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A NEW EMPIRICAL APPROACH TO CATCHING UP OR FALLING BEHIND

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The literature on 'catching up' suggests that due to technology spill-overs, relatively backward countries should grow at a faster rate. The possibility of 'falling behind' is not considered (explicitly) in most of these models. In this paper a dynamic (non-linear) model is developed in which 'catching up' and 'falling behind' are both possible. The model is tested empirically using non-linear least squares methods.

1. INTRODUCTION

Economic growth is not taking place equally among the nations of the world. Although mainstream neo-classical growth models predict that in the long run international growth rate differentials cannot exist, the economic history of this century has shown an increasing gap between rich and poor nations in the world (Lucas, 1988).

The aim of this paper is to set out a simple formal model of technology gaps which can, in contrast to other models dealing with technology gaps, explain why some countries are able to 'catch up' to a high level of economic growth, while others tend to fall behind. In order to do so, the paper is organized as follows. In Section 2, a brief overview of the literature on catching up and technology gaps is given. In Section 3, some observations about the nature of (international) technology spill-overs will be made, after which a simple formal model of technology gaps will be presented and analysed. Section 4 sets out some consequences of the model for the process of economic development. In Section 5, a cross-country estimation of the model developed in Section 3 will be carried out. The model will also be tested against other models. Finally, in Section 6, the main arguments and conclusions are summarized.

2. CATCHING UP AND ITS EMPIRICAL RELEVANCE

In the literature on international growth rate differentials it has been suggested that the phenomenon of *catching up* plays an important role in explaining a tendency of national growth rates to converge (Abramovitz, 1979, 1986).[2] Catching up refers to the principle that countries with relatively low

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[2] Note that the literature on growth rate differentials covers much broader themes than just catching up. Examples of other approaches in the field are the well-known 'growth accounting' tradition (Denison, 1967) and the 'export base Kaldorian models' (for a recent application, see Molana and Vines, 1989).

technological levels are able to exploit a backlog of existing knowledge and therefore attain high productivity growth rates, while countries that operate at (or near to) the technological frontier have less opportunities for high productivity growth. Therefore, countries with lower levels of technological knowledge will tend to realize higher growth rates. The literature on catching up is also referred to as the 'convergence' literature, for the obvious reason that if countries with low initial per capita incomes tend to grow faster, per capita income levels and growth rates will eventually show a tendency to converge.[3] Some early, formal approaches to catching up can be found in Ames and Rosenberg (1963) and Gomulka (1971).

Implicitly, the catching up hypothesis is based on the intuition that technological change is to some extent a 'public' good, i.e. it can be used 'freely' by other countries besides the initial innovator. International knowledge spill-overs then bring about the tendency for countries with lower technological levels to achieve faster productivity growth.

Empirical studies that investigate the strength of the catching up phenomenon, such as Abramovitz (1979), Abramovitz (1986), Baumol (1986), Dollar and Wolff (1988), and Dowrick and Nguyen (1989), generally arrive at the conclusion that there is indeed a strong (negative) correlation between growth rates and (initial) per capita income (the latter is taken as a measure of the technological level of a country). However, while there is agreement on the relevance of the argument for some countries, it is also clear that catching up is not a global phenomenon. Most studies only take into account the industrialized (OECD) countries, and do not look at convergence between the industrialized world, socialist economies, and developing nations.

Baumol (1986) is a notable exception to this rule. The conclusion reached there is that 'rather than sharing in convergence, some of the poorest countries have also been growing most slowly' (Baumol, 1986, p. 1079). Lucas (1988, p. 4) connects these growth rate differentials directly to the per capita income levels of countries: 'the poorest countries tend to have the lowest growth; the wealthiest next; the 'middle-income' countries highest'. De Long (1988), in a comment on Baumol (1986), has also convincingly shown that catching up is not a global phenomenon. His analysis demonstrates that some countries which could initially be identified as 'candidates' for taking part in the catching up process, have failed to do so in actual practice. Finally, Baumol *et al.* (1989) have demonstrated that education might be an important variable in explaining this failure.

The simple model presented in the next section is aimed at explaining why some countries are able to take part in the catching up process, while others tend to *fall behind.* It is also shown that the general theoretical intuition behind the (empirical) catching up literature can be seen as a special case of the model presented here.

[3] Note that the 'export base Kaldorian models' reach an opposite conclusion (diverging growth rates under some conditions) (Dixon and Thirlwall, 1975).

3. A SIMPLE DYNAMIC MODEL OF TECHNOLOGY GAPS

3.1. *Some General Observations about (International) Knowledge Spill-overs*

The basic (implicit) intuition behind the convergence hypothesis seems to be that international knowledge spill-overs take place *automatically*. In the (economic) literature dealing with the nature of technological change in more detail (e.g. Dosi, 1988) it is argued that this assumption is indeed a heroic one. Since the process of (international) technology spill-over is essentially a process of adoption of new techniques at the microeconomic (firm) level, the capabilities of the 'receiving' country (firms) to 'assimilate' (foreign) technological knowledge are critical to the success of diffusion. If countries (firms) do not have the relevant capabilities to assimilate new knowledge, spill-overs may not take place at all.

Indeed, a number of scholars from different branches and viewpoints within the economic sciences have also identified this important characteristic of technology diffusion. At the microeconomic firm level, this consideration led Cohen and Levinthal (1989) to formulate a model in which the degree to which firms can use spill-overs from knowledge generated by other firms (inside as well as outside the industry) is dependent on the R&D outlays of the firm itself.

At the macroeconomic level of (inter-) national economic growth, Kristensen (1974), Rostow (1980), and Baumol *et al.* (1989) have pointed to the fact that the extent to which a country can apply the backlog of unused knowledge crucially depends upon its capabilities to assimilate this knowledge. Kristensen (1974, p. 24) argues that technology spill-overs will not take place when the capability of the receiving country is too low. '. . . The most rapid economic growth should be expected to take place in countries that have reached a stage at which they can begin to apply a great deal more of the existing knowledge. This requires capital for investment'.

