γ is a measure of the sacrifice in scale economies that an MNC must incur and $(1-\phi)/(1+\phi)$ is a measure of sacrifice an n-type firm must incur since $(1-\phi)/(1+\phi)$ measures the closed-ness of markets (it is zero for fully open economies and one for fully closed ones). Intuitively, this says that FDI occurs when it is sufficiently cheap ($\Gamma\approx0$), or trade costs in X are sufficiently high ($\phi\approx0$).

Determining the number of varieties is trivial when there are only n-type or only m-type firms. In the former case N=K, in the latter $N=K/(1+\Gamma)$. When there are both types of firms (i.e. $\Gamma=(1-\phi)/(1+\phi)$ holds), K's full employment condition is $K=n+(1+\Gamma)m$. Rearranging, this says that $K/N=1+s_m\Gamma$. Of course, with monopolistic competition, we cannot determine s_m precisely since when $\Gamma=(1-\phi)/(1+\phi)$ holds, any $1\geq s_m\geq0$ satisfies the equilibrium conditions, so we simply take s_m as a parameter when (5) holds with strict equality.[*]

3 A Simple Endogenous Growth and MNC Model

This section expands the model to allow for endogenous growth. In the model, FDI affects growth via an economic mechanism that has been well established empirically, namely technology transfer (Blomström and Kokko, 1998).

The basic MNC model is that of section-2 (i.e. it is akin to Horstmann and Markusen 1992). The basic endogenous growth model is based on Baldwin and Forslid (1999), which is itself a simplified version of the Romer-Grossman-Helpman product-innovation model. The intuition for the growth mechanism is simple.

[*] Markusen´s and other´s work avoid this indeterminacy by adopting the more difficult market structure of oligopoly. This route, however, would enormously complicate the growth model.

Long-run growth is always and everywhere based on the ceaseless accumulation of capital, typically human, physical or knowledge capital.[*] A central challenge faced by endogenous growth models is to explain how accumulation remains profitable in spite of the ever-growing capital stock. For the Romer-Grossman-Helpman model, where each Dixit-Stiglitz variety is associated with a unit of capital, the specific question is how to keep the number of varieties continually growing despite the implied drop in operating profits. The solution is to find a way to keep the fixed cost F falling at a constant rate. The path-breaking assumption that justified this was introduced by Lucas (1988) and Romer (1990). They postulate a learning curve in the capital-producing sector.[†] That is, the labour required to make a new unit of knowledge (equal to a_I in our model) falls as the cumulative output of the capital-producing sector rises. Combining the Lucas-Romer learning curve assumption with the Krugman-Dixit-Norman trade model easily yields an elegant and tractable trade-and-endogenous-growth model, as Grossman and Helpman (1991) showed.

Since learning externalities in the capital producing (i.e. innovation) sector are at the heart of our endogenous growth model--and, as we shall see, at the heart of MNCs' growth implications--a discussion of these externalities is in order.

3.1 Spillovers: the Engine of Tech-Transfer and Growth

Glaeser, Kallal, Scheinkman and Shleifer (1992) distinguish three types of dynamic externalities (spillovers). The first two--the Marshall-Arrow-Romer (MAR) type and the Porter type--stem from ongoing communication among firms within a sector. For our model, differences between MAR and Porter externalities are moot and Romer applied them to endogenous growth, so we call them MAR or Romerian externalities. In many formulations of MAR spillovers, the degree of spillovers is determined by location, rather than, say, the level of economic intercourse among firms. The actual spillover mechanism envisaged in these formulations can be via face-to-face discussions, telecommunications, scientific papers, or informal exchange of workers via hires and fires. In any case, the basic idea is that knowledge flows from one firm to another via a process that we can label "osmosis". Our model below assumes a sector-wide learning curve in the knowledge-capital producing sector (i.e. the innovation sector) where learning is of this "osmosis" or MAR type. Specifically, the productivity of innovation-sector labour improves as the cumulative output, and thus the experience level, of the innovation-sector rises. Variety-developers therefore get more efficient at developing varieties as more varieties are developed.[‡]

The third type of spillovers discussed by Glaeser, Kallal, Scheinkman and Shleifer (1992) is called Jacobian spillovers, after Jacobs (1969). These stem from a build up of knowledge or ideas associated with diversity. Jacobian spillovers therefore involve learning across sectors. In the Jacobian spillover approach, firms learn from other sectors and activities. Applying this to our model, we assume that X-sector manufacturing is a source of cost-saving

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[*] In models such as the Solow and Young models, the accumulation is unintentional or exogenous.

[†] Lucas, Romer and their followers describe this as a technological externality or 'knowledge spillovers', but trade economists will recognise it as a learning curve. Lucas works with human capital and Romer with knowledge capital, but the logic is the same.

[‡] Grossman and Helpman (1991) justify the learning curve as follows. Developing a new variety produces two types of knowledge. The first type, which is appropriable, allows a new X-sector firm to produce a new variety. The second type is non-appropriable public knowledge that 'spills over' into the innovation-sector itself, thus lowering the marginal cost of developing further varieties. Innovation activity is both the source and beneficiary of this spillover, so this is a within-sector (MAR) spillover.

spillovers to the I-sector. The idea here is that variety-developers in the innovation-sector can do their job more efficiently when able to observe a wide-range of X-sector manufacturing processes. This is a natural assumption in the present context since the full one-time costs of developing a new good must include development of a manufacturing process as well as its design characteristics. To the extent that differentiated products are made with similar but not identical production processes, developing manufacturing know-how may be easier when developers can observe on-going manufacturing of existing varieties.

