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The Theories of Trade, FDI and Technology Transfer: A Survey

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Abstract

This paper surveys the most relevant theoretical studies on the relationship between trade, FDI and technology transfer. Its aim is to give an analysis of theoretical models, highlighting their implications for the growth performance of globally integrated economies relative to that of more autarchic economies. The main conclusion coming from the theoretical literature surveyed is that international trade and FDI play a key role in technology transfer and economic growth, but additional research is needed to completely understand the mechanisms driving technology transfer from trade and FDI.

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Keywords: trade, FDI, technology transfer, technology spillovers.

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1. Introduction

Growth literature has long been interested in searching for the causes and effects of the growth of income and why some countries grow faster than others. In the neoclassical growth models developed by Solow (1956) and Swan (1956), capital accumulation and technical progress are considered as the determinants of economic growth. The work of Solow and Swan has later been extended in many directions and in different economic fields. For example, Mankiw, Romer and Weil (1992) introduce human capital formation as an additional factor to the above-mentioned determinants of economic growth. The endogenous growth theory pioneered by Romer (1986) and Lucas (1988) has set a new paradigm for macroeconomic analysis. The endogenous growth models focus on the role of human capital, research and development (R&D) and externalities as endogenous factors of the economic system. In practice, all these determinant factors display their dominant impacts at certain stages of economic development.

Some theories of endogenous economic growth emphasize the importance of technology diffusion in explaining the pattern of long-run economic growth and cross-country income differences (Romer, 1990; Grossman and Helpman, 1991; and Aghion and Howitt, 1992). Technology diffusion may occur through international trade and foreign direct investment (FDI). On the one hand, technology spillovers may come from importing new capital goods used in R&D activities, so that an importing country's productivity would be improved by employing a wider variety of capital inputs or by using better capital inputs in final goods production. On the other hand, FDI often involves the transfer of knowledge from one country to another by setting up production units using advanced technologies in the recipient country (Borensztein, Gregorio and Lee, 1998); this makes it an important channel for international technology diffusion.

The literature on endogenous growth has reached various conclusions, depending on the main object of its analysis: international trade, FDI, or technology diffusion. This paper surveys the major theoretical contributions on these three components of research. Its aim is to give an analysis of theoretical models, highlighting their implications for the growth performance of well-integrated economies relative to that of more autarchic economies. This will pave the way for empirical work aimed at identifying the more realistic of technology spillovers through trade and FDI.

The remainder of the paper is organized as follows. Section 2 is a review of different schools of thought in international trade and growth, which focus on the role of trade in technology spillovers and economic growth. In section 2.1, the literature treats technology as exogenous, and trade does not have any growth effect. Section 2.2 considers dynamic models in which the evolution of technology is endogenous, and international trade plays an important role in technology diffusion. Section 3 contains models in which foreign direct investment is considered as a channel for technology transfer. Section 4 presents a review of another branch of economic growth, which focuses on the determinants of technology transfer. The last section presents a brief conclusion.

2. Trade, Technology and Growth

2.1. Exogenous growth theory and exogenous technology

Exogenous growth theory, which is also called neoclassical growth theory, was developed and dominated research on economic growth during the period from the 1950s to 1960s. The basic model for this branch of economic growth theory is the model which Solow (1956) and Swan (1956) developed independently from each other. They consider a closed economy with a production function as follows:

$$Y(t) = F(K(t), A(t)L(t)) \qquad (1)$$

where *Y(t), K(t), A(t)* and *L(t)* are output, capital, knowledge and labour at time *t* respectively. In this model, the level of knowledge or technology *A(t)* and labour force *L(t)* are assumed to grow at constant exogenous rates:

$$\frac{\dot{A}(t)}{A(t)} = g \qquad (2) \qquad \text{and} \qquad \frac{\dot{L}(t)}{L(t)} = n \qquad (3)$$

Since the function *F* is homogeneous of degree one, output per capita can be yielded from (1) as follows:

$$\frac{Y(t)}{L(t)} = F\left(\frac{K(t)}{L(t)}, A(t)\right) \qquad (4)$$

This expression implies that output per capita depends on capital intensity $\frac{K(t)}{L(t)}$ and the magnitude of knowledge *A(t)*. In this model knowledge *A* is treated as exogenous. The model therefore provides no insight as to which policy can be used for the progress of knowledge in order to consider the issue of differences in national income.

We now turn to consider the growth rate of the economy in the long run. Assume that the net increase in the stock of capital at a point in time equals gross investment less depreciation:

$$\dot{K}(t) = sY(t) - \delta K(t) \qquad (5)$$

where s is the saving rate and δ is the rate of depreciation.

Under the neoclassical assumptions of competitive factor markets and constant return to scale, (1) and (5) can be written in intensive form:

$$y = \frac{Y(t)}{A(t)L(t)} = F(\frac{K(t)}{A(t)L(t)}, 1) = f(k) \qquad (6)$$

$$\dot{k} = sf(k) - (n + g + \delta)k \qquad (7)$$

where $y = \frac{Y(t)}{A(t)L(t)}$ and $k = \frac{K(t)}{A(t)L(t)}$ stand for income per effective worker and capital per effective worker respectively.

In the Solow-Swan model, the steady state corresponds to $\dot{k} = 0$. That is:

$$sf(k) - (n + g + \delta)k = 0 \quad (8) \quad \text{or} \quad sf(k)/k - (n + g + \delta) = 0 \quad (9)$$

Since the production function is assumed to exhibit diminishing returns to each input, the function $f(k)$ also exhibits diminishing returns to capital per effective worker *k*. This then produces a unique steady state at *k**, and *k** satisfies the following condition.

$$s\,f(k^*) = (n + g + \delta)k^* \qquad (10)$$

At the steady state, k is constant, and y is also constant at the value $y = f(k^*)$. Hence, in the exogenous growth model, capital per effective worker and income per effective worker do not grow in the steady state. This implies that in the long run, both the growth rates of capital per worker and income per worker coincide with the growth rate of knowledge (*A*). Without continuous progress in knowledge, long-run growth in per capita income is impossible. This is one of the important implications of the model about economic growth. The per capita outputs of an economy with fixed technology will not grow. Thus, government policies that do not affect the growth rate of technology will not change the steady state growth rate of the economy. For example, as mentioned by Lucas (1988), international trade will not have any growth effect as long as it does not affect the growth rate of technology.

Despite being incompletely explained, many empirical studies show that knowledge or technology is the main responsibility in explaining the differences in per capita income and labour productivity growth. For example, Solow (1957) tests his model and argues that most of the growth of the United States over the past one hundred year could not be explained by increases in labour and capital. He attributes nearly 90 percent of US per capita output growth to exogenous technical progress.

Hall and Jones (1999) examine the contribution of human capital, physical capital intensity and of technology to the income differences for 127 countries for the year 1988. They then compare the five richest countries and five poorest countries in the dataset, showing that while contribution of human capital and capital intensity just make up a factor of 1.8 and 2.2 to the income differences respectively, technology contributes by factor of 8.3.

Therefore, even though the Solow-Swan model makes a great contribution to growth theory, the main drawback of this model is that it leaves the source of long-run growth - knowledge or technology - unexplained. To go further, we need a theory that can explain the evolution of technology and why it affects economic growth. This is one of the motivations of endogenous growth theory.

2.2. Endogenous growth, technology and trade

Endogenous growth theory has been established by the works of Romer (1986), Lucas (1988) and Rebelo (1991). Their motivation is based on the desire to avoid the implication of the exogenous growth model that diminishing returns to capital make exogenous technical progress the only source of long-run growth in income per capita. They attempt to explain how private economic agents make decisions that drive long-run growth through increasing returns, technology spillovers and other non-traditional effects.