Support for the hypothesis that the capability to assimilate technological knowledge is crucial in the process of international diffusion can also be found from case studies in economic development and technology transfer. For example, Westphal *et al.* (1985, pp. 168–9), in a case study of South Korea's economic development, observe that '. . . assimilation [of foreign technology] often seems to be characterized as being automatic and without cost. If this were correct, assimilation would not merit much attention. But it is not accomplished by passively receiving technology from overseas. It requires investments in understanding the principles and use of technology, investments reflected in increased human and institutional capital'. A model that tries to explain the patterns of international diffusion of knowledge should take these considerations into account.

3.2. *The Model*

The model that is presented in this section will be aimed at incorporating these considerations in the catching up approach. At first, the model will be formulated in continuous time and without time lags between the variables. This is done to make the analysis easier. Later (Section 5), we will discuss the notion of time and the possibility of time lags in more detail.

The setting of the simple dynamic model of technology gaps presented here is a two country (North–South) relation. It is assumed that one of these countries (the North) is a technologically advanced nation, while the other (the South) is less developed (in a technological sense). The model will attempt to explain the dynamics of the technology gap between these two countries. The relation to the catching up studies discussed above is straightforward, and lies in the connection between the technology gap and the productivity gap.[4] Because the focus of the paper is primarily on the effects of knowledge spill-overs, all other sources of knowledge generation (e.g. research) are assumed to be exogenous.

Let us first define the technology gap between the two countries as

$$G = \ln \frac{K_{\mathrm{n}}}{K_{\mathrm{s}}}, \tag{1}$$

where G is the technology gap, K represents the knowledge stock of a country, and subscripts n and s denote North and South, respectively. The logarithmic specification has the convenient property that the gap is zero for equal levels of the stocks of technological knowledge in the countries.

Next, the equations for the knowledge stock in the two countries are specified.

$$\frac{\dot{K}_{\mathrm{n}}}{K_{\mathrm{n}}} = \beta_{\mathrm{n}} \tag{2}$$

$$\frac{\dot{K}_{\mathrm{s}}}{K_{\mathrm{s}}} = \beta_{\mathrm{s}} + S. \tag{3}$$

In these equations, β stands for the exogenous rate of growth of the knowledge stock (due to research), which is assumed to differ between the two countries. Dots above variables denote time derivatives. S represents the rate of growth of the knowledge stock in the South due to spill-overs from the North. Because it is assumed that the North will 'always' be the technological leader,[5] the knowledge spill-over term does not appear in equation (2). This also implies that $\beta_{\mathrm{n}} > \beta_{\mathrm{s}}$.

The next (and final) step in setting up the model is to specify the spill-over term. On the basis of the observations on (international) knowledge spill-overs above, a distinction is made between *potential* spill-overs and *actual* spill-overs. The concept which connects them is the *learning capability* of a country.

The learning capability of a country is assumed to depend both on an *intrinsic* capability, and on its technological distance from the leading country. The reason

[4] Here, as in the (empirical) catching up literature, it is assumed that there is a one-to-one relation between these variables. Alternatively to the interpretation in the text, one could thus interpret the variable K below as the country's productivity level.

[5] Consequently, the model can only deal with the phenomenon of '*overtaking*' in the way of 'switching' the subscripts n and s when overtaking takes place. Obviously, this is a severe limitation when one is attempting to describe what happens in the real world. However, given the present aim to explain the difference between catching up and falling behind, this assumption seems to be appropriate.

why the technological distance is included is the following. Technological knowledge is a highly heterogenous good that is (in general) embodied in highly heterogenous capital goods. Let us imagine the range of goods that embody technology as a range that can be ordered according to technological (or productivity) level. Then, given that an entrepreneur (or, in more general terms, a country) is using a capital good from the lower part of this range, it will be easier to move to a slightly more sophisticated capital good than to move to a highly sophisticated type of capital. Moreover, for a *given* technological distance, a country's learning capability varies with its intrinsic learning capability, which is determined by a mixture of social factors (Abramovitz, 1986), education of the workforce (Baumol *et al.*, 1989), the level of the infrastructure, the level of capitalization (mechanization) of the economy, the correspondence of the sectoral mix of production in the leading and following country (Pasinetti, 1981), and other factors.

In view of these considerations, the functional form of the knowledge spill-over term in equation (3) can be specified as follows.

$$S = aGe^{-G/\delta}. \tag{4}$$

In this equation, the potential spill-over rate (aG with $0 < a \leq 1$) is proportional to the size of the technology gap. The learning capability ($e^{-G/\delta}$ with $\delta > 0$) is a function of the intrinsic learning capability, δ, and the technological distance as measured by the gap itself, with the properties discussed above. This functional specification also satisfies some basic restrictions regarding the nature of the spill-over term: the actual technology spill-overs cannot be bigger than the potential spill-overs, the actual spill-overs are zero for closed technology gaps, and spill-overs can grow for larger values of δ.

With these four equations, it is possible to analyse the dynamics of the technology gap. The picture that arises from this analysis will prove to be much richer (in the sense that it leaves open more possible patterns of development) than the basic intuition behind the catching up hypothesis discussed above.

To analyse the dynamics of the technology gaps, we take the time derivative of the technology gap in equation (1) and substitute equations (2), (3), and (4), so that, setting $\beta_n - \beta_s$ to b, we arrive at the following expression for the dynamic behaviour of the technology gap:

$$\dot{G} = \frac{d}{dt} \ln \frac{K_n}{K_s} = \frac{\dot{K}_n}{K_n} - \frac{\dot{K}_s}{K_s} = b - aGe^{-G/\delta} \tag{5}$$

This equation can be analysed using Fig. 1. The horizontal line B in the graph depicts the tendency of the technology gap to *increase* due to the (exogenous) difference between the rates of growth of the knowledge stock in North and South (b in equation 5). The curves S_i ($i = 1 \ldots 3$) represent the tendency of the technology gap to *decrease* due to knowledge spill-overs. The different S curves are drawn for different values of the intrinsic learning capability δ ($S_i(G) =$

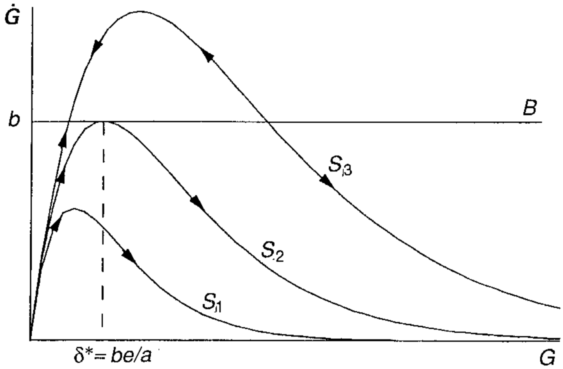

FIG. 1. The dynamics of the technology gap.

aGe^{-G/δ_i} with higher i's representing higher values of δ)[6] and fixed values for a. It can easily be shown that the S-curves have a maximum at the point where $G = \delta$.