There is substantial empirical evidence that spillovers are partially localised (see Eaton and Kortum 1996, Cabellero and Jaffee 1993, and Keller 1997). That is, home innovators learn more from home-based innovation and manufacturing than they do from that which is done abroad. We incorporate this into our model by assuming the beneficial effects of the "osmosis" are greater when innovators are in the same nation, while Jacobian spillovers only operate within a country.

<u>3.2 Introducing Endogenous Growth</u>

The first additional assumption concerns intertemporal preferences. The instantaneous preferences of the representative consumer (in both countries) are as in (1). The intertemporal dimension of preferences is made as simple as possible by assuming:

$$U_s = \int_{t=s}^{\infty} e^{-\rho(t-s)} \ln\left(C_X^{\alpha} C_Z^{1-\alpha}\right) dt, \quad C_X \equiv \left(\int_{i=0}^{N+N^*} c_i^{1-1/\sigma} di\right)^{\frac{1}{1-1/\sigma}}, \quad \sigma > 1 \tag{6}$$

where $\rho>0$ is the rate of pure time preference. As is well known, utility optimisation implies the demand functions as in section 2, an Euler equation $\dot{E}/E = r-\rho$ (r is the rate of return to savings) and a transversality condition.[6]

The second extra assumption concerns the innovation sector (I-sector for short). The I-sector produces a new unit of K using a_I units of L, where a_I is subject to learning that is external to individual I-firms. All of the spillovers-considerations discussed above are transcribed into the model via the I-sector learning curve. Formally, the learning curve is:

$$a_I = \frac{1}{(K+\lambda K^*)+\mu(n+m+m^*)}; \quad 0 \le \lambda \le 1, \quad 0 \le \mu \tag{7}$$

where λ measures the internationalisation of MAR spillovers and μ measures the importance of Jacobian spillovers relative to MAR spillovers. In (7), $K+\lambda K^*$ captures MAR spillovers that occur by "osmosis", i.e. are unrelated to the level of international commerce. The term n+m+m* reflects the Jacobian learning stemming from manufacturing undertaken by home-based firms (recall that m-type firms produce in both nations, so n+m+m* varieties are produced in home). When $\lambda=1$, MAR spillovers are equally strong for all varieties regardless of where they are invented. When λ is less than unity, spillovers are at least partially localised.

The implied I-sector production function gives the flow of new capital, Q_K, as:

$$Q_K \equiv \dot{K} = L_I / a_I \tag{8}$$

Converting (8) to growth-rate form, using (7) and $K=n+m(1+\Gamma)$, we get[7]:

$$g = L_I A; \qquad A \equiv 1 + \lambda + \mu \frac{1 + s_m}{1 + s_m \Gamma} \tag{9}$$

where A is a measure of I-sector labour productivity that depends on spillovers parameters and the degree of multinationality, s_m. Note that I-sector labour productivity is increasing in the degree of multinationality. The expression for foreign is symmetric.

I-sector firms face perfect competition, so the price of capital is wa_I.*

Jones' Critique. The learning curve assumed above is standard in the trade-and-endogenous-growth literature, and as such displays so-called scale effects. Jones (1995) casts doubt on the existence of scale effects, so some defence of our assumption is called for.

In the literature, the term scale-effect is applied to two distinct propositions. It is used to describe the result, found in the earliest endogenous growth models, that bigger autarkic nations grow faster. This result, which is obviously rejected by the data, is not a serious consideration. The point is that endogenous-growth models that allow for any positive level of international knowledge spillovers (e.g. Grossman and Helpman 1991) imply convergence of long-run growth rates. Thus, apart from transitional effects, learning curves such as ours imply that all nations should grow at the same pace, in the long run. Obviously, nations do grow at different rates, however it is plausible to view as transitory the high growth rates experienced by particular nations.

The second, more serious use of the scale-effect terminology, focuses on the fact that knowledge-production functions, such as (9), assume a unitary learning-elasticity (e.g. a 1% increase in K reduces F by 1%). This implies that output--i.e. the rate of technical progress--should be positively related to the level of inputs.** Jones (1995), which ignores international factors and works with macro data, tests this by taking the number of R&D scientists and engineers as a proxy for inputs and total factor productivity (TFP) as a proxy for the output. He rejects the unitary learning elasticity since "TFP growth exhibits little or no persistent increase, and even has a negative trend for some countries, while the measures of L_A [Jones' notation for our L_I] exhibit strong exponential growth."

Jones' claim, however, is no better than his proxy and TFP is a notoriously bad measure of innovation (Nelson 1996). In particular, TFP figures depend critically on aggregate price indices that systematically underestimate the impact of quality and variety. This is a critical shortcoming since mainstream endogenous growth models rely entirely on quality and/or variety effects as their growth engines. Quite simply, a price index that is not revised every year to reflect expanding variety will systematically understate the TFP growth predicted by the Romer-Grossman-Helpman product innovation model. To take an extreme example, suppose that TFP is measured with a price index that aggregates all varieties together (i.e. it divides expenditure by the average price of varieties). Since the physical output of the manufacturing sector (X) is constant through time in the Grossman-Helpman model, such a price index would indicate, as Jones found, that there was no relationship between L_I and TFP growth--even if (9) were correct. The same problem holds *a fortiori* for quality-ladder models. Empirical price indices, after all, are famously unable to reflect quality improvements. These shortcomings have been addressed for goods such as computers, but not for services--which account for about two-thirds of economic activity in OECD nations.