The literature on trade, technology and endogenous growth can be divided into two main streams. In the first one, trade may change the pattern of specialisation of a country, and endogenous growth is the result of a process of learning by doing. In the second stream, endogenous growth is determined by specific research activities carried out by profit maximizing agents, and trade in goods and factors of production may open new sources of technological spillovers.

2.2.1. Learning by doing

In models of learning by doing, comparative advantage and growth are closely related to trade. Trade may change the pattern of specialisation of a country in goods with different degrees of learning potential, and the effect of trade depends on the extent of learning externalities. In the case of intra-national spillovers, learning is faster if the country specialises in goods with higher learning potential because the increase in the level of production of these goods that are exported augments the relative efficiency of their production technology relative to that of other countries. In contrast, in the case of global learning externality, trade does not affect each country's specialisation, and there are no international knowledge spillovers.

The early work on learning by doing began with Arrow (1962). Arrow considers technological progress as a side product of economic activities and then shows that although new knowledge can be gained from doing a repetitive task, it is sharply decreasing. To make learning by doing a continuous process, it requires continuous stimuli. In this model, the continuous stimuli is brought about by a flow of new capital. New knowledge gained from working with existing capital is put into new capital. New capital is hence regarded as different from the existing capital in the sense that it is more productive. Accordingly, new investment is a source for learning by doing. This implies that new knowledge acquired from learning is just a side product of investment. Arrow also assumes that the arrival of new knowledge is outside the reckoning of an individual firm, since firms do not take into account the effects of their investment on the learning by doing process. This means that knowledge has the nature of a public good which is an unintentional product of an increase in investment. This also creates the possibility for the aggregate production function to exhibit increasing returns to scale even under conditions of perfect competition.

Krugman (1987) considers a world economy with two countries, namely Home and Foreign. He takes the production of each traded good in each country to be as follows:

$$X_i(t) = A_i(t) L_i(t) \qquad i = 1, \ldots, n \tag{11}$$

Where X_i is the output of traded good *i* in each country, L_i is labour devoted to that good's production. A_i is the productivity of resources in each industry and in each country, and depends on an index of cumulative experience, K_i:

$$A_i(t) = K_i(t)^{\varepsilon} \qquad 0 < \varepsilon < 1. \tag{12}$$

The relative productivity of the home country to the foreign country is simply a function of the relative experience indices:

$$\frac{A_i^H(t)}{A_i^F(t)} = \left(\frac{K_i^H(t)}{K_i^F(t)} \right)^{\varepsilon} \tag{13}$$

where *H* and *F* denote home country and foreign country respectively.

Some goods are now produced exclusively in the home country, some exclusively in the foreign country. Over time, learning by doing makes the home producers more productive in each of the goods initially produced at home, while foreign producers gain no experience in these goods. Since the experience indices determine the relative productivity, the left hand side of equation (13) becomes larger over time. In other words, the relative productivity advantage of the home country in each of these industries grows over time. Similarly, foreign firms gain experience and knowledge in producing the range of goods initially manufactured abroad, while home firms learn nothing about these industries. As a result, the foreign relative productivity advantage of export sectors becomes larger. In this model, the determination of the long-run trade pattern depends not only on intrinsic ability, but also on the initial stock of industry knowledge in each country.

Lucas (1988) introduces a similar model, but with two goods (*x* and *y*) and a continuum of small countries. In his model, all countries have the same labour force *L* and the same intrinsic productivities, $1/a_x$ and $1/a_y$. They differ in their initial stock of knowledge (*A*). Then countries with the highest ratios A_x / A_y at time 0 initially produce good *x* and the remaining countries initially produce good *y*. In the countries that produce good *x*, the productivity of this good grows at the rate $\delta_x L/a_x$ (δ is a measure of the internationalisation of learning). If no country changes its sector of specialisation, world output of good *x* will grow at this same rate. Similarly, productivity grows at the rate $\delta_y L/a_y$ in the countries producing good *y*. Then, if $\delta_x / a_x > \delta_y / a_y$, the countries that specialise in producing goods *x* will grow faster than those that specialise in producing good *y*. The relative price of good *x* to good *y* is falling. This may induce some countries to change their patterns of specialisation from producing good *y* to producing good *x*. However, the decline in the rate of price never exceeds the rate at which productivity grows in sector *x*. Therefore, if these countries change their pattern of specialisation, they will lose their income until they have collected enough experience in the new pattern of specialisation. This model suggests that policies that temporarily alter the pattern of trade may affect the long-run specialisation of a country. Lucas's model has an interesting policy implication. In terms of the economy's growth, the right policy for a country is that its trade can only be liberalised when it has gained a comparative advantage in the fast growing good.

Other models of trade with learning by doing have been suggested. Young (1991) develops a model of bounded learning by doing based on the framework of the Ricardian model of international trade. In his model, labour is the only factor of production, and trade is driven by differences in technology rather than differences in factor endowments. Young considers the effect of trade between two countries, a less developed country (LDC) and a developed one (DC), with the latter denoted by a star. Both countries produce any one of an infinite number of goods *s*, which is indexed along $[0,\infty)$, in terms of increasing technological sophistication, and under conditions of perfect competition. Technologies in two countries differ in terms of unit labour requirements. He assumes that there is a lower bound to the potential unit labour requirement for each good. In a special case of the Young model, potential unit labour requirements $\bar{a}(s)$ are exponentially decreasing in the degree of technological sophistication *s*.

$$\bar{a}(s) = \bar{a}.e^{-s} \tag{14}$$

At each point in time *t*, actual unit labour requirements $a(s,t)$ are assumed to be increasing in *s* and given as follows.

$$a(s,t)=\bar{a}.e^{-s} \text{ for all } s \leq T(t) \text{, and } a(s,t)=\bar{a}.e^{-T(t)}.e^{s-T(t)} \text{ for all } s > T(t) \tag{15}$$

where $T(t)$ denotes the most sophisticated good for which all potential for learning by doing has been exhausted and characterises the stock of technological knowledge.

Since there are externalities in learning by doing across goods, $T(t)$ rises at a rate depending on the economy-wide flow of skilled labour devoted to production of goods.

$$\frac{dT(t)}{dt} = \int_{T(t)}^{\infty} L(s,t)\, ds \tag{16}$$

Representative consumers in each country maximise the intertemporal utility function:

$$U_t = \int_t^{\infty} e^{-\rho(\tau - t)} . \int_0^{\infty} \log[C(s,\tau)+1]\, ds\, d\tau \tag{17}$$

where $C(s,\tau)$ denotes consumption of goods at time τ; ρ is the subjective rate of time preference.

In the absence of both trade and international spillovers of ideas, the growth rate of the economy depends on the rate of learning by doing on goods that potential unit labour requirement have not yet been attained. In equilibrium, Young shows that:

$$\frac{dT(t)}{dt} = \frac{L(t)}{2} \tag{18}$$

This means that only half of labour force is devoted to the production of goods due to the symmetrical nature of demand around $T(t)$. Thus, under autarky the growth rate of the economy, like the rate of technical progress, is equal to $L(t)/2$.

In the absence of international spillovers of ideas, the two countries are assumed to be identical. They are only different in the size of labour force *L(t)* and the stock of technological knowledge $T(t)$. The key element that distinguishes the DC from the LDC in this model is that $T^*(t) > T(t)$. This assumption implies that relative unit labour requirement in the DC $a^*(s,t)/a(s,t)$ will be lowest in more sophisticated goods where it has greater opportunity to benefit from learning by doing. In contrast, relative unit labour requirement in the LDC $a(s,t)/a^*(s,t)$ will be lowest in less sophisticated goods. As a result, trade between two countries will induce the DC to specialise in more sophisticated goods where learning by doing still occurs. The LDC will specialise in least sophisticated goods where no learning by doing exists, resulting in poorer growth performance. An implication of Young's model is that in a world with two identical countries, temporary subsidies to high-tech industries in one country will give the country a permanent advantage.