The point of tangency, which occurs at the S curve for which $\delta_i = \delta^* = be/a$, and the intersection points between the line B and the S curves in Fig. 1, correspond to points where the motion (time derivative) of the technology gap is zero. In other words, these points are *equilibrium* points of the technology gap.

With regard to the stability of the equilibrium points, the following can be said. Whenever the S curve cuts the line B with positive slope, the resulting equilibrium point is stable, and is unstable otherwise. An economic interpretation of this stability analysis is as follows. Whenever the S curve is below the line B, knowledge spillovers will be smaller than the exogenous increase of the technology gap, resulting in a (net) increase of the gap. The opposite case results in a (net) decrease of the gap. Thus we can draw arrows of (G) motion on the S curves, as has been done in Fig. 1.

It can then easily be seen that, depending on the initial value of the technology gap and the value of δ, the technology gap either converges to the left-most equilibrium point, or goes to infinity.[7] In economic terms, this means that depending on the intrinsic learning capability and the initial technology gap, the country will either catch up or fall behind.

The characteristics of the equilibrium points of the system can be summarized in the *bifurcation diagram* in Fig. 2. On the horizontal axis of the bifurcation diagram are the values of the intrinsic learning capability δ. On the vertical axis are the (equilibrium) values of the technology gap. The line E_s represents a stable equilibrium, while the line E_u represents an unstable equilibrium. The line S_{max} represents the maximum of the knowledge spill-over term in

[6] Note that instead of assuming that the value b (the line B) is fixed, one could also assume that the value of δ (the S curve) is fixed, and vary b. This would lead to the same conclusions.

[7] A third possibility is that the value of the technology gap remains *exactly* at the right-most equilibrium point. However, because in this case the slightest (exogenous) shock would result in either of the other two possibilities, this third possibility is not considered explicitly here.

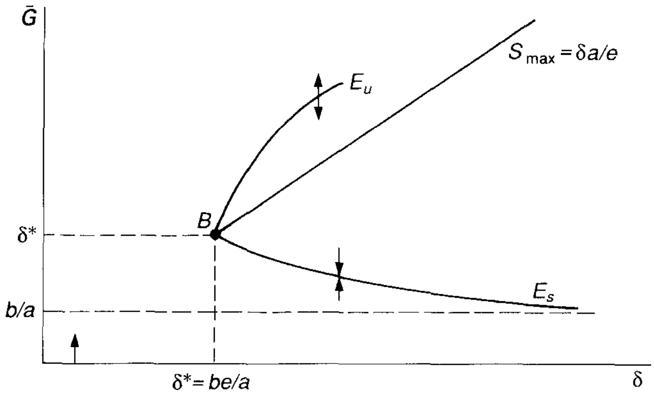

FIG. 2. The bifurcation diagram of the equation for the dynamics of the technology gap.

equation (5) (the S curve in Fig. 1).[8] Figure 2 shows that for small values of δ no equilibrium value of the technology gap exists. Then, for the threshold value δ^* $(=be/a)$, an equilibrium value is established. This point B is the *bifurcation point*. In terms of Fig. 1, this equilibrium point is the point of tangency between the line B and the S_2 curve. For values of δ larger than the threshold level, two equilibria exist, as described by the curves in the bifurcation diagram. As shown in Fig. 2, the value of the stable (unstable) equilibrium is always lower (higher) than the maximum of the knowledge spill-over term. Since for δ going to infinity, the solution of equation (5) goes to $G = b/a$, the stable equilibrium point is bounded by b/a. This reflects the intuitive argument that an imitative strategy (in the South) *by itself* will never lead to a *complete* closing of the gap. Only when the (exogenous) difference between the advances in knowledge in North and South becomes zero, will the technology gap close completely.

Summarizing, we can say that both the value of the intrinsic learning capacity and the initial value of the technology gap determine the dynamic behaviour of the latter. Countries with a high intrinsic learning capacity and/or small initial gaps are likely to catch up, while countries with a low intrinsic learning capacity and/or large initial gaps are likely to fall behind.

To conclude this section, we consider the case of an infinitely large δ in some more detail. This can be viewed as a special case of the present model, corresponding to the intuition behind the catching up hypothesis found in the literature and discussed above. In this literature it is assumed that the (intrinsic) learning capability does not matter, which comes down to the same thing as assuming it is infinitely large in the present model. For δ going to infinity, equation (5) reduces to

$$\dot{G} = b - aG. \tag{6}$$

[8] The *approximate* form of the curves describing the equilibrium points of equation (5) around the curve S_{max} in the neighbourhood of δ^* can be found by linearizing equation (5) around the maximum. A more exact form could be found by numerically solving the equation. Both methods will, however, not be applied here, but are available on request.

In terms of Fig. 1, equation (6) corresponds to a positively sloped, straight S curve. Only one (stable) equilibrium point exists in this case. This means that countries starting from an initial gap larger than b/a will catch up to this level, while countries originally closer to the leader will fall back to this point (always assuming a given disparity in research levels).

4. SOME IMPLICATIONS FOR ECONOMIC DEVELOPMENT

The model outlined in the previous section has some interesting implications for economic development policy.[9] These are derived from the two conclusions drawn from the model: that for some combinations of initial values and intrinsic learning capacity no convergence will occur, and that the technology gap will only converge to zero when the exogenous rates of technological change in the backward and the leading country are equal.