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* Imperfect competition in the I-sector permits consideration of new trade-growth links, but does not alter the fundamentally nature of steady-state growth (Baldwin and Forslid 1999).

**In a closed economy $\dot{K}/K = L_I K^{1-\eta}$; if the learning elasticity η<1, L_I must rise to keep $\dot{K}/K$ constant.

Furthermore, Backus, Kehoe and Kehoe (1992) find evidence of scale effects in industry-level data, as do we below. The fact that scale effects are found in industry data but not in macro data (where services are dominant) lends further credence that Jones' result is based on a mis-measurement of output, i.e. technological progress.

Jones (1995) raised important questions, but a sober evaluation of the evidence suggests that one cannot reject (9) until more detailed empirical work is undertaken. In any case, non-scale growth models do not provide substantially different implications concerning trade and growth links (e.g. Young 1998, or Baldwin and Seghezza 1996) and they are more complex to work with since they have transitional dynamics.

3.3 The Long-Run Dynamic Equilibrium

The simplest way to analyse the model, is to take L as numeraire (as assumed above) and to take L_I as the state variable (i.e. the variable whose motion must stop in steady state).[8] The simplest solution technique involves Tobin's q. L_I is the amount of labour devoted to the creation of new K, so it is, in essence, the national level of real investment. While there may be many ways of determining investment in a general equilibrium model, Tobin's q-approach--introduced by Tobin (1969)--is a powerful, intuitive, and well-known method for doing just that. The essence of Tobin's approach is to assert that the equilibrium level of investment is characterised by equality of the stock market value of a unit of capital--which we denote with the symbol V--and the cost of capital, F. Tobin took the ratio of these, so what trade economists would naturally call the X-sector free-entry condition becomes Tobin's famous condition $q \equiv V/F=1$.

FDI or No FDI? The pricing and location decisions facing a typical firm in this dynamic model are analogous to those in the static section-2 model. The pricing decision, in particular, is identical since prices can be set independently in each period. The location decision is only slightly more complicated. If the firm becomes an n-type, the flow of operating profit (measured in units of L) is given by the first expression in (3); if it becomes an m-type, its operating profit flow is given by the second expression in (3).[**] The firm makes its decision by comparing the present value of the two operating profit streams--call these V^n for n-types and V^m for m-types--with the respective one-time costs, namely F and $F(1+\Gamma)$.

Calculation of the steady-state V's is simple. It is intuitively obvious (and simple to demonstrate) that the steady-state discount rate is the rate of pure time preference ρ.[9] Also, in steady state L_I must be time-invariant (by definition of a state variable) and s_m is time-invariant (it is zero, unity or an exogenous s_m). Thus, from (9) and symmetry, K will grow at a time-invariant rate. From (3) and the time-invariance of nominal E, both π^N and π^M fall at the rate g. Of course, a flow that falls at g and is discounted at $r=\rho$ has a present value of[10]:

$$V^i = \frac{\pi^i}{\rho + g} \; ; \quad i = n,m \qquad (10)$$

X-sector firms are atomistic, so each firm takes as given the value of equilibrium variables, such as g, when making their FDI decision. A new X-firm will, therefore, find it optimal to set up a factory in both nations when $\pi^m/[(\rho+g)F(1+\Gamma)] \geq \pi^n/[(\rho+g)F]$. Since $1/(\rho+g)$ enters both sides of the inequality, we see that the necessary and sufficient condition for FDI in the dynamic model is identical to (5) from the static model, i.e. $\Gamma \leq (1-\phi)/(1+\phi)$. When this

[**] In the static model E is income; here it is income less investment.

condition holds with equality, the equilibrium s_m is indeterminate as in section 2, so we take it as determined by factors outside of the model. A parsimonious summary is that:

$$0 = s_m(1-s_m)\left(\frac{V^n}{F} - \frac{V^m}{F(1+\Gamma)}\right); \quad s_m \equiv \frac{m}{K} \tag{11}$$

That is, all firms are m-types, all firms are n-types, or firms are indifferent between types. Note that V^n/F and $V^m/F[1+\Gamma]$ are the Tobin q's for n-type and m-type firms.

Equilibrium Growth. Consider the case where there are some MNCs, so the long-run accumulation rate is determined by solving $q^m=q^n=1$. To find the steady-state flow of π^m and thus the numerator of q^m, V^m, we need expenditure. E is income less investment/savings, so $E=L+\pi K-L_I$. With mark-up pricing and symmetry, total operating profit worldwide is $\alpha 2E/\sigma$. Half of this accrues to home residents, so $E=(L-L_I)/(1-\alpha/\sigma)$. Using (3), (9) and the facts that $K/N=(1+s_m\Gamma)$ and $\Gamma=(1-\phi)/(1+\phi)$ when $0<s_m<1$, steady state q^m is[11]:

$$q^m = \frac{\alpha(L-L_I)A}{(\sigma-\alpha)(\rho+L_I A)} \tag{12}$$

Solving $q^m=1$ for the steady-state L_I and plugging the result into (9), we have:

$$g = \frac{\alpha LA - \rho(\sigma-\alpha)}{1-\alpha+\sigma} \tag{13}$$

The expression for the no-FDI case and the all-FDI case, i.e. $\Gamma>(1-\phi)/(1+\phi)$ and $\Gamma<(1-\phi)/(1+\phi)$, is identical with $s_m=0$ and $s_m=1$ respectively.