Another finding of the Young model is that technology gap plays an important role in income convergence between the DC and the LDC. Equation (16) shows that the model is characterised by a scale effect because the rate of learning by doing in each country depends on the flow of skilled labour devoted to the production of goods. As a result, if the learning gap between two countries is small enough and the LDC's labour force sufficiently large relative to the DC's, the LDC will be able to exploit large economies of scale, and income per capita in the LDC will rise relative to that in the DC until the roles of LDC and DC are reversed.

Stokey (1991) develops a model of learning by doing with national spillovers in human capital accumulation. In her model, private investment in human capital raises the social stock of knowledge. International trade influences growth by affecting the incentive for schooling and other investments in human capital. Stokey shows that human capital can be substituted for learning by doing without significantly changing Young's conclusions. In particular, free trade reduces the incentive to accumulate human capital in a backward country, which in turn does not affect the growth rate of that country.

Both Young (1991) and Stokey (1991) have important contributions to the literature as they show clearly what happens when trade does not generate international knowledge flows. The findings of the models of Young and Stokey are too restrictive to derive policy implications for developing countries. These models, for example, may not account for the extraordinary growth of some East Asian countries during the 1970's and 1980's.

Matsuyama (1992) constructs a model of a small open economy with learning by doing to address the question of how the pattern of trade affects the long-run specialisation of the country. In his model, the economy is assumed to have two sectors, an agricultural sector using a constant technology, and an industrial sector using a technology characterised by learning by doing. Under these assumptions, the model shows that free trade can be detrimental to economic growth of a country with an initial comparative advantage in the agricultural sector and lagging in technological development. In particular, after free trade, the amount of resources employed in the industrial sector decreases compared to autarky, thereby reducing the rate of knowledge accumulation through learning by doing. As a result, the productivity of the manufacturing sector will be reduced, and then the growth rate of the economy will slow down in the long run.

In contrast to the models of Young, Stokey, and Matsuyama; Van and Wan (1997), in a model of growth with learning by doing, find that trade and learning by doing have a positive effect on the rate of growth of an integrated economy. Based on the contagion theory suggested by Findlay (1978), they show that technological progress, international trade and factor accumulation are complements in the growth of the economy. This implies that international trade provides a channel to the economy through which it learns from other economies.

Mountford (1998) analyses the growth and trade of an economy based on a two-country, two-sector overlapping generation structure with the standard Heckscher-Ohlin framework. This model shows that in the presence of national externalities, international trade forces a country trapped in low growth equilibrium to switch to its high growth equilibrium. International trade is also associated with convergence and overtaking dynamics, in which a country with relatively low output per capita can catch up and overtake output per capita of a country with relatively high output per capita.

A similar result is obtained by Goh and Olivier (2002) in a model of learning by doing and trade in capital goods. The model is a two-country overlapping generation model with an assumption that capital goods are to be traded. Under these hypotheses, trade in capital goods allows a country to gain access to cheaper capital goods, which raises investment, output per worker and learning by doing.

There are some implications of the learning by doing models for convergence and the overall growth effects. In the case of national externalities, international trade induces the specialisation of a country, which in turn increases the size of production within the given country and augments the positive effect of externalities on its productivity and economic growth. In the case of global externalities, international trade does not affect the country's specialisation and convergence. In both cases, the overall growth rate of the integrated country increases because of international trade.

2.2.2. Research and development (R&D) models

In the models of R&D, knowledge accumulation is introduced as an activity carried out by profit maximising firms. The R&D models rely on a hypothesis that the knowledge externality is dynamic. The rationale behind the hypothesis of dynamic spillovers comes from two fundamental characteristics of knowledge. First, knowledge is a non-rival good. This means that the use of knowledge from research activity by one firm or person does not preclude its use by another one. Secondly, knowledge can be made excludable by means of legal protection. But, it is likely that excludability is usually imperfect; knowledge and ideas can be copied or adapted. Therefore, research activity by one firm or person may generate positive spillovers for others undertaking the same activity.

One important model that is considered as a theoretical background for examining the international transmission of technology transfer is that of Rivera-Batiz and Romer (1991). We provide a brief description of this model because it is the basic theoretical model used for empirical studies.

Rivera-Batiz and Romer examine two models, which refer to two channels for transferring technological knowledge. The first one is the knowledge-driven R&D model in which the transmission of ideas can be traded independently from goods. The second one is the lab equipment model in which trade of intermediate inputs incorporates new ideas.

Final goods are produced with human capital, unskilled labour, and intermediate inputs as follows.

$$Y = H^{\alpha} L^{\beta} \int_0^A x(i)^{1-\alpha-\beta}\, di \tag{19}$$

where A denotes the index of the most recently invented goods.

In the knowledge-driven model, new designs for intermediate inputs are produced by the research sector, at a rate given by:

$$\dot{A} = \delta H A \tag{20}$$

In the lab equipment model, the specification of new designs is assumed to be the same as in the production of final goods.

$$\dot{A} = B H^{\alpha} L^{\beta} \int_0^A x(i)^{1-\alpha-\beta}\, di \tag{21}$$

where B denotes a constant scale factor.

This specification indicates that human capital, unskilled labour, and intermediate goods are productive in research, and knowledge per se has no direct productive value.

The balanced growth equilibrium for each of the two specifications of new designs can be calculated in terms of two linear relations between the rate of growth and the interest rate. As shown in Appendixes 1 and 2, the interest rates from the knowledge-driven model and the lab equipment model are respectively as follows:

$$r = (\delta H - g)/\Lambda \tag{22}$$

where $\Lambda = \alpha(\alpha+\beta)^{-1}(1-\alpha-\beta)^{-1}$

and $r = \Gamma H^{\varepsilon} L^{\beta}$ (23)

where $\Gamma = B^{\alpha+\beta} (\alpha + \beta)^{\alpha+\beta} (1-\alpha-\beta)^{2-\alpha-\beta}$

The other balanced growth relation between the interest rate and the rate of growth captures dynamic consumer optimization (Ramsey preference). The individual's lifetime utility is assumed to take the form of:

$$U = \int_0^\infty \frac{C^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt \qquad (24)$$

where ρ is the discount factor and σ is the risk aversion factor.

Under balanced growth, the rate of growth of consumption is equal to the rate of growth of output. Thus, the interest rate from the consumer's first order conditions for intertemporal optimization is as follows:

$$r = \rho + \sigma g \qquad (25)$$

The balanced rate of growth for an economy under the knowledge-driven model is calculated from the relation between *r* and *g* determined in equations (22) and (25).

$$g = (\delta H - \Lambda\rho) / (\Lambda\sigma + 1) \qquad (26)$$

Similarly, the balanced rate of growth for an economy under the lab equipment model is derived from equations (23) and (25).

$$g = (\Gamma H^{\alpha} L^{\beta} - \rho) / \sigma \qquad (27)$$

Now suppose that international flows of goods and knowledge between the two countries are allowed. In the knowledge-driven model, the stock of ideas that can be used in research is now twice as large as it was prior to trade.

$$\dot{A} = \delta H (A + A^*) = 2 \delta A \qquad (28)$$

The balance rate of growth now is:

$$g = (2\delta H - \Lambda\rho) / (\Lambda\sigma + 1) \qquad (29)$$

Thus, international trade has two effects on the economy equilibrium rate of growth in the knowledge-driven model. On the one hand, the increase in the stock of ideas has a direct positive effect on the rate of growth of the research sector. On the other hand, because productivity in the research sector increases, the growth rate of the economy will rise. In this model, although trade in intermediate inputs has no effect on the economy growth rate, it has important level effects on final goods and economic welfare.