Starting from the first of these conclusions, we observe (again) that countries which have a (very) high level of backwardness cannot automatically assume that catching up will occur. The reason is that their capability to apply the knowledge from the more advanced country may be inadequate. Thus, before catching up can become a relevant process in very backward countries, there must therefore be a phase in which the country builds up its intrinsic learning capability.

In terms of the model from the previous section, this building up of the intrinsic learning capability would consist of trying to achieve a better education of the labour force, a better infra-structure, and other measures. Most of the measures one could imagine contributing to a better intrinsic learning capacity would involve *public* rather than *private* investment. Therefore, it seems that there would be a large role for government (considering the δ as a policy variable) in this '*pre-catching up*' phase.

In Fig. 3, this process is represented by the move from point A to point C. Note that in the 'pre-catching up' phase, time is running against the policy makers, in the sense that a move towards point B might not be enough, because the technology gap is constantly in motion.

The phase that follows can be labelled as the *actual* catching up phase. It is this development phase which has received most attention in the literature. Applying the knowledge from the advanced country, the backward country now closes the technology gap up to a certain level, without necessarily increasing the domestic (exogenous) rate of technological change. This process corresponds to the movement from point C to point E in Fig. 3. At first, the spill-overs will increase, until point D is reached. Then, the amount of spill-overs will decrease slowly, until the equilibrium gap is reached at E. As in traditional catching up theory, this development phase leads to (some) convergence of technological (productivity) levels.

[9] The aim of this section is rather limited in the sense that it does not mean to provide a full fledged theory of economic development, and is also not properly rooted in the field of development economics (for an overview of this latter field, see Stern, 1989).

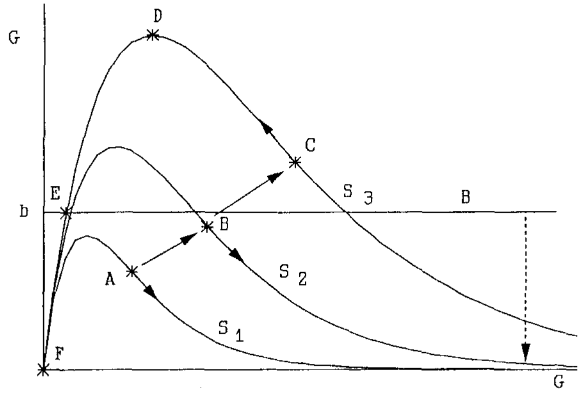

FIG. 3. Development phases in the model.

Total convergence of technological levels will, however, not be reached by means of catching up alone. In order to close the gap completely, the backward country will have to go through one more phase. The relevant feature of this phase is the expansion of domestic research efforts up to a level comparable with the advanced country. This '*post-catching up*' phase, in which the tendency of growth rates to converge halts, might be a relevant feature of the experience in the industrialized world after the mid-1970s (Abramovitz, 1986). In Fig. 3, this phase is illustrated by the movement from point E to point F.[10]

5. ECONOMETRIC TESTS OF THE MODEL

The model presented in Section 3, as well as some of the models described in Section 2, will be estimated using data on (maximal) 114 countries for the period 1960–85. The data on productivity (and population) is taken from Summers and Heston (1987).[11] Data on the variables used as indicators for the capability to assimilate knowledge spill-overs is taken from the United Nations and the World Bank.

The model developed in Section 3 is a dynamic model in the sense that it tries to explain a movement of a variable over time. In the formulation, we have implicitly assumed that time is a continuous variable and that there are no time lags in the explanation of variables involved. Moreover, we have not specified the notion of time very explicitly (i.e. we have not explicitly defined time in months, years or days). All this was done because it proved to be 'easy' in the formulation

[10] Of course, the strict distinction between the different phases in this development process is only an analytical one. It might well be the case that features of these different phases occur next to each other in the same period rather than neatly following each other. In general, however, one should expect some (time related) distinction between the 'pre-catching up' phase and the 'post-catching up' phase, since a country which is very far from the technological frontier will not be very efficient in performing research. In graphical terms this would come down to the argument that, for an initially 'very' backward country, it is much cheaper to move the S curve up than to move the line B down.

[11] For a critical review of the methods used in constructing this data, see Stollar *et al.* (1987).

of the model (it enabled us to use the method of simple differential equations). Now that the model is to be estimated explicitly, we may develop the notion of time in a more detailed way.

First, we deal with the notion of time. The movements which the model is trying to explain are not likely to reveal themselves in short periods. The model is not so refined that it can pretend to be able to explain the (productivity) growth path of an economy with all its short run disturbances that we know so well from practice. It can only attempt to explain the long run tendency of the growth path of the economy, i.e. whether a country will catch up to the technological frontier or rather fall behind. Therefore, the model cannot be tested by using short run data on productivity growth, but must use long run trends.

Second, the problem of time lags between variables becomes important when we attempt to estimate the model empirically. In practice, there will be numerous time lags between the variables in the model of Section 3. To name a few, there is a lag between the 'invention' of knowledge and the time when this knowledge will be able to flow to the other country; there is a lag between 'investments' in intrinsic learning capability and the actual increase of this variable; there is a lag between the invention (or 'first spill-over') of new knowledge and the diffusion of this knowledge, etc. While it would principally be desirable to develop an economic theory which would explain these lags, this is not possible yet (certainly not in the context of this paper). Moreover, there is no reason to assume beforehand that this lag would be constant, or that it would in any way be possible to determine a satisfying empirical formulation of the processes involved.

Taking these problems into consideration, the following procedures to test the model proposed in Section 3 will be applied. We will estimate the model in a *cross-country* sample, with the *long run movement of the technology (productivity) gap* as the dependent variable. This will implicitly mean that we elaborate the model in Section 3 to a multi-follower–one leader context. Although time is assumed to be 'constant' in this cross-country approach, the dynamic character of the model is preserved in the sense that the movement of a variable over time is explained. This cross-country approach 'solves' the problems involved in a time series approach explained above. Moreover, this approach closely links up to previous research in the field of catching up (see Section 2), as will become clear from the explicit formulation of the models to be estimated.