The g's derived so far give the rate of knowledge capital accumulation, i.e. the rate at which new varieties are introduced. We turn now to real income growth. Nominal income, $L+\pi^i K$ (i=N, M), is time-invariant along any steady state growth path (π and K grow at opposite rates). Real income growth is thus the opposite of the rate of decline of the perfect price index. Given the usual CES perfect price index and (13):

$$g_{GDP} = g\frac{\alpha}{\sigma-1} \tag{14}$$

The growth rate with no MNCs is given by (13) and (14) with $s_m=0$.

The equilibrium growth rate rises with the degree of multinationality s_m. To see this, note that g_{GDP} is monotonically increasing in g, and g is monotonically increasing in s_m since A rises with s_m. Intuitively this should be obvious. s_m has no impact on π, yet it raises the productivity of I-sector workers and thus lowers the cost of innovation. In other words, raising s_m, leads to an incipient rise in Tobin's q since it lowers the replacement cost of knowledge capital. As Baldwin and Forslid (1999) Proposition 1 shows, anything that leads to an incipient rise in q is pro-growth.

4 Empirical Analysis

We turn now to the evidence, first deriving our main estimating equations before discussing data issues and presenting our results.

4.1 The Estimating Equation

Our empirical work focuses on labour-productivity growth in manufacturing sectors, so the first task is to find the equilibrium expression for this from the Section 3 model.

Value added and output are identical in our theoretical model because intermediate inputs are assumed away. Value added in the industrial X-sector is, therefore, the equilibrium nominal output divided by the sector's perfect price index P_X. Since varieties are symmetric, the value of output equals the producer price times the labour input (L_X) divided by the unit-input coefficient ($a_x \equiv 1-1/\sigma$). The producer price is unity (due to mark-up pricing and our choice of units and numeraire), so real output is $L_X/(1-1/\sigma)$ divided by $(P_X)^{\alpha}$. Using the definition of P_X from (2), labour productivity (value added per worker) is:

$$y_X = \frac{1}{1-1/\sigma}\left(\int_{i=0}^{N+N^*} p_i^{1-\sigma}\, di\right)^{\frac{\alpha}{\sigma-1}} \tag{15}$$

where y_X is real value-added per worker.

Nominal output is time-invariant in steady state. X-sector labour productivity (y_X) thus grows at the rate that $(P_X)^{\alpha}$ falls. In steady state, this rate is $\alpha/(\sigma-1)$ times g, so from (9) the growth of y_X is:

$$\frac{\dot{y}_X}{y_X} = \frac{\alpha}{\sigma-1}\left(L_I + \lambda \frac{K^*}{K} L_I + \mu \frac{1+s_m}{1+s_m \Gamma} L_I \right) \tag{16}$$

Our estimations are based on this equation.

4.2 Data and Construction of Variables

Our data cover a cross section of seven manufacturing industries in nine OECD-countries. The industries comprise processed food, textiles and clothing, paper, chemicals, non-metallic mineral products, basic metal industries, and machinery and equipment (i.e. ISIC groups 31, 32, 34, 35, 36, 37 and 38). The list of countries is Canada, Denmark, France,

Table 1: Labour Productivity and Tangible Inputs: Descriptive Statistics for 7 Industries. (Unweighted Average for 9 Countries in 1979 to 1991).

	L productivity	*L force*	*K stock*	*R&D stock*
ISIC Group	*growth*	*growth*	*growth*	*growth*
Food, beverages and tabacco	1.4%	-0.5%	2.6%	5.7%
Textile, clothing and leather	1.8%	-3.1%	0.7%	3.5%
Paper, printing & publishing	1.4%	0.0%	4.0%	5.4%
Chem., coal, rubber & plastic prod.	2.8%	-0.3%	2.3%	5.6%
Non-metal, non-petro.mineral prod.	1.5%	-1.8%	1.2%	4.8%
Basic metal industries	3.7%	-3.1%	0.6%	2.8%
Mach'y, equip. & fab'd metal prod.	3.2%	-0.6%	4.1%	6.8%

Note: L productivity is value-added per worker.
Source: Authors' calculations.

Germany, Italy, Japan, Sweden, the UK and the US.

Data were collected from a number of sources. Data on value added, employment, capital stocks, exports and imports are from ISDB (1994). R&D-expenditures are taken from

ANBERD (1994), Science, and Technology Indicators: Basic Statistical Series-Volume D (1983), while PPP-estimates and GDP-deflators are from the OECD Economic Outlook (*various issues*). Finally, stocks of foreign direct investment (FDI) have been computed from data from the World Investment Directory (1993) published by the UN.* Stocks of knowledge are computed (according to the perpetual inventory method) using real R&D spending in each sector from 1963 and onwards.† Reported results are based on an assumed rate of depreciation equal to 5 percent. All variables are in 1990 US $ equivalents and based on average values for the period 1979-1991.

Table 1 shows summary statistics on the sectors' labour productivity growth (i.e. growth in value-added per employee) and the input growth (un-weighted averages for the nine countries). The first column gives labour-productivity growth performance by sector and here we see a good deal of variation. At the high end, labour productivity in the basic metal

Table 2: R&D, Openness and Size Statistics for 7 Industries in the Manufacturing Secto
(Unweighted Average for 9 Countries in 1979 to 1991).