In the lab equipment model, knowledge is diffused internationally only if there is trade in intermediate goods since knowledge is embodied in these goods. International trade in intermediate goods expands the variety of inputs that may be used in research and increases the marginal product of labour in research. Again, there are two effects on the economy's rate of growth in this model. First, there is a direct positive effect from the increase in the productivity of research. Secondly, there is an indirect positive effect through the incentive to engage in research. However, due to the fact that ideas in themselves do not affect the productivity of research, international flows of ideas alone have no effect on an economy's rate of growth.

The two models by Rivera-Batiz and Romer (1991) imply that there are different mechanisms of technology diffusion, and the form of knowledge diffusion plays an important role in determining the rate of growth. However, Rivera-Batiz and Romer (1991) focus only on symmetric countries. If two countries are not symmetric, the country with a larger stock of accumulated knowledge will have a comparative advantage, and research will concentrate in the country with larger endowment of human capital.

Devereux and Lapham (1994) consider the effect of international trade in goods between dissimilar countries in the knowledge-driven model of Rivera-Batiz and Romer (1991). They show that if countries start from different initial stocks of knowledge, the country with a smaller stock of knowledge will stop doing research and specialise in the production of goods because trade in goods creates an incentive for itself. As a result, all research is undertaken in the country with the large initial stock of knowledge. Devereux and Lapham then argue that the finding of Rivera-Batiz and Romer in the knowledge-driven model that international trade in goods per se does not affect the rate of growth is not robust. It holds only in the knife-edge case where pre-liberalisation stocks of knowledge are exactly equal across countries. Thus, trade in goods alone increases as long as there are even slight differences in the initial levels of national income between countries. These findings reinforce the importance of trade in goods and comparative advantage in the process of technology diffusion and economic growth when two countries integrate with each other.

In another study, Grossman and Helpman (1991) extend the framework of Rivera-Batiz and Romer (1991) to the case of asymmetric countries and the case in which there is more than one final good. In the Grossman and Helpman model, inputs are differentiated horizontally, and output is produced from an assortment of intermediate inputs with a greater number of inputs associated with more specialisation and refinement of each stage of production. A production function is as follows:

$$X = \left[\int_0^n z(j)^\alpha \, dj \right]^{1/\alpha} \quad , \quad 0 < \alpha < 1 \tag{30}$$

where X and z denote final output and the inputs of intermediate good j; n is the number of intermediates employed.

Grossman and Helpman consider knowledge flows between two countries indexed by i, $i = A, B$. These countries have the same technologies for developing new blueprints and intermediate goods, but different sizes of their labour force ($L^A \geq L^B$). Two countries share common preferences and a common discount rate, ρ.

As shown in Appendix 3, the long-run rate of innovation in the steady state satisfies the following:

$$(1-\alpha)\, V^i = \rho + g^i \tag{31}$$

where V is the aggregate value of innovations, g is the rate of innovation.

Equilibrium in the labour market requires:

$$g^i + \alpha\, V^i = \frac{L^i}{a} \tag{32}$$

where L represents the aggregate labour force.

Combining (31) and (32), the long-run rate of innovation in a closed economy is as follows:

$$g^i = (1-\alpha)\,\frac{L^i}{a} - \alpha\rho \tag{33}$$

Now suppose that international trade takes place between the two countries. Researchers in each country now learn not only from the R&D projects undertaken locally, but also from those that are carried out abroad. It is straightforward to derive the long-run rate of innovation in the world economy with international knowledge spillovers.

$$g^{i} = (1-\alpha)\,\frac{L^{A} + \varphi L^{B}}{a} - \alpha\rho \qquad (34)$$

where φ is the fraction of products available in country A that are not available in country B.

By comparing (33) and (34), Grossman and Helpman show that international spillovers stimulate innovation and growth in both countries. In each country, the rate and level of innovation produced under trade is larger than that of innovation experienced under autarky. In particular, international trade expands not only the range of intermediate inputs available to a producer of final goods, but also provides access to the general knowledge generated abroad.

Another finding from this model is that benefits from international trade are attenuated by any duplication of research effort. It is clear from equation (34) that the smaller the extent of overlap in the research project of the two countries (i.e. the greater the φ), the higher the common long-run rates of innovation and growth.

The Grossman and Helpman (1991) model has an implication for developing countries. If developing countries engage in international trade with developed countries, they will obtain a greater variety of intermediate inputs and knowledge, and therefore grow faster than they otherwise would. In other words, international trade may help raise the growth rates of developing countries.

In the models of Rivera-Batiz and Romer (1991), and Grossman and Helpman (1991), the effects of technology spillovers on growth are considered under steady-state conditions. Barro and Sala-i-Martin (1997) address this issue by introducing a model to analyse transitional paths and conditional convergence. The key element in their model is that imitation is typically cheaper than invention. Therefore, they argue that technology is diffused from a leading country, an innovator, to a follower country, an imitator. They show that the world growth rate in the long run is determined by inventions in the leading countries. The follower countries converge towards the leading countries because imitation and implementation of inventions are cheaper than innovation. They also show that this mechanism tends to generate a pattern of conditional convergence, as a tendency of an increase in copying costs reduces the growth rate of the follower country.

More recently, the framework of R&D models of growth has been extended to study the spatial dimension of economic development by merging endogenous spatial agglomeration and endogenous growth models. Martin and Ottaviano (2001) construct a model in which aggregate growth and spatial agglomeration are jointly determined. In their model, agglomeration fosters growth by making it possible to pay a lower price for an identical amount of intermediate inputs necessary for research. More specifically, if R&D activities use goods from imperfectly competitive industries as inputs, these industries will be attracted towards the location where the R&D activities take place. Due to the presence of transaction costs, this in turn lowers the cost of innovation and promotes the incentives to innovation and growth. This model implies that geography is a channel, through which trade can affect growth.

Baldwin and Forslid (2000) consider how agglomeration affects growth by extending the core-periphery model of Krugman (1991) with endogenous growth. They show that the presence of knowledge spillovers in the R&D sectors introduces growth linkage as a factor of circular causation that determines agglomeration. In their model, the integration of the R&D process is viewed as a lowering of the cost of trading information and goods. As a result, a reduction of the transport costs may not only increase concentration of all economic activities, but also guarantee a higher equilibrium rate of growth of total output for the global economy.

2.2.3. Comparing different types of models on endogenous growth, trade and technology, and their implications

We have examined two types of technological progress: learning by doing and R&D activities. These two types of technological progress affect the production and economic growth of an economy in different ways. On the one hand, models describing different types of technological progress vary a lot in terms of the underlying preferences, market structures, production technology, features of the research sector, the extent of technology spillovers, the role of trade, and so on. On the other hand, the growth rate of an economy is often measured in different ways. In some models, the growth rate of an economy is represented by the growth rate of per capita income or the growth rate of output. In other models, the growth of the number of varieties and the growth rate of the utility of a representative consumer are considered as measures of the growth of the economy. Consequently, the results obtained also vary a lot. Moreover, international trade affects technological progress and economic growth of an economy in different ways. For models on learning by doing, trade does not affect international knowledge spillovers. For R&D models, international trade induces an increase in the variety of intermediate inputs and knowledge, and therefore helps to raise the growth rate of an economy.