We now proceed to explain the cross-country estimation of the model in more detail, and will elaborate on the formulation of the empirical models and the measurement of the variables.

The following equations, which can be estimated for a cross-country sample using ordinary least squares (7 and 8) or non-linear least squares (9),[12] can be used to describe different models that have been discussed in Sections 2 and 3:

$$\dot{G} = c_1 + a_1 G_0 + \varepsilon_1 \tag{7}$$

[12] The software used to estimate the equations in this section is TSP for the MSDOS PC, version 4.1C. Procedures used were OLSQ (for ordinary least squares), LSQ (for non-linear least squares), and FIML (for the calculation of the N statistic).

$$\dot{G} = c_2 + bP + a_2G_0 + dE + \varepsilon_2 \tag{8}$$

$$\dot{G} = \beta_1 + \beta_f P + \alpha G_0 e^{\delta(G_0/E)} + \varepsilon_3. \tag{9}$$

In these equations, E is a (vector of) variable(s) influencing the intrinsic capability to assimilate knowledge spill-overs; P is a variable representing the exogenous rate of knowledge growth in the backward country; the subscript 0 denotes initial values; c_i, a_i, b, d, α, β_i, and δ are parameters to be estimated; and ε_i are random disturbances with the normal characteristics.

Equation (7) specifies the simplest catching up hypothesis, as it has been put forward and tested by Abramovitz (1979). It simply, and unconditionally, states that countries with a low initial level of productivity should grow faster. Equation (8) adds the two extra terms that have been proposed in Section 3 to equation (7), but is not specified in the non-linear way as proposed in the model in Section 3. The extra terms are meant to measure the capability to catch up. Such a linear equation (with the growth of population instead of the variable P) has been used by Baumol *et al.* (1989). It is applied here mainly to test whether the *non-linear* specification of (9) improves the goodness of fit. Equation (9) is the equation developed from the model in Section 3. It is aimed at taking into account the capability to assimilate knowledge spill-overs. Its characteristics include the possibility of falling behind and the bifurcation as described in Section 3.

In the estimation results it should be expected (on the basis of the reasoning in Sections 2 and 3) that

$$a_i,\ b,\ d,\ \beta_f,\ \alpha,\ \delta < 0$$

and

$$\beta_1 > 0.$$

The constant c_i might take on any sign.

It can be noted that equation (7) is nested in equations (8) and (9), so that specifications (8) and (9) can be tested against specification (7) by a simple t-test with null-hypothesis $b = 0$, $d = 0$ (in the case of equation 8) or $\delta = 0$, $\beta_f = 0$ (in the case of equation 9).

Variables are measured as follows (for a listing of the value of variables, descriptive statistics and a correlation matrix, the reader can refer to Appendix A). Productivity is defined as per capita real gross domestic product (RGDP), taken from Summers and Heston (1987). The authors provide alternative measures of RGDP, so that a choice between these alternatives must be made. The indicator used here is the *chain index* of RGDP, which "has the substantial merit that price weights are much more current in *intertemporal* comparisons" (Summers and Heston, 1987, p. 13, emphasis added; see reference for more information on the construction of the variable). The value of this per capita RGDP index of the US is taken as the productivity of the technological leader in the definition of the technology gap (equation (1)).

The long run motion of the technology gap G (i.e. the dependent variable in the regressions) is *estimated* using the following equation for the period 1960–85 for each country in the sample.

$$G = \phi t + c_3 + \varepsilon_0. \tag{10}$$

In this equation, t represents a time trend. $\hat{\phi}$ (i.e. the estimated derivative of the technology gap with respect to time) is taken as a measure of the growth of the technology gap.[13] The values of this dependent variable, together with the t-values obtained in the estimation, are given in Appendix A. This procedure of estimating the growth rate of the technology gap has the advantage that it uses all the data on G, instead of only the first (1960) and last (1985) values, as is done, for example, in some of the equations in Baumol *et al.* (1989). G_0 in equations (7) to (9) is measured as G_{1960}.

Three different indicators for E are used. The first two of these three refer to education data (as a measure of the quality of the labour force), while the latter refers to the quality of the infrastructure as an indicator for the capability to assimilate knowledge spill-overs. The first indicator of education, EDUWB, is taken from the World Bank. This indicator is defined as the percentage of age group enrolled in secondary education in 1965, and is the same as is used in Baumol *et al.* (1989). The second indicator for education, denoted by EDUUN, is a *weighted average* of per capita enrolment in tertiary education over the years 1965 (weight 0.6) and 1975 (weight 0.4), using United Nations (UNESCO) data.

The indicator for the capability to assimilate knowledge spill-overs related to the quality of the infrastructure is a weighted average (weights between brackets) of the per capita *electricity generating capacity* for the years 1965 (0.2), 1970 (0.2), 1975 (0.3), 1980 (0.2), and 1984 (0.1). This data is taken from the United Nations. This variable is denoted by INFRA.

The (exogenous) rate of productivity growth due to research activities in a follower country, P in equation (8) and (9), is measured by the sum of the per capita number of patent grants for inhabitants from the country in the US over the period 1962–85. This variable is denoted by PAT. The data is taken from the US Patent Office. Patent data have also been used by Fagerberg (1988) in an inquiry into 'why growth rates differ'. It should be noted that this proxy of the autonomous rate of productivity growth in a follower country has several disadvantages. The disadvantages of patent data as an indicator of innovation are well-known (for an overview of the characteristics of patent data in this respect, see Pavitt, 1985; Basberg, 1987). Since US patents are *external* patents for all the follower countries in the sample, the advantage of a comparable patent institution only comes at the cost of the fact that the data used might just reflect a trend in the internationalization of an economy.

Using these different indicators, we test four different variants of equations (8) and (9), and one variant of equation (7). The four different variants of (8) and (9)

[13] Note that equation (10) implies that the dependent variable is equal to the (estimated) growth rate of the productivity ratio of the leading and following country. Moreover, the equation implicitly assumes that during the period under consideration no 'switch' from a falling behind to a catching up situation occurred (as in Section 4).

relate to versions of the equations with each indicator used for E separately, and one version with EDUWB and INFRA combined. The results of the estimation procedures are presented in Table 1, where estimations of parameters are denoted by hats above parameter names. Note that in equation (9), the estimated constant is to be interpreted as the estimation of β_1, while the estimations of a_i in equations (7) and (8) are listed in the same column as the estimation of α in equation (9).