ISIC Group	*R&D stock to value added*	*Imports to value added*	*FDI stock to K stock*	*Value added Share*
Food, beverages and tabacco	1%	42%	5%	13%
Textile, clothing and leather	1%	133%	2%	6%
Paper, printing & publishing	1%	28%	5%	8%
Chem., coal, rubber & plastic prod.	7%	86%	7%	16%
Non-metal, non-petro.mineral prod.	2%	31%	2%	4%
Basic metal industries	3%	73%	5%	6%
Mach'y, equip. & fab'd metal prod.	10%	79%	9%	46%

Note: Sector's value-added share is of total manufacturing.
Source: Authors' calculations.

industries grew 3.7% on average, while at the low end, the food, beverages and tobacco sector and the paper sector grew at only 1.4%. The next three columns present figures for the growth of inputs. Employment in all sectors fell, but physical and knowledge capital inputs rose.

Table 2 presents descriptive statistics on R&D, openness and size of the sectors. The last sector (machinery, equipment, and fabricated metal products) is by far the largest, accounting for almost half of total manufacturing value-added. Chemicals and processed foods also account for double-digit shares. The shares do not add to 100% due to averaging and the exclusion of ISIC sectors 33 and 39 (33 because of lack of data, 39 because it contains a grab bag of industries not elsewhere included). We also see that machinery and equipment is the most R&D intensive and the most open to foreign capital.

Based on the findings of Braconier and Sjöholm (1998), all spillover effects are assumed industry-specific.

Construction of the Variables. Since we work with data aggregated by industry and country, we interpret L_I as sector-specific, country-specific R&D spending. This is labelled *R&DSPEND*. The second term in (16), $(K^*/K)L_I$ captures MAR spillovers that occur by "osmosis", i.e. are unrelated to FDI. This we construct for each sector and each nation by summing the relevant K_{ij}/K_i ratios (in K_{ij} 'j' is the foreign nation and 'i' is the sector, K_i is

* See Appendix for details on computations of FDI stocks.
† See Appendix for details on computations of R&D stocks.

home-nation's K in sector i; the K's are our calculated R&D capital stocks). We call this constructed variable, MAR-SPILL (short for Marshall-Arrow-Romer spillovers).

The third term captures FDI-linked spillovers. Our theoretical model provides only a rough guide to constructing this variable since K is both the stock of local experience in the R&D sector, and proportional to the number of local firms. Moreover, the model has only a single industry but empirically we must account for cross-sector diversity in R&D intensity leading to different degrees of FDI-linked spillovers. A foreign-owned bottling plant, for instance, is likely to provide fewer spillovers than a foreign-owned pharmaceutical plant. To allow for this we construct a variable that reflects the R&D intensity of each sector in each FDI source-country. Specifically, for each partner country j, we multiply two ratios. The first ratio reflects R&D intensity by sector and source country. It is (K_{ij}/M_{ij}), where K_{ij} is the j's knowledge stock in industry i and M_{ij} is j's physical capital stock (M is a mnemonic for machines) in industry i. The second ratio reflects importance of each source country. It is FDI_{ij}/M_i where FDI_{ij} is the inward FDI flow from j in sector i and M_i is the home nation's physical capital stock in sector i. The products of the pair of ratios for each partner country are summed and the result is multiplied by L_I, i.e. the flow of home-country R&D spending in sector i. The variable is called FDI-SPILL.

4.3 Econometric Results

We start the econometric analysis by estimating (16) taking the dependent variable to be labour productivity growth (growth in value added per employee). Table 3 shows the results.*

Table 3: Basic Theoretical Model Results, Sign & Significance of Explanatory Variables

Regression	*1*	*2*	*3*
R&DSPEND	+*	+*	+***
MAR-SPILL	+	+*	+***
FDI-SPILL	-	+	+**
Fixed Effects	None	Sector	Both
R^2	0.04	0.17	0.30
Observations	63	63	63

Notes: Single, double and triple * indicate significant at 10%, 5% and 1% level of confidence, respectively.
Source: Author's Calculations.

Column-one results were generated with simple least-squares while column-two results allow for industry fixed effects (this allows for the inevitable heterogeneity found in industry panel data). We find the expected signs for both the R&D spending and MAR-spillovers variables in regressions one and two although none are significantly different from zero at a 5% confidence level. The sign of the FDI-spillovers variable is as expected in the fixed effect regression, but it is insignificant in both regressions even at the 10% level. Note also that the explanatory power of both regressions is quite low.

Column-three re-does the regression allowing for country-specific and sector-specific fixed effects.† As Nelson (1993) has convincingly argued, nations have very different innovation systems and as such, it is likely that countries have systematically different abilities to garner productivity advances from inward FDI. The results are presented in column3. Note

* The point estimates, which are not particularly revealing since the model is estimated in levels, are listed in the appendix.
† Thus, a total of 16 dummies, 9 country and 7 sector.

first that the explanatory power rises and although the signs do not change compared to column-2, the coefficients all become significant.

Overall, Table 3 provides a modicum of support for the basic model. The main innovation variables have the expected sign. In particular, we find strong evidence of the "osmosis" type spillovers. We also find evidence that FDI leads to knowledge spillovers beyond the "osmosis" type. In this sense, we can say that FDI appears to promote growth by promoting technology transfer. Interestingly, the significant and positive sign on L_I confirms the findings of Backus, Kehoe and Kehoe (1992) that so-called scale effects do exist in industry level data.

Table 4 Summary of Results for Alternate FDI Proxies

Regression	4	5	6	7
	FDI-alt1	FDI-alt1	FDI-alt2	FDI-alt2
R&DSPEND	+	+**	+**	+***
MAR-SPILL	+	+***	+	+***
FDI-SPILL	-	+	+	+**
Fixed Effects	None	Both	None	Both
R^2	0.06	0.28	0.04	0.30
Observations	63	63	63	63

Source: Author's Calculations.