Although these models differ in their measures and economic interpretations, they have similar mathematical expressions, especially the expression for the growth rate of an economy. Specifically, the growth rate of the economy in a steady state can be measured as an increasing function of the employment engaged in the research activity.

These endogenous models have three major implications for the economic growth of the economy. The first implication is that endogenous growth theory points out the important role of technological progress in economic growth and income difference across countries. Romer (1990) shows that improvement in technology is the fundamental source of growth that makes output per hour worked in the US today 10 times as valuable as it was 100 years ago. Keller (2001) mentions that the fast development in new information and communication technologies is the reason to explain why the United States lead in per capita income over Japan has increased from 10% in 1990 to 20% by 1999.

The second implication is that an increase in the size of the R&D sector will increase the growth rate of the economy. This effect is called the scale effect of R&D and comes from the idea that the bigger the knowledge base, and the more resources devoted to research, the easier it is to accumulate more knowledge, and the higher the economic growth. However, existing empirical evidence does not support the implications of scale effects of R&D. Jones (1995a, 1995b) uses aggregate data on R&D inputs to test R&D based endogenous growth models in industrialized countries and finds no evidence of a relation between the growth rate of output and the relevant scale variables. Jones (1995a) shows that the growth rates in the US and other OECD countries are not proportional to economy-wide R&D investment in these countries. Using more sophisticated econometrics, Jones (1995b) further shows that while R&D input, measured by the number of scientists and engineers in the US, grows by more than five times from 1950 to 1998, the growth of productivity for the same period is constant or even negative.

Another implication of R&D models is the role of R&D spillovers in an international context. Coe and Helpman (1995) use a sample of OECD countries to examine the relation between international R&D spillovers and economic growth. They define foreign R&D capital stocks as the import share-weighted average of trade partners' domestic R&D capital stocks. Coe and Helpman find evidence that international R&D spillovers are an important source of productivity. In particular, the productivity level in a country is associated with past R&D investments of close trading partners, and international R&D is more important for small countries. Keller (1998) addresses the problem of foreign R&D measure in the study of Coe and Helpman, and calculates trade weights by considering only imports of machinery used in production in a given industry. Keller finds similar results that foreign R&D stocks have significant and positive effects on productivity. Coe, Helpman, and Hoffmaister (1997) confirm these results in their analysis of foreign R&D spillovers and economic growth in 77 developing countries. They also point out that openness to and trade with developed countries are key channels for developing countries to obtain access to foreign R&D. These three studies provide empirical evidence to reflect the role of R&D spillovers developed in the models of Rivera-Batiz and Romer (1991), and Grossman and Helpman (1991).

3. FDI and Technology Spillovers

3.1. Theoretical models on FDI and technology spillovers

Among the different ways of modelling international technology diffusion, technology transfer via foreign direct investment is an important research agenda. The literature on the role of FDI in technology transfer and its effects on the economic growth of host countries focuses on two distinct processes in international technology transfer. The first one is technology transfer from the parent firm of a multinational company to its subsidiary abroad. The second is technology transfer in the form of an externality from the subsidiary to domestic firms.

Koizumi and Kopecky (1977) are the first to explicitly model FDI and technology transfer. They develop a model of international capital movements and technology transfer in a small open economy context to analyse the role of international technology transfer. In their model, technology transfer is assumed to take place when foreign capital creates an externality in technology to the host country. Specifically, the technology level of the host country is assumed to be an increasing function of the stock of foreign capital per capita. Foreign capital and domestic capital are physically the same but foreign capital imparts spillovers in the form of technological transfers. As a result, while foreign capital and domestic capital are paid at the same world interest rate, the social marginal productivity of foreign capital is higher than that of domestic capital. They find that an increase in the savings rate of the country would reduce foreign capital and its steady state capital intensity through its effect on technical efficiency.

Findlay (1978) develops a model of international technology transfer by international corporations to examine the relationship between FDI and technology change in a backward region. In his model, the rate of technological diffusion to the backward country is assumed to depend on two factors, which are called the "relative backwardness" and the "contagious effect". The hypothesis of relative backwardness, which was introduced by Gerschenkron (1962), states that the larger the gap in development levels between advanced and backward countries, the faster the rate at which the backward country can catch up in technology. Findlay puts forward this hypothesis and shows that the rate of technological progress in the backward country is an increasing function of the technology gap between it and the advanced country. The contagion idea, following Arrow (1962), stresses the importance of personal contacts. That is, advanced technology is most efficiently diffused when there is personal contact between those who already have the technology and those who eventually adopt it. With the effect of contagion, Findlay argues that the rate of technology change in the backward country increases proportionally to the extent to which it opens up to FDI. This extent is measured by the ratio of foreign-owned capital stock to domestic-owned capital stock. He considers the effects of changes in various parameters in the steady state and shows that the economy approaches the steady state where it grows at the rate equal to the exogenous growth rate of foreign technology.

Das (1987) uses a price-leadership model from oligopoly theory to examine technology transfer from the parent firm to its subsidiary abroad. Domestic firms learn from subsidiaries and become more efficient. In her model, a domestic firm's production efficiency is assumed to be an increasing function of the level of activities of the subsidiaries. The larger the level of a subsidiary's operation, the greater the opportunity for the domestic firm to learn from it.

In another study, De Mello (1997) provides a model in which the existence of foreign direct investment creates externalities in the stock of technology of the host country. The stock of technology (*H*) is assumed to be a function of foreign-owned and domestic-owned physical capital stock.

$$H = \left[k_d \, k_w^{\alpha} \right]^{\eta} \tag{35}$$

where α and η are the marginal and the intertemporal elasticities of substitution between foreign and domestic owned capital stocks.

A general growth accounting equation in this model is defined as follows

$$g_y = g_A + \left[\beta + \eta(1-\beta)\right] g_d + \left[\alpha\,\eta(1-\beta)\right] g_w \tag{36}$$

By equation (36), De Mello argues that the effect of FDI on the growth performance of the host country is manifold. In his model, FDI is found to be a growth-determining factor where a higher growth rate of the economy is associated with a higher level of FDI.

In the models of Koizumi and Kopecky (1977), Findlay (1978), Das (1987) and De Mello (1997), the advanced technology introduced by foreign firms is considered under the assumptions that it naturally is a public good and transferred automatically. However, as argued by Fan (2002, p6), "the growing importance of international patent agreements and the licensing of technology suggest that technological knowledge is frequently a private rather than a public good, and that technology can rarely be automatically transferred". As a result, these models do not raise or deal adequately with the issue of interaction between foreign subsidiaries of multinational firms and host country firms.

Wang and Blomstrom (1992) construct a model in which international technology transfer is examined in a game theory context. In particular, technology transfer in this model is assumed to be a process by which foreign subsidiaries of multinational firms obtain foreign technology, which is subject to diffusion to domestic firms. Both foreign subsidiaries and domestic firms solve their individual dynamic optimization problems subject to the others' action. The strategic decisions between firms then determine the rate of technology transfer. The model also shows that technology transfer via foreign direct investment is positively related to the level and cost efficiency of the domestic firm's learning investment.

More recently, Borensztein, Gregorio and Lee (1998) propose a model to address the question of how foreign direct investment affects the economic growth of developing countries through technology diffusion. Their model is based on the idea that the economic growth rates of developing countries are partly explained by a "catch- up" process in the level of technology. In particular, the extent of adoption and implementation of new technology that is already in use in leading countries will determine the economic growth rate of the developing country. In their model, technological progress takes the form of new types of intermediate goods introduced by foreign firms and available in the developing country. The existence of FDI lowers the cost of introducing new technology and thus raises the rate of technological changes and economic growth in the developing country.

