efficiency. Analysis reveals, however, an important difference between the two channels. Knowledge diffused through FDI is more general (disembodied) than that from imported capital goods (embodied). Over the observation period, whereas all countries become more efficient, gains are especially evident for the group of Asian countries in the panel. This result can be linked to the early outward orientation and the favourable climate for FDI in the 80s.

The remainder of the paper is organised as follows. In the model developed in Section two, the high value-added sectors (i.e. import-substitution sectors) benefit from technological diffusion through trade liberalisation. Section three explains the stochastic frontier methodology used. The fourth section uses this stochastic frontier approach to test the model in Section two and analyses the results. A fifth section concludes.

2. THE MODEL

The model in this section builds on the argument that openness allows an economy's dynamic sector to develop. Drawing on the ideas of Lucas (1988), Matsuyama (1992) and Weinhold and Rauch (1999), the model links imports of intermediate goods and faster less developed country (LDC) growth. Trade openness leads to increased specialisation and this, in turn, accelerates productivity growth through dynamic economies of scale. The dynamic sectors (import-substitution) sectors benefit from technological diffusion by trade liberalisation.

Consumption side

The number of individuals is assumed equal to L. Each individual is endowed with one unit of labour per unit of time, and supplies this inelastically without disutility.[4] Therefore, total labour supply per unit of time is equal to L.

[4] Barro and Sala-i-Martin (1995) p. 62.

The utility function of the representative individual is

$$U(C) = \int_0^{\infty} C e^{-dt} dt \qquad , \qquad (2.1)$$

where δ is the rate of time preference. Consumption, *C*, is given by

$$C = \left[A^r + M^r \right]^{1/r} \qquad , \qquad (2.2)$$

where *A* is the consumption of agricultural goods and *M* is the consumption of manufacturing goods. The parameter ρ represents the preference for each good. The elasticity of substitution between agricultural and manufacturing goods is constant and equal to σ =1/(1-ρ) (σ >1). Aggregate consumption *C* is a sub-utility function of two varieties of goods defined by a constant elasticity of substitution.

The budget constraint of the agents is

$$\dot{a} = w + ra - c \quad , \qquad (2.3)$$

where a represents the assets in the form of ownership claims on capital (both domestic and foreign capital, the dot over the variable represents a time derivative), *r* is the interest rate on these assets and *w* is the wage rate paid per unit of labour services. Equation (2.3) states that assets per person rise with per capita income and fall with consumption.[5]

A two-stage budgeting procedure applies. The first step in the consumer's problem is the choice of each good in order to minimise the cost of attaining a given level of consumption *C*:

$$\min\left(A + pM\right) \qquad \text{s.t. } C = \left[A^r + M^r\right]^{1/r} \quad , \tag{2.4}$$

where p is the price of manufacturing goods relative to agricultural goods.
The first order condition implies

$$\frac{M^{r-1}}{A^{r-1}} = p \quad , \tag{2.5}$$

and therefore

$$M = \left(p\right)^{1/r-1} A \quad . \tag{2.6}$$

The second step of the consumer's problem is to choose consumption such as to maximise the utility function (2.1). The growth rate of consumption

$$\frac{\dot{c}}{c} = s\ \left(r - d\right) \tag{2.7}$$

gives the optimal condition for consumption growth. Equation (2.7) says that individuals choose a pattern of consumption according to the relation between the interest rate on assets (capital) and the rate of time preference. A lower willingness to substitute intertemporally (a small value of σ) implies a lower rate of growth of consumption for a given gap between r and δ. Accordingly, individuals save more today and postpone consumption.

Production side

The economy has two sectors: a low-value added sector (a) and a high value-added sector (m). The latter is subject to learning-by-doing. For convenience, the low-value added sector can be associated with "agriculture", and the high-value added sector with "manufacturing". Labour is mobile between the two sectors, and both it

[5] Population is assumed to be constant. Relaxing this assumption would require to subtract the

and the relative world price of goods from sector *m* are normalised to unity. The production functions of the two sectors are:

$$X_t^m = M_t L_t^a K_t^b \tag{2.8}$$

$$X_t^a = A(1 - L_t)^a \tag{2.9}$$

where L_t represents labour in manufacturing sector and α is the share of labour in value added; *t* is a time subscript; K_t is the capital stock used only in the manufacturing sector, and β is the share of capital in value added. The parameter *A* captures the specific characteristics of the agricultural sector, M_t represents the productivity coefficient in manufacturing and evolves according to

$$\dot{M}_t = d F_t^m \quad . \tag{2.10}$$

The parameter δ is the learning coefficient, and F_t^m is the level of foreign capital employed in the manufacturing sector.