To check for the robustness of our results, we re-do the basic regressions using two alternative proxies for the third term in (16). The first differs from FDI-SPILL in that the FDI penetration ratios are not weighted by the R&D intensity ratios. That is, (FDI_{ij}/M_{ij}) in each sector is summed over all partners and the result is multiplied by L_I, i.e. the flow of home-country R&D spending in sector i. This is called FDI-alt1. The second replaces the FDI penetration ratio (FDI_{ij}/M_{ij}) with (FDI_{ij}/K_i), where K_i is the home nation's R&D stock in sector i. The idea being that spillovers occur faster when sector i in the MNC's home country has a lot of knowledge capital relative to sector i in the host country. Again the product of the two ratios is summed over all partners and the result is multiplied by L_I. This is called FDI-alt2.

Results for these proxies are listed in Table 4. We see that the FDI measure that is un-weighted by R&D intensity fails to add any spillovers to the "osmosis" type. This negative result (the FDI variable is insignificant even when nation and sector dummies are allowed) sheds some light on the role of FDI in knowledge spillovers. The FDI-alt1 variable essentially reflects a nation's openness to FDI in a particular sector. The fact that the coefficient on this proxy is insignificant indicates that the mere presence of MNCs is not enough to increase spillovers beyond those that occur via "osmosis". This is a useful result since one of the many stories about FDI's role in tech-transfer involves a pro-competitive effect. The idea being that the very presence of MNCs forces domestic firms to keep up with the latest technology. Our results show that unless the FDI flows are weighted by R&D intensity, they do not make the host country L_I more efficient. This suggests that--at least in our sample of rich nations--FDI is pro-growth because it amplifies the transmission of know-how from the MNC's home nation to its host nation.

The results for FDI-alt2 are very similar to those of FDI-SPILL. This is not very surprising since physical capital stocks and knowledge capital stocks are quite co-linear in the data (nations and industries that invest a lot in machines also tend to invest a lot in R&D). It is, however, comforting that a slightly different proxy yields qualitatively identical results. Many other proxies are, of course, possible.

5 Conclusions

FDI is almost entirely absent from theoretical and empirical work on the overall link between openness and growth, despite the mass of empirical and anecdotal evidence showing MNCs to be important transferors of technology. This is a serious shortcoming, given the strongly held belief that FDI is good for growth.

The neglect of FDI in empirical trade and growth studies is matched by - but also explained by - a neglect of MNCs in the theoretical trade and endogenous growth literature. The seminal trade and endogenous growth literature - Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991a, b) - mainly ignores MNCs. Grossman and Helpman (1991) do introduce MNCs into one variant of their basic growth model. However, MNCs in this model are of the Helpman (1984) type and as such merely serve to expand the factor-price equalisation set in a manner analogous to the static trade and MNC model in Helpman and Krugman (1985). In particular, MNCs in the Grossman-Helpman model do not affect the internationalisation of learning externalities, so MNCs play no direct role in determining the endogenous growth rate.

This paper focuses on the pro-growth role of MNCs. We first present a simple theoretical model in which MNCs play a critical role in determining the endogenous long-run growth rate via technological spillovers. We then present an empirical test (using industry-level panel data from seven OECD nations) that broadly supports our model.

Our findings are far from conclusive, but they do suggest that more theoretical and empirical work needs to be done on the growth effects of MNCs.

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Appendix

Construction of Variables

Observations on R&D for the period 1973-1991 are available for all the studied industries and countries. Individual missing observations from before 1973 have been estimated by taking the average value of the preceding and the following year. Missing observations at the beginning of the period have been estimated through extrapolation based on the average growth rate in spending from 1973 to 1991. R&D conducted before 1963 is assumed to be fully depreciated by 1978. The sample of observations on privately funded R&D prior to 1973 can be found in Table A1.

Table A1- Observations Prior to 1973 on Private R&D Expenditures Over Industries, Countries and Time.

Industry	ISIC	France	German.	Italy	Japan	UK	US	DK	Canada	Swed	U.S
Food	3100	1970-72	-64,-67, -69,-71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	-67, -69, -71, -72	-64,-67, -69,-71	1967-72
Textile	3200	1970-72	-64,-67, -69,-71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	-67, -69, -71, -72 –	-64,-67, -69,-71	1967-72
Paper	3400	1970-72	-67,-69, -71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	67, -69, -71, -72 –	-64,-67, -69,-71	1967-72
Chemi-cal	3500	1970-72	-64,-67, -69,-71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	67, -69, -71, -72 –	-64,-67, -69,-71	1967-72
Non-metal.	3600	1970-72	-67,-69, -71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	67, -69, -71, -72 –	-64,-67, -69,-71	1967-72
Basic-metal	3700	1970-72	-64,-67, -69, -71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	67, -69, -71, -72 –	-64,-67, -69,-71	1967-72
Fabr. metal	3800	1970-72	-67,-69, -71	-63,-65, 1967-72	1963-72	1967-72	1967-72	1970	67, -69, -71, -72	-64,-67, -69,-71	1967-72

Source: Science and Technology Indicators (1983)

The nominal R&D spending series are converted into US $ (1990 prices) with the help of PPP estimates and the GDP-deflator for the US. We use the perpetual inventory method to construct stocks of R&D. The assumed rate of depreciation is 0.05.