The Borensztein et al. (1998) model considers the role of FDI in the process of technology diffusion and economic growth in developing countries. We now provide a full description of this model, as it is the theoretical background for the empirical studies.

The model is based on the concept of an increase in the number of varieties of capital goods as in Romer (1990), Grossman and Helpman (1991), and Barro and Sala-i-Martin (1997). The production function of a developing country is as follows:

$$Y_t = A L_t^{\alpha} H_t^{\beta} X_t^{1-\alpha-\beta} \qquad (37)$$

Where Y is output, A is a scalar productivity parameter denoting various control and policy influencing the level of productivity in the economy, L and H denote labour and human capital respectively, and X denotes physical capital that consists of a composite of different varieties of capital goods.

$$X = \{\int_0^N x(j)^{1-\alpha-\beta}\, dj\}^{\frac{1}{1-\alpha-\beta}} \tag{38}$$

where $x(j)$ denotes each type of capital good; N is the total number of varieties of capital goods in the developing country. The domestic firms produce n varieties out of the total number N and the foreign firms produce n^* varieties.

$$N = n + n^* \tag{39}$$

Let F denote a setup cost when a new type of capital good is utilised in production. Thus, if the new capital comes from foreign countries, F may represent the cost of imitating or adapting the new capital.

Assume that the developing country, in imitating, begins with the easiest and cheapest invention that exists in developed countries, then F will increase with the increase in the number of capital varieties in the developing country (N) compared with that of developed countries (N^*).

$$\frac{\partial F}{\partial (N/N^*)} > 0 \tag{40}$$

This assumption is consistent with the fact that it is cheaper to imitate a product already in existence for some time than to create a new product at the frontier of innovation. Therefore, the level of technology of the developing country is the result of an increase in the number of capital goods that is invented in developed countries.

It is also assumed that $F(N/N^*) = 0$ is too small to encourage imitation in the country, and $F(N/N^*) = 1$ is large enough to discourage adoption or encourage imitation.

Also, assume that the setup cost depends negatively on the ratio of the number of capital goods produced by foreign firms operating in the country to the total number of capital goods (n^*/N). This means:

$$\frac{\partial F}{\partial (n^* / N)} < 0 \qquad (41)$$

This assumption can be explained in many ways. First, the presence of foreign investors in the host country may motivate firms' imitation activities in the host country through demonstration, thereby reducing information costs. This is because new technology generally requires demonstration in the local environment before it can be transferred effectively (Findlay, 1978). Secondly, foreign investors are more familiar with their invention and hence may be better suited than local investors in adapting their invention in foreign countries. Thus, by making it easier to adopt the technology necessary to produce new capital varieties, foreign direct investment is considered as a channel of technology diffusion in this framework.

Let *m(j)* denote the marginal product of each variety of capital goods.

$$m(j) = A(1-\alpha-\beta)\, L^{\alpha}\, H^{\beta}\, x(j)^{-\alpha-\beta} \qquad (42)$$

The flow of revenues for the producer of a new variety of capital *j* is:

$$P = \int_{t}^{\infty} \{m(j)\, x(j) - x(j)\}.\, e^{-r(s-t)}\, ds \qquad (43)$$

The profits for the producer from sales of a new variety of capital *j* are:

$$\Pi = -F(n^* / N, N / N^*) + \int_{t}^{\infty} \{m(j)\, x(j) - x(j)\}.\, e^{-r(s-t)}\, ds \qquad (44)$$

Maximising (44) subject to equation (42) gives

$$A\,(1-\alpha-\beta)^2\; L^{\alpha}\; H^{\beta}\; x(j)^{-\alpha-\beta} = 1 \qquad (45)$$

Rearranging (45) generates the following equilibrium level for the production of each capital good *x(j)*:

$$x(j) = A^{1/\alpha+\beta} L^{\alpha/\alpha+\beta} H^{\beta/\alpha+\beta} (1-\alpha-\beta)^{2/\alpha+\beta} \qquad (46)$$

Substituting (46) into (42) and rearranging the result we have:

$$m(j) = 1/(1-\alpha-\beta) \qquad (47)$$

We assume that there is free entry and hence profits are equal to zero. This means:

$$F(n^*/N, N/N^*) = \{m(j)\,x(j) - x(j)\}.\int_t^\infty e^{-r(s-t)}\,ds = \frac{\{m(j)\,x(j) - x(j)\}}{r} \quad (48)$$

(The proof of $\int_t^\infty e^{-r(s-t)}\,ds = \frac{1}{r}$ is shown in Appendix 4)

Substituting (47) into (48) gives:

$$F(n^*/N, N/N^*) = \frac{\{(1/(1-\alpha-\beta) - 1).\,x(j)\}}{r} \quad (49)$$

Substituting (46) into (49) and rearranging the result, we have

$$r = (\alpha+\beta)(1-\alpha-\beta)^{(2-\alpha-\beta)/(\alpha+\beta)}\,A^{1/(\alpha+\beta)}\,F(n^*/N, N/N^*)^{-1}\,L^{\alpha/(\alpha+\beta)}\,H^{\beta/(\alpha+\beta)} \quad (50)$$

A representative household receives income from working wage and/or interest on rented assets and uses this income to purchase consumption goods and/or accumulate the assets. Each individual maximizes the following standard intertemporal utility function:

$$U_t = \int_t^\infty U(c)\,.\,e^{-\rho(s-t)}\,ds \qquad \text{where} \qquad U(c) = \frac{c^{1-\sigma} - 1}{1-\sigma} \quad (51)$$

subject to the income flow constraint:

$$\dot{a} = w + r\,a - c \quad (52)$$

where a is the net assets of the individual under consideration; w and r are the wage rate and interest rate on rented assets respectively; ρ is the rate of time preferences; c is consumption. A positive value of ρ implies that an individual values future utility less than current utility.

The optimal consumption path is:

$$g(c) = \frac{\dot{c}}{c} = \frac{r-\rho}{\sigma} \quad (53)$$

In a steady state equilibrium, the rate of growth of output is equal to the rate of growth of consumption. This means $g(c)=g(Y)$ (54)

Then, substituting (50) into (53) and using (54), we get:

$$g(Y)=\frac{1}{\sigma}[(\alpha+\beta)(1-\alpha-\beta)^{(2-\alpha-\beta)/(\alpha+\beta)}\ A^{1/(\alpha+\beta)}\,F(n^{*}/N, N/N^{*})^{-1}\,L^{\alpha/(\alpha+\beta)}\,H^{\beta/(\alpha+\beta)}-\rho] \quad (55)$$

Equation (55) shows that the set up cost F is negatively related to the fraction of products produced by foreign firms in the total number of products (n^*/N), which is alternatively measured by the ratio of FDI to GDP. The theoretical positive impact of FDI on economic growth in equation (55) can be explained in the way that FDI reduces the costs of introducing new capital goods in the host country. In addition, countries that produce fewer varieties of capital goods than leading countries (lower N/N^*) have a lower cost of adoption of technology and tend to grow faster. In other words, a developing country can promote economic growth by increasing a variety of capital goods adopted from developed countries. The result also indicates that growth rate is positively related to human capital and labour force.

In addressing the question of how FDI affects local firms in the same industry, Markusen and Venables (1999) propose a model in which profits of local firms are explained by the effects of competition and backward linkages generated from FDI. On the one hand, the entry of foreign firms may increase the level of competition in the home country, which in turn reduces profits of local firms. On the other hand, FDI may lead to the establishment of backward linkages between foreign firms and local suppliers. Then, the linkages may reduce input costs and raise profits of domestic firms. This model provides a theoretical framework to assess the effects of technology spillovers via FDI at firm level.