According to the estimations in Table 1, the explanatory power of the equations, as measured by the (adjusted) R^2 statistic, varies from small to almost zero. The highest R^2 statistics are found in the estimation of equation (9), while the other two equations have lower R^2 values. The majority of the estimated parameters have the expected sign and are significantly different from zero at the 5% level. However, these characteristics are not equally distributed over equations (7)–(9).

The estimation of a in equations (7) and (8) takes on the wrong sign in four out of five cases, although it is only significant in two of these four cases. This points to the conclusion that the catching up hypothesis is not valid in its most simple form in this big sample of countries. The significant and correctly signed parameters for the variable EDUWB in equations (8)i and 8(iv) point to the fact that education is an important variable in explaining the growth pattern in this cross-country sample, and thus seem to reject the most simple specification (7). This is the same result that has been found by Baumol *et al.* (1989). It should be noted, however, that the parameter for EDUUN in equation (8)ii is not significant, thus not supporting the 'education hypothesis'. Moreover, the only variant of equation (8) that gives the expected sign (although not significant) of a is the variant including (only) EDUWB.

Equation (9) gives the best results in terms of significance of parameters, and all the parameters have the expected signs. Only the β_1 values are weakly significant, and the δ_{INFRA} in the variant 9(iv) is not significant. Thus, the evidence in favour of the specification in (9) is quite strong, especially compared to the evidence found for the other specifications. Note also that it is (again) confirmed that specification (7) fits the data less well (t-tests on δ).

Summarizing the conclusions from Table 1, we might say that the evidence of the positive influence of education in the catching up process is quite strong. Also, the statistical evidence for the model presented in Section 3 is quite strong.

At this stage, we have tested specification (7) against (8) and (9), and have found that the most simple catching up model does not seem to apply. We have, however, not tested which of the equations (8) and (9) fits the data better, other than by looking at the R^2 statistics and the t-values of the parameters. In trying to do such a test, two different strategies can be followed. First, a new equation in which both (8) and (9) are nested can be estimated, and t-tests can be applied to test the specifications (8) and (9) against this 'third' equation, and, thus, against each other. This method has the drawback that such a 'third' equation has no (economic) meaning on its own, and that the estimation of such an equation will most likely suffer from multi-collinearity. Second, a method for non-nested

TABLE 1. *The Estimation Results for the Three Different Models*[1]

Equation no.	$\hat{c}, \hat{\beta}_l$	$\hat{b}, \hat{\beta}_f$	$\hat{a}, \hat{\alpha}$	$(\hat{d}, \hat{\delta})_{EDUWB}$	$(\hat{d}, \hat{\delta})_{UDUUN}$	$(\hat{d}, \hat{\delta})_{INFRA}$	$\bar{R}^2$	n
7	−0.0120 (2.87)***		0.0059 (2.90)***				0.06	114
8								
i	0.0115 (1.19)	0.0038 (0.90)	−0.0010 (0.28)	−0.0004 (3.11)***			0.15	100
ii	−0.0065 (0.93)	0.0043 (1.28)	0.0035 (1.21)		−0.006 (1.33)*		0.04	98
iii	−0.0154 (2.21)**	0.0038 (1.11)	0.0078 (2.53)**			0.0008 (0.21)	0.08	101
iv[2]	0.0070 (0.78)	0.0032 (0.71)	0.0006 (0.15)	−0.0004 (2.94)***		0.0027 (0.57)	0.15	90
9								
i	0.0125 (4.31)***	−0.0054 (1.54)*	−0.0244 (4.90)***	−8.1191 (3.35)***			0.25	100
ii	0.0083 (2.87)***	−0.0033 (1.30)*	−0.0201 (4.48)***		−1.4220 (2.60)***		0.20	98
iii	0.0120 (3.98)***	−0.0039 (1.51)*	−0.0267 (5.55)***			−0.0652 (3.76)***	0.26	101
iv[2]	0.0149 (4.67)***	−0.0055 (1.62)*	−0.0294 (5.80)***	−0.0876 (3.21)***		−4.5277 (1.19)	0.31	90

[1] Values between brackets are absolute t-values, subscripts for parameters δ, b refer to variable names.
[2] Note that in this version of the equation, the δ_s values appear in the denominator of the exponential term, i.e. they should be interpreted as being equal to $1/\delta$ in the other versions of this equation.
* Significantly different from zero in a one-tailed Student's t-test at the 10% level.
** Significantly different from zero in a one-tailed Student's t-test at the 5% level.
*** Significantly different from zero in a one-tailed Student's t-test at the 1% level.

hypothesis testing can be applied. Such a method for nonlinear equations (like equation 9) was proposed in Pesaran and Deaton (1978), and is applied here. We will proceed here first with the 'nested testing' method.

Equations (8) and (9) are both nested in the following equation.

$$\dot{G} = c + \beta_f P + dE + \alpha G_0 e^{\delta(G_0/E)} + \varepsilon_4 \tag{11}$$

The two specifications can be tested against each other by testing the following hypotheses.

If

$$\delta = 0 \quad \text{and} \quad d < 0$$

then the hypothesis that specification (9) is to be preferred has to be rejected;

If

$$\delta < 0 \quad \text{and} \quad d = 0$$

then the hypothesis that specification (8) is to be preferred has to be rejected. The results of the estimation of equation (11) are presented in Table 2.

The results of the test of the specifications (8) and (9) against each other provide some evidence that specification (9) is better. At the 5% significance level, all the requirements for a rejection of the hypothesis that (8) fits the data better are met in all the variants of the equations. However, the insignificance of *d* might be caused by the multi-collinearity between the right-hand side variables. At the 10% significance level, neither hypothesis can be rejected. The results in Table 2 thus point towards the conclusion that equation (9) is the 'better' one, although the evidence is not altogether conclusive.