Data on FDI is available for either specific countries or specific industries.* Inward FDI to a specific industry in a specific country was constructed by assuming the national outward FDI-pattern to apply for each country. For instance, to construct a measure of industry-specific FDI from Germany to Italy, we took the share of Germany's total outward stock of FDI invested in each industry and multiplied it by Germany's total FDI to Italy.† We construct three measures of FDI-linked spillovers:

$$FDI - SPILL = \sum_{j=1,}^{n} \left(\left(\frac{FDI_{ij}}{M_i} \right) \left(\frac{K_{ij}}{M_{ij}} \right) \right), \qquad \textbf{(A1)}$$

* The respective years are: 1987 for the U.K, 1989 for France, 1990 for Italy, Germany, Japan and the U.S.
† We also constructed a variable with the share of Italy's total inward stock of FDI invested in each industry multiplied by the stock of German FDI in Italy. The two proxies were very highly correlated.

$$FDI-SPILL\ (\text{alt. }1)=\sum_{j=1,}^{n}\left(\frac{FDI_{ij}}{M_{ij}}\right) \qquad \textbf{(A2)}$$

and

$$FDI-SPILL\ (\text{alt. }2)=\sum_{j=1,}^{n}\left(\left(\frac{FDI_{ij}}{K_{i}}\right)\left(\frac{K_{ij}}{M_{ij}}\right)\right), \qquad \textbf{(A3)}$$

where i, k and j denote industry, home country and partner country respectively.

Regression Results

Table A.2. Regression Results

Regression	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Constant	2.0E-02	3.9E-02	-7.9E-02	2.0E-02	-6.4E-02	2.0E-02	-6.6E-02
	(7.6)	(1.0)	(2.2)	(7.7)	(1.9)	(7.7)	(1.9)
R&DSPEND	5.4E-04	8.1E-04	1.1E-03	1.0E-03	1.1E-03	3.8E-04	1.2E-03
	(1.7)	(1.7)	(2.8)	(1.6)	(2.0)	(2.4)	(3.2)
MAR-SPILL	8.5E-05	4.5E-04	6.9E-04	8.0E-05	6.2E-04	7.0E-05	5.9E-04
	(1.3)	(1.7)	(3.2)	(1.6)	(3.2)	(0.9)	(2.8)
FDI-SPILL	-9.2E-03	1.4E-02	2.8E-02	-1.7E-02	5.8E-03	1.8E-03	1.4E-02
	(0.5)	(0.7)	(2.1)	(1.1)	(0.5)	(0.2)	(2.2)
Fixed Effects	None	Sector	Both	None	Both	None	Both
R^2	0.04	0.17	0.30	0.06	0.28	0.04	0.30
Observations	63	63	63	63	63	63	63

SUPPLEMENTAL GUIDE TO CALCULATIONS

[1.] Without symmetry, a formal sufficient condition is that max{L, L*} is insufficient to meet global demand for Z. Since a_Z=1 this requires that max{L, L*}<(1-α)E^w, where E^w is world expenditure. αE^w is total spending on X and the monopolistic operating-profit margin is 1/σ, so E^w equals L^w plus αE^w/σ. Rearranging, max{L, L*}<(1-α)σL^w/(σ-α). This places limits on the degree of size asymmetry that is consistent with factor price equalisation.

[2.] All these prices follow from the fact that monopolistically competitive firms engage in 'mill pricing', that a_x=1-1/σ and w=w*=1.

[3.] Consider the case of an n-type firm where operating profit earned on local sales is (p-a_x)c and the operating profit earned on export sales is (p*-a_xτ)c*. The first order condition for local sales can be rearranged into (recall w=1):

$$p(1-1/\sigma) = wa_x \quad <=> \quad (p-wa_x) = p/\sigma \quad <=> \quad (p-wa_x)c = pc/\sigma$$

where c is home consumption of the particular variety. Thus, the operating profit is 1/σ times sales. Similar manipulations show the same result for export sales. For m-type firms all sales are local.

[4.] As always with monopolistic competition, operating profit is 1/σ times the value of sales (consumption at consumer prices or shipments at producer prices). The key to deriving the formula in the text is therefore to relate the value of sales to τ, n and m. Since locally produced varieties have a consumer price of 1 and nonlocally produced varieties a price of τ (due to optimal pricing), the CES demand function implies that the share of a locally produced variety is:

$$s = \frac{1}{n+m+m^*+\phi n^*} \ ; \quad \phi \equiv \tau^{1-\sigma} \ , \quad NB: \ 0 \le \phi \le 1$$

since n+m+m* varieties are produced locally and n* varieties are imported. Using symmetry and defining θ_m as the share of a typical nation's firms that are m-types, s becomes:

$$s = \frac{1}{(1-s_m)(1+\phi)+2s_m}\frac{1}{K} \ ; \quad s_m \equiv \frac{m}{n+m}$$

Likewise the share of an imported variety s* is:

$$s^* = \frac{\phi}{(1-s_m)(1+\phi)+2s_m}\frac{1}{K}$$

Similar manipulations yield the shares for an m-type firm (such firms have s in both markets).