3.2. Comparing the theoretical models on FDI and technology spillovers, and their implications

All the models focusing on FDI and technology spillovers have a common characteristic in terms of technology spillovers. Technology spillovers through FDI are in the form of an externality from multinational firms to local firms in the host country. In particular, technology is first transferred from multinational firms to their subsidiary abroad, and it is then diffused from the subsidiary to domestic firms.

However, these models differ in their interpretation of technology. In some models, technology introduced by foreign firms is assumed as a public good and therefore it is transferred automatically. As a result, a host country's production function efficiency is measured as an increasing function of the presence of foreign firms in these models. In other models, foreign technology is considered as a private good, and the adoption of new technology is costly. Consequently, the extent of technology transfer depends on the capacity of local firms and their interaction with foreign firms.

Based on these models, many empirical studies have used data at both national level and firm level to consider FDI as a mechanism of technology spillovers. The empirical results so far are inconclusive.

At the national level, Blomstrom et al. (1992) study the effect of FDI on economic growth of 78 developing countries, using data from 1970 to 1990. They find that FDI by multinational enterprises is positively associated with per capita income growth in the long run via technological upgrading and knowledge spillovers in those countries. Lichtenberg and Pottelsberghe (1996) examine the importance of FDI for technology spillovers in 13 OECD countries by adding both inward and outward FDI flows as additional channels of technology diffusion to the approach that Coe and Helpman (1995) and Keller (1998) use for trade. They find that a country's outward FDI is a channel for foreign technology in these countries. However, inward FDI does not contribute to the technology transfer in this study.

With the increasing availability of micro data, the study of FDI and technology transfer has increasingly turned to it. Aitken and Harrison (1999), using data on Venezuelan firms from 1976 to 1989, find that an increase in foreign ownership in an industry negatively affects productivity of domestic plants in the same industry. Similar results are found in studies on transition economies (Djankov and Hoeckman, 1998 on Czech; and Konings, 2001 on Bulgaria and Romania). In contrast, several studies find positive spillovers in the more developed countries such as the UK (Haskel et al., 2002) and the US (Keller and Yeaple, 2003). Recent studies on technology transfer through vertical linkages between foreign firms and domestic ones find strong evidence on the existence of technology spillovers (Blalock and Gertler, 2002; and Smarzynska, 2004). The findings from these studies are also consistent with the idea suggested by the above theoretical models that the extent of technology spillovers depends on the linkages between domestic firms and foreign firms.

4. Determinants of Technology Transfer

A different stream of the literature considers the different effects of technology adoption on the rates of growth across countries. This type of models is particularly suited to studying the determinants of technology adoption.

In a short paper in 1966, Nelson and Phelps introduce a new hypothesis of the role of human capital in technological diffusion. They formulate the change in the level of technological implementation in a country as follows:

$$\frac{\dot{A}(t)}{A(t)} = \phi(H(t))\,\frac{T(t) - A(t)}{A(t)} \qquad (56)$$

where *A(t)* is level of technology in practice in the country in year *t*, *T* is the theoretical level of technology that is defined as the best practice level of technology that would prevail if technological diffusion were completely instantaneous, and *H* is level of human capital.

With this formulation, Nelson and Phelps argue that the rate of technology adoption depends on the technology gap between the leading country and the follower country. They also show that the rate at which the technology gap narrows depends on the level of human capital. In other words, the greater the rate of return to education, the more technologically progressive is the economy.

Wang (1989) develops a model of firm-level technology adoption in a developing country. The technology level of a firm in the country (*z)* is as follows:

$$z_{t+1} = z_t + I_t + \tau(I_t, g_t)\bar{z}_t \qquad (57)$$

where I_t denotes the amount of R&D expenditures, g_t is technology gap, $\tau(I_t, g_t)$ is a function that represents the capability of absorption. $\bar{z}_t$ is the size of technology level of the firm that is determined by the size of foreign existing technology and other factors influencing technology diffusion such as the degree of economic integration.

In this model, Wang shows that $\frac{\partial \tau}{\partial I_t} > 0$ and $\frac{\partial \partial \tau}{\partial g_t \partial I_t} > 0$. This implies that the absorptive capability of the firm increases with the amount of its own R&D, and the effect of its own R&D increases with the size of the technology gap.

Cohen and Levinthal (1989) consider many theoretical implications of the dual role of R&D. They argue that R&D not only generates new technologies, but also enhances a firm's ability to adopt existing technologies. Therefore, learning and technology adoption are affected by the characteristics of knowledge inputs. They also show that an innovation, which is purely capital-embodied, is less costly to adopt than a more disembodied innovation that requires more complementary internal effort and more pre-existing expertise in an area.

A further aspect of absorptive capacity has been emphasized in the literature recently. Parente and Prescott (1994) construct a model to explain the wide disparity in income per capita across countries. They consider the production function of a country as follows:

$$y = A.k^{\alpha} \tag{58}$$

where *y*, *k*, and *A* are output per worker, capital per worker and technology level respectively.

In this model, they assume that the level of technology in the country depends on investment and the level of its technology relative to the level of world knowledge. In other words, the technology is not constant, but it varies through time and is defined as follows:

$$A = f(X)\left(A - \overline{A}\right) \tag{59}$$

where *f(X)* is an increasing and bounded function, X is a set of exogenous variables, and $\overline{A}$ is the average level of world knowledge.

From equation (59), they argue that technological asymmetry between countries can be explained by the difference in the endowment of the factors in *X*. Countries with higher levels of capital and output per worker have a higher level of technology. Moreover, the rate of growth of output per worker is an increasing function of the distance between the country's technology and the world frontier.

Eaton and Kortum (1996) develop a model of technology diffusion and growth based on an R&D model of endogenous growth. In their model, the world level of knowledge is not exogenous and depends on the research activities of each country and on the degree of international knowledge diffusion. They show that the level of productivity of each country is determined by its ability to adopt new inventions. However, spillovers in R&D eventually bring countries to the same rate of growth. This implies that the productivity level is better than the growth rate in reflecting a country's ability to adopt new technology.

A similar result is obtained by Brecher, Choudhri and Schembri (1996), who build a model of monopolistically competitive industry in which the productivity of a country is determined by both national and international spillovers of knowledge. They show that in the long run, the growth rate of productivity is the same in each country, although the level of productivity can be lower in the smaller country. They also incorporate the role of openness into the model and show that spillovers of knowledge across international borders depend on the extent to which countries are open to international trade and FDI. The more open the countries, the greater the scope for international spillovers.

Basu and Weil (1998) introduce a model of appropriate technology. In their model, new technologies can only be implemented successfully by countries with the appropriate portfolio of endowments. In particular, a follower country can use the technology of a leading country if it has a sufficiently high level of development at which this technology is appropriate to its needs. They also show that technology spillovers are usually not symmetric between countries. A country that is the technology leader benefits less than its followers benefit from it.

In another line of interest, Parente and Prescott (1999) construct a model to explain why some countries do not adopt leading edge technologies. In their model, monopoly power is considered as the main institutional factor that acts as a barrier to adoption of foreign technologies. In particular, adopting new technologies depend on the monopoly power of endogenous rent-seeking coalitions of incumbent firms. In the absence of these monopoly rights, groups have no incentive to block the use of new technologies, and production is therefore efficient. This implies that more competitive economies are likely to benefit from spillovers to a larger extent, given that the presence of monopolies is the same.