The second method makes use of techniques for non-nested hypothesis testing. In order to test two alternative models against each other, we can (in turn) maintain the hypothesis that one of these two models is correct. On the basis of this hypothesis a test-statistic *N* (the 'Cox' statistic), which is (asymptotically) distributed as $N(0, 1)$, can be calculated by a procedure which involves estimating four equations: the two models themselves, plus one more non-linear regression and one more linear regression (see Pesaran and Deaton, 1978, for more background on this method). Since the method to calculate the statistic makes use of maximum likelihood estimates of the variance of the regression, the best way to proceed is to estimate the equations by the maximum likelihood method. Appendix B describes the precise method that has been applied to estimate the statistic for these one-equation models. Table 3 gives the value of the statistic itself, for the variants (i), (ii) and (iii) of equations (8) and (9). Variant (iv), which yielded a less-significant estimate in both cases, is no longer considered.

The evidence in Table 3 is quite strong although, again, not altogether conclusive. For all three variants of equation (8), the hypothesis that this model fits the data better than (9) clearly has to be rejected, since the values of the statistics (the lower left corner of the table) are clearly significantly different from 0. The hypothesis that variant (i) of equation (9) is the correct one has to be

TABLE 2. *The Estimation Results for Equation* (11)[1]

Equation 11	$\hat{c}$	$\hat{\beta}_f$	$\hat{\alpha}$	$\hat{d}_{EDUWB}$	$\hat{d}_{EDUUN}$	$\hat{d}_{INFRA}$	$\hat{\delta}_{EDUWB}$	$\hat{\delta}_{EDUUN}$	$\hat{\delta}_{INFRA}$	$\bar{R}^2$	n
i	0.0148	−0.0022	−0.0176	−0.0002			−6.1611			0.26	100
	(4.13)***	(0.53)	(2.93)***	(1.50)*			(2.14)**				
ii	0.0082	−0.0034	−0.0204		0.00003			−1.4429		0.20	98
	(2.68)***	(1.00)	(3.44)***		(0.08)			(2.34)**			
iii	0.0138	−0.0013	−0.0244			−0.0048			−0.0529	0.27	101
	(4.25)***	(0.44)	(5.25)***			(1.59)*			(3.42)***		
iv[2]	0.0187	−0.0002	−0.0188	0.0002		−0.0049	−0.2423		5.0357	0.31	90
	(4.30)***	(0.05)	(3.50)***	(1.04)		(1.06)	(2.41)***		(3.57)***		

[1] Values between brackets are absolute t-values, subscripts for parameter δ, b refer to variable names.

[2] Note that in this version of the equation, the δ values appear in the denominator of the exponential term, i.e. they should be interpreted as being equal to $1/\delta$ in the other versions of the equation.

* Significantly different from zero in a one-tailed Student's t-test at the 10% level.

** Significantly different from zero in a one-tailed Student's t-test at the 5% level.

*** Significantly different from zero in a one-tailed Student's t-test at the 1% level.

TABLE 3. *A Non-Nested Test of Specifications* (8) *and* (9) *Against each Other*

	Testing the correctness of hypothesis					
Against hypothesis	*(8)i*	*ii*	*iii*	*(9)i*	*ii*	*iii*
(8) i				−1.67		
ii					−0.20	
iii						−0.07
(9) i	−5.05					
ii		−8.12				
iii			−8.93			

rejected (in a two-tailed test) only at the 10% level,[14] so that this evidence is less strong. In the tests of variants (ii) and (iii) of equation (9), clearly the hypothesis that these equations fit the data less well than the corresponding variants of (8) cannot be rejected. Summarizing the information in Table 3, it seems that there is quite strong evidence in favour of specification (9).

6. SUMMARY AND CONCLUSIONS

The literature on 'catching up' and convergence of growth rates investigates the hypothesis that, due to international knowledge spill-overs, international growth rate differentials tend to vanish over time. However, empirical research indicates that this catching up tendency is only valid within the group of developed countries, and does not hold *between* developed and less developed countries.

Here it is suggested that, contrary to what is implicitly assumed in the catching up literature, technology spill-overs do not occur automatically. In order to assimilate knowledge from abroad, a country must be able to apply this knowledge in its own economic system. In the model presented here it is assumed that this 'learning capability' depends on an 'intrinsic' learning capability (depending on such variables as the education of the labour force and the quality of the infra-structure), and the technological distance between the technology receiving country and the technological leader.

The model shows that countries with relatively low levels of intrinsic learning capability and a large technological distance face a high probability of falling even further behind, while countries with relatively high levels of intrinsic learning capability and a small technological distance are more likely to catch up. It is also shown that the standard catching up hypothesis can be seen as a special case of the present model.

With regard to the development process, the model suggests that, besides a catching up phase, there is a also a 'pre-catching up phase', in which a country builds up its intrinsic learning capability, and a 'post-catching up phase' in which domestic research activities begin to assume a greater importance than technology spill-overs.

[14] The situation that in case of variant *i* (at the 10% level) both equations (8) and (9) have to be rejected might seem paradoxical, but is quite a 'normal' outcome of the testing procedure applied here. See Pesaran and Deaton (1978, pp. 678–9) for a discussion of this feature of the procedure.

In an econometric estimation for a cross-country sample of 114 countries, it was shown that the model proposed fits the data well, yielding (highly significant) parameters with the expected sign. In the statistical procedure, it was shown that education is indeed an important factor in the catching up process, as has been shown by other research too. The specific non-linear model proposed here, with its features summarized above, is shown to fit the data better than linear models involving the same variables. This result is established by considering the common 'goodness of fit' statistics, a procedure using nested equations to test different functional specifications against each other, and a procedure for testing (non-linear) non-nested regression models.