The first order condition of the profit maximisation problem states that the real interest rate is equal to the marginal productivity of the capital in the manufacturing sector:

$$r = b M_t L_t^a K_t^{b-1} \quad . \tag{2.11}$$

Inserting equation (2.11) into (2.7) gives

$$\frac{\dot{c}}{c} = s \left(b M_t L_t^a K_t^{b-1} - d \right). \tag{2.12}$$

Equation (2.12) states that consumption growth depends positively on M_t. From

term *na*, where *n* is population growth (Barro and Sala-i-Martin , 1995, p.62).

equation (2.10) manufacturing grows at a rate proportional to the foreign capital. To simplify the model without altering the main assumptions, assume that capital in the manufacturing sector is equal to one. The equilibrium condition of the labour market requires an equal marginal product of labour in the two sectors:

$$A(1-L_t)^{a-1} = M_t L_t^{a-1} \qquad . \tag{2.13}$$

From equation (2.13) it is possible to calculate labour growth in sector *m*:

$$L_t = \frac{A^{\frac{1}{a-1}}(1-L_t)}{M^{\frac{1}{a-1}}} \qquad . \tag{2.14}$$

Taking logs yields

$$\ln L_t = \frac{1}{a-1}\ln A + \ln(1-L_t) - \frac{1}{a-1}\ln M_t \, . \tag{2.15}$$

Deriving equation (2.15) with respect to time, and taking into account that *A* is constant, gives

$$\frac{\dot{L}_t}{L_t} = -\frac{1}{1-L_t}\dot{L}_t - \frac{1}{a-1} d\,\frac{F_t^m}{M} \, . \tag{2.16}$$

Rearranging the terms in (2.16), one obtains the final expression for labour growth:

$$\frac{\dot{L}_t}{L_t} = (1-L_t)\frac{1}{1-a} d\,\frac{F_t^m}{M} \tag{2.17}$$

The growth rate of labour depends positively on the learning coefficient δ and the amount of foreign capital in manufacturing sector. It depends negatively on the productivity coefficient *M*: labour and foreign capital are substitutes more than complements.[6] Aggregate output in the economy is given by

$$Y_t = M_t L_t^a + A(1-L_t)^a \quad . \tag{2.18}$$

Taking the time derivative of equation (2.18) results in

$$\dot{Y} = \dot{M} L_t^a + a L_t^{a-1} M \dot{L}_t + \dot{A}(1-L_t)^a - a A(1-L_t)^{a-1} \dot{L}_t \quad . \tag{2.19}$$

After substituting $\dot{A} = 0$, $\dot{M} = d F_t^m$, and dividing by Y_t, one obtains the growth rate of output

$$\frac{\dot{Y}_t}{Y_t} = d \frac{F_t^m}{Y_t} L_t^a + a L_t^{a-1} \frac{M_t}{Y_t} \dot{L}_t - a \frac{A}{Y_t} (1-L_t)^{a-1} \dot{L}_t . \tag{2.20}$$

Rearranging terms, substituting $\dot{L}_t$ with expression (2.17) and using the ratio of foreign capital in total output at time t, $l_t = \frac{F_t^m}{Y_t}$, yields

$$\frac{\dot{Y}}{Y} = d l_t L_t^a + a L_t^{a-1} \frac{M_t}{Y_t} (1-L_t) \frac{1}{1-a} d l_t - a \frac{A}{Y_t} (1-L_t)^a \frac{1}{1-a} d l_t . \tag{2.21}$$

Substituting $X_t^m = M_t L_t^a$ and $X_t^a = A(1-L_t)^a$, $x_t^m = \frac{X_t^m}{Y_t}$ (share of manufacturing output in total output) and $x_t^a = \frac{X_t^a}{Y_t}$ (share of agricultural output in total output) in (2.21) gives

$$\frac{\dot{Y}}{Y} = d l_t L_t^a + \frac{(1-L_t)}{L_t} \frac{a}{1-a} d l_t x_t^m - \frac{a}{1-a} d l_t x_t^a . \tag{2.22}$$

[6] The import substituting, or manufacturing, sector is capital-intensive. The export, or agricultural, sector is labour intensive.

It follows from equation (2.13) that $x_t^m = L_t$. Using this equality, the growth equation can be rewritten as

$$\frac{\dot{Y}}{Y_t} = d\,l_t\left[L_t^a + \left(\frac{a}{1-a}\right)\left(1 - L_t - x_t^a\right)\right] \tag{2.23}$$

The growth rate of output depends positively on the learning coefficient in manufacturing, δ, and on the foreign capital's share in total output, λ, but negatively on output in the agricultural sector. The larger the proportion of foreign capital, the higher the growth rate.

Learning is assumed not to be subject to decreasing returns, and this implies unbounded productivity growth. LDCs face a technological frontier exogenously expanding as determined by research in the technologically developed countries.[7] Technology is embodied in imported capital, and since the LDCs never reach the frontier they escape decreasing returns.

The main theoretical implications of the model are that growth in LDCs depends on the human capital accumulation. The latter stems from specific training and on-the-job experience, captured by the learning coefficient in the manufacturing sector δ. An increase of foreign capital will raise human capital and, consequently, the productivity of labour. Therefore, policies which favour free trade and promote the import of foreign capital goods will help developing countries to close the technology gap and increase productivity growth. In the empirical analysis which follows, these gains will show up through an effect on the efficiency term in the stochastic frontier model.

3. ECONOMETRIC METHODOLOGY

To test empirically the implications of the model requires a measure of technological progress, one widely used approach is a residual of the Abramovitz/Solow type,