Howitt and Mayer-Foulkes (2005) provide a model of R&D, implementation and stagnation, based on Schumpeterian growth theory, that considers the growth rate within three groups of countries: those carrying on leading edge R&D, those implementing efficiently the leading edge technologies developed abroad, and those implementing inefficiently the same leading edge technologies. This specification is based on the initial skill level of a country. Within this framework, they show that countries in the first two groups grow at the same rate in the long run as a result of technology transfer, but inequality of per capita income between these two groups increases during the transition to the steady state. Countries in the third group experience a slower rate, with relative incomes that fall asymptotically to zero. This suggests that economic policy aimed at fostering technology transfer should focus on skill acquisition and human capital investment.

Many empirical studies provide strong evidence on the role of human capital, R&D activity, technology gap, and other factors in technology transfer. Benhabib and Spiegel (1994), and Foster and Rozenzweig (1995) use cross-country data to investigate the Nelson-Phelps hypothesis and conclude that technology spillovers flow from leaders to followers and the rate of flow depend on levels of education. The empirical studies of Eaton and Kortum (1996), and Xu (2000) also confirm that human capital is a necessary condition for successful technology adoption.

Griffith, Reading, and Van Reenen (2000a,b) use industry-level data from 12 OECD countries from 1974 to 1990 to examine the importance of indigenous R&D in facilitating technology from abroad. They show that technology gap, which is measured by the difference between total factor productivity (TFP) of a given country and TFP of the leader country, is negatively related to TFP growth. In addition, the interaction between R&D and the technology gap is negative and significant. This implies that R&D enables a country to reduce the technology gap with the leader country and adopt foreign technology successfully. Kinoshita (2000) finds a similar result in the case of the Czech Republic. In particular, the effect of technology diffusion through FDI is conditional on a relatively high absorptive capacity of the country, which is measured by its own R&D investments.

5. Conclusion

In this paper, we have surveyed the major models and issues of international trade, FDI, technology transfer and growth. The main conclusion coming from the theoretical literature surveyed is that international trade and FDI play a key role in technology transfer and economic growth. The models presented in this paper have explained differences in technology adoption across countries by differences in technology gap and absorptive capacity measured by human capital or R&D activities. The literature on trade, FDI and technology transfer, with its diversity of results, suggests that no simple implication should be made without an understanding of the structure and the key characteristics of the country under consideration.

It is clear that the theoretical literature so far has improved our understanding of some channels and characteristics of technology transfer. The ways in which technology transfer through trade and FDI are modelled, however, still lack necessary empirical evidence to identify the actual mechanisms of technology transfer. Existing empirical studies on technology transfer focus more on developed countries than on developing countries, while the potential effects of technology transfer and better policy recommendations are far larger for the latter group. In addition, only a few of the technology spillover studies on developing countries have been undertaken for economies, which have little resemblance to the dynamic and export-oriented economies of East Asia. Therefore, more empirical analyses of technology transfer through trade and FDI for developing countries are still required to provide evidence for theoretical prescription regarding the roles of trade and FDI in technology transfer and economic growth.

Appendix

1. Derivation of equation (23)

In the lab equipment model the value of total production in manufacturing and research depends only on the aggregate stocks of inputs, not on their allocation between the two sectors:

$$Y+\frac{\dot{A}}{B}=H^{\alpha}L^{\beta}\int_{0}^{A}x(i)^{1-\alpha-\beta}\,di. \tag{A.1}$$

Taking its supply of H and L as given, each representative firm in the manufacturing sector chooses a level of *x(i)* to maximize profits. Consequently, the first order condition for the problem of maximizing $Y+\dot{A}/B$ minus total input cost $\int p(i)x(i)di$ with respect to the use of input *i* yields the economy wide inverse demand curve for good *i*. The rental rate *p* that results when *x* units of the capital good are supplied is:

$$p=(1-\alpha-\beta)H^{\alpha}L^{\beta}x^{-(\alpha+\beta)} \tag{A.2}$$

Input producers choose *x* to maximize the present value of monopoly rent minus *x* times the unit cost of each price of capital, $P_A=\max(px/r-x)$. Using equation (A.1), the first order condition that determines the number of machines $\bar{x}$ that the holder of the patent on goods *i* rents to manufacturing firms is

$$(1-\alpha-\beta)^2H^{\alpha}L^{\beta}\bar{x}^{-(\alpha+\beta)}r^{-1}-1=0 \tag{A.3}$$

which implies that $p/r=(1-\alpha-\beta)^{-1}$. The discounted value of profit collected by the holder of the patent can then be simplified to

$$P_A=\left(\frac{p\bar{x}}{r}\right)-\bar{x}=\frac{\alpha+\beta}{1-\alpha-\beta}\bar{x} \tag{A.4}$$

Since $P_A=1/B$, this implies that $\bar{x}=(1-\alpha-\beta)/B(\alpha+\beta)$. Substituting this expression into equation (A.2) yields equation (23) in the text:

$$r=B^{\alpha+\beta}(\alpha+\beta)^{\alpha+\beta}(1-\alpha-\beta)^{2-\alpha-\beta}H^{\alpha}L^{\beta} \tag{A.5}$$

2. Derivation of equation (22)

The demand for the capital goods in this model has exactly the same form as in the lab model, with the qualification that since all of the demand comes from the manufacturing sector, H must be replaced by H_Y. If we use equation (A.1) with this replacement to substitute for p in the experience for P_A, we have

$$P_A=(\alpha+\beta)\frac{p\bar{x}}{r}=\frac{\alpha+\beta}{r}(1-\alpha-\beta)H_Y^{\alpha}L^{\beta}\bar{x}^{1-\alpha+\beta}. \tag{A.6}$$

Equating the wages of human capital in manufacturing and research yields $P_A\ \delta A = \alpha H_Y^{\alpha-1} L^{\beta} A \overline{x}^{-1-\alpha-\beta}$ (A.7). Combining these expressions and solving for H_Y gives $H_Y = (1/\delta)\ \alpha(\alpha+\beta)^{-1}(1-\alpha-\beta)^{-1}$, $r = (\Lambda/\delta)r$. Hence,

$$g = \delta H_A = \delta H - \delta H_Y = \delta H - \Lambda r. \tag{A.7}$$

3. Derivation of equation (31)

The price of each variety of differentiated products is as follows:

$$p^i = \frac{w^i}{\alpha} \tag{A.8}$$

where w^i is the wage rate in country *i*, and also the marginal and average cost of a unit of output manufactured there. In an equilibrium with ongoing R&D, the value of the representative firm must be equal to

$$v^i = \frac{w^i a}{n^i} \tag{A.9}$$

where n^i is the measure of products previously developed in country *i* and also the local stock of knowledge capital. Arbitrage equates the total return on equity claims to the interest rate ρ, or

$$\frac{1-\alpha}{n^i v^i} + \frac{\dot{v}^i}{v^i} = \rho \tag{A.10}$$

Equilibrium in the labour market requires that

$$\frac{a}{n^i}\dot{n}^i + \frac{1}{p^i} = L^i \tag{A.11}$$

which is equality between the sum of the demand for labour by R&D and manufacturing enterprises and the exogenous factor supply.

In a steady state the aggregate value of the stock market and its inverse $V^i \equiv 1/n^i v^i$ turn out to be constant. The value of a representative firm declines at the rate of new product development; that is $\dot{v}^i/v^i - \dot{n}^i/n^i \equiv -g^i$ (A.12). The no-arbitrage condition that applies in the steady state can be written as equation (31) in the text.

4. Transforming the Integral in Equation (48)

$$\int_t^{\infty} e^{-r(s-t)}\,ds = -\frac{1}{r}\int_t^{\infty} -r.e^{-r(s-t)}\,ds = -\frac{1}{r}\int_t^{\infty} d\,e^{-r(s-t)} = -\frac{1}{r}[e^{-r(\infty-t)} - e^{-r(t-t)}] = \frac{1}{r} \tag{A.12}$$

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