[6.] Given that preferences are intertemporally separable and consumers take the path of prices as given, we can solve the utility maximisation problem in two stages. The first is to determine the optimal path of consumption expenditure E. To this end we set up the Hamiltonian, which for this problem is:

$$H[E,K,\lambda,t] = e^{-\rho t}\left(\ln(\frac{E}{P}) + \lambda(\frac{\pi K + wL - E}{P_K})\right)$$ where C=E/P, P is the perfect price index, P_K is the price of K, and the law of motion for the representative consumer's wealth isK =(Y-E)/F since K is the only store of value. The four standard necessary conditions for intertemporal utility maximisation are:

$$\frac{\partial H}{\partial E} = 0 \quad <=> \quad e^{-\rho t}\left(\frac{1}{E} - \frac{\lambda}{P_K}\right) = 0$$

$$d\frac{e^{-\rho t}\lambda}{dt} = -\frac{\partial H}{\partial K} \quad <=> \quad \rho - \frac{\dot{\lambda}}{\lambda} = \frac{\pi}{P_K}$$

$$\textit{law of motion} \quad <=> \quad \dot{K} = (Y - E) / F$$

$$\textit{transversality condition} \quad <=> \quad \lim_{t \to \infty} \lambda(t)K(t) = 0$$

The first three conditions characterise the optimum path at all moments in time, while the transversality condition is only an endpoint condition. The total time derivative of the first expression can be used to eliminate λ from the second expression. The result reduces to:

$$\frac{\dot{E}}{E} = \left(\frac{\pi}{P_K} + \frac{\dot{P}_K}{P_K}\right) - \rho$$

The Euler equation is found by noting that the right-hand expression in parentheses is the rate of return to K (the first term is the 'dividend' component and the second is the 'capital gains' component) and that this is the rate of return to savings, viz. r.

[7] Grouping terms in (7), we have:

$$1/a_I = K\left(1+\lambda\frac{K^*}{K} + \mu\left(\frac{N}{N} + \frac{m^*}{N}\right)\frac{N}{K}\right)$$

Since K=n+m(1+Γ), K/N=1+s_mΓ. Using this and symmetry yields:

$$1/a_I = K\left(1+\lambda + \mu\frac{1+s_m}{1+s_m\Gamma}\right)$$

With this, the expression in the text is easily obtained.

[8] These are somewhat unconventional choices for numeraire and state variable, but they can be justified as follows. First, consider why L is the natural numeraire. The model has only one primary factor, L, so expenditure allocation by the representative consumer is tantamount to resource allocation. When the consumer optimally decides to save a certain fraction of her income, she is implicitly directing the same fractions of GDP to the production of investment goods. This is true regardless of numeraire, but it comes out most clearly with labour is numeraire.

Consider next why L_I is the natural state variable. The primary goal of any growth model is to identify the endogenously determined growth rate. Most simple models--Romer (1986, 1990), Lucas (1988), Grossman and Helpman (1991) and the model in this paper--make assumptions that allow the steady-state growth rate to be constant. In all these models, the intersectoral allocation of primary resources is constant along the steady-state growth path. It is therefore natural to focus on the time-invariant allocation of primary resources. After all, solving for the equilibrium allocation of labour among sectors is something that trade economists have been doing for centuries. Baldwin and Forsild (1999) refer to this as the static-economy representation of the steady-state growth path.

[9.]Since L_I is the state variable, L_I must, by definition, be time-invariant in steady state. Since all labour is employed, this implies that the amount of labour employed in creating goods for consumption is also time invariant. Given the X- and Z-sector production function, we know that the steady-state output of consumption goods--measured in terms of the numeraire L--must also is time invariant. Moreover the goods markets must clear, so consumer spending on this time-invariant flow of goods must also be time invariant. We see directly, therefore, thatEQ $\dot{E} = 0$ in steady state, in both nations. From the Euler equations this implies thatEQ rEQ=r*=ρ.

More formally, E=Y-I, where I is spending on investment goods and $Y=wL+m\pi^M+n\pi^N$ is national income (i.e. income of the representative consumer). To prove the assertion, we need to express E in terms of parameters and the state variable. This tells us that E stops moving in steady state since parameters and state variables do not evolve in steady state.

Since the I sector is competitive, $I=wL_I$ and by choice of numeraire w=1. π might seem more involved since there may be α2E/σ. Half of this accrues to capital in each nation so $E=L+\alpha E/\sigma-L_I$, i.e. $E=(L-L_I)/(1-\alpha/\sigma)$. Plainly this is time-invariant in steady state, so EQr=rEQ*=ρ in steady state.

[10.] The present value of the π^i stream, namely:

$\int_{s=t}^{\infty} e^{-r(s-t)} \pi_s^i \, ds$ Since g is time-invariant, $K_s=K_t e^{gs}$ in steady state. Thus π falls at the constant rate EQg and:

$$J_t = \int_{s=t}^{\infty} e^{-r(s-t)} \pi_s \, ds = \pi_t \int_{s=t}^{\infty} e^{-(\rho+g)(s-t)} \, ds$$

Solution of the integral yields the formula in the text.

[11] The denominator of q is $wa_I(1+\Gamma)$ i.e.

$$(1+\Gamma)a_I = \frac{1}{K} \frac{(1+\Gamma)}{1+\lambda+\mu\frac{1+s_m}{1+s_m\Gamma}}$$

where s_m=m/N and w=1. The numerator is:

$$V^m = \frac{\alpha E}{\sigma N(\rho+g)}\left(\frac{2}{s_m(1-\phi)+1+\phi}\right)$$

since $K=N(1+s_m\Gamma)$, Γ=(1-φ)/(1+φ) and (1+Γ)(1+φ)=2, this becomes:

$$V^m = \frac{\alpha E}{\sigma(\rho+g)}\left(\frac{1+\Gamma}{K}\right)$$

The numerator and denominator together yield:

$$q^m = \frac{\alpha EA}{\sigma(\rho+g)}$$

Using $E/\sigma=(L-L_I)/(\sigma-\alpha)$ and the growth rate form of the I-sector production function:

$$q^m = \frac{2\alpha(L-L_I)A}{(\sigma-\alpha)(\rho+L_I A)}$$