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APPENDIX A: DESCRIPTION OF THE DATA

TABLE A1. *Correlation Matrix of the Variables used in Section 5*

INFRA	$\dot{G}$	G_0	PAT	EDUWB	EDUUN	
$\dot{G}$	1					
G_0	0.25	1				
PAT	−0.07	−0.51	1			
EDUWB	−0.37	−0.78	0.45	1		
EDUUN	−0.29	−0.74	0.39	0.81	1	
INFRA	−0.19	−0.69	0.61	0.70	0.62	1

TABLE A2. *Descriptive Statistics of the Variables used in Section 5*

	Mean	*Standard deviation*	*Variance*
$\dot{G}$	−0.0025	0.0188	0.0004
G_0	1.7309	0.8931	0.7976
PAT	0.1963	0.5650	0.3192
EDUWB	25.5926	22.6262	511.9444
EDUUN	5.9552	5.8223	33.8996
INFRA	0.4202	0.6942	0.4819

TABLE A3. *Data used in the Regression*

Country	$\hat{\phi}$	$t_{\hat{\phi}}$	G_0	*PAT*	*EDUWB*	*EDUUN*	*INFRA*
Algeria	−0.01398	5.33993	1.801143	0	7	1.71438	0.0852
Angola	0.04808	12.68049	2.017933	0.00071	NA	NA	0.06727
Benin	0.02334	15.32828	2.596419	0	3	NA	0.00409
Botswana	−0.03066	14.0683	2.601935	0	3	NA	NA
Burundi	0.0181	4.55845	2.845418	0	1	0.1591	NA
Cameroon	−0.0093	5.74789	2.678006	0	5	0.54807	0.03887
Central African Republic	0.0218	16.87458	2.710102	0.00031	2	NA	0.00873
Chad	0.04841	18.63833	2.652568	0	1	NA	0.00611
Congo, P. Rep.	−0.01065	3.43622	2.541477	0.00024	10	2.70958	0.03929
Egypt	−0.01441	7.72986	2.683846	0	26	NA	0.10297
Ethiopia	0.0183	26.68706	3.248562	0.00089	2	0.13185	0.00723
Gabon	−0.04568	8.51039	2.281803	0.00005	11	0.47047	0.08712
Gambia	0.00206	0.93136	2.928074	0	NA	NA	NA
Ghana	0.03302	13.33548	2.726622	0	13	0.70876	0.07596
Guinea	0.01914	8.78578	2.859455	0	5	NA	NA
Ivory Coast	0.00855	4.35259	2.323809	0.00021	6	0.74153	0.06236
Kenya	0.00656	5.32463	2.691931	0.00041	4	0.50878	0.01973
Lesotho	−0.02765	10.62992	3.403099	0.00199	4	0.40877	NA
Liberia	0.01478	3.76524	2.172861	0	5	1.00801	0.15394
Madagascar	0.3065	26.30433	2.403179	0.00178	8	0.74277	0.01239
Malawi	−0.00162	0.80616	3.374945	0	2	0.1545	0.01531
Mali	0.02111	7.71065	2.903153	0.0054	4	0.22919	0.00548
Mauritania	0.0071	4.07755	2.880976	0.00541	1	NA	0.02693
Mauritius	−0.00623	2.26732	2.053306	0.00243	26	0.5569	0.16835
Morocco	−0.00411	2.18148	2.601935	0.00098	11	1.47436	0.05627
Mozambique	0.04137	11.38177	2.195167	0.00333	3	0.06918	0.08326
Niger	0.00341	1.61607	3.309895	0	1	NA	0.00462
Nigeria	0.00929	2.19954	2.476343	0	5	0.28871	0.01598
Rwanda	−0.00884	2.24914	3.383161	0.0003	2	0.12559	0.00744
Senegal	0.00205	14.93523	2.335005	0	7	1.08295	0.0247
Sierra Leone	0.00753	3.40197	3.187377	0.00101	5	0.37855	NA
Somalia	0.02853	10.73516	2.734908	0	2	0.21066	NA
S. Africa	0.00225	1.4436	1.00794	0	15	3.27474	0.5394
Sudan	0.02945	15.86395	2.32524	0.06076	4	0.90073	0.01204
Swaziland	−0.02448	14.77822	2.92304	0.0005	NA	0.96436	NA
Tanzania	0.00627	4.10963	3.379045	0	2	0.09956	0.01387
Togo	0.01242	3.70329	2.871393	0.00064	5	0.4416	0.01195
Tunisia	−0.01909	8.51371	2.103243	0.00225	16	2.45763	0.08526
Uganda	0.0266	10.19449	3.069594	0.0004	4	0.28949	0.01522
Zaire	0.04455	9.86727	3.099317	0.00003	5	NA	0.04764
Zambia	0.03435	13.19778	2.13023	0.00275	7	0.75129	0.21546
Zimbabwe	0.00945	4.09932	2.256847	0	6	NA	NA
Afghanistan	0.02305	11.66012	2.389778	0	2	0.53416	NA
Bangladesh	0.01142	4.3669	2.762401	0	13	NA	0.00897
Burma	−0.00058	0.26769	3.220878	0.00004	15	1.24989	0.01422
Hong Kong	−0.04534	45.25816	1.397355	0.07111	29	5.93905	0.5005
India	0.00935	5.39992	2.620314	0.00045	27	3.49601	0.03707
Iran	−0.01588	3.55205	1.421259	0.00161	18	2.76556	0.15618
Iraq	0.00648	1.09036	1.263404	0.00029	28	5.26279	NA
Israel	−0.01056	4.7655	0.908844	0.53388	48	17.88162	0.57812
Japan	−0.03514	18.12784	1.168187	1.03807	82	15.1889	0.89561
Jordan	0.00226	0.6014	1.858733	0.00077	38	2.40722	NA
Korea, Rep. of	−0.04518	21.60202	2.323809	0.00534	35	7.16097	0.16011
Malaysia	−0.02893	12.7374	1.821085	0.00223	28	2.27274	0.12997
Nepal	0.01796	13.33863	2.736913	0	5	1.20199	0.00491
Pakistan	−0.00463	2.98697	2.60369	0.00021	12	3.6888	0.03478
Philippines	−0.00395	2.29528	2.099889	0.00309	41	15.79454	0.07178

TABLE A3. (*Continued*)

Country	$\hat{\phi}$	$t_{\hat{\phi}}$	G_0	*PAT*	*EDUWB*	*EDUUN*	*INFRA*
Saudi Arabia	−0.00751	1.56894	0.492887	0.0038	4	1.6876	0.27971
Singapore	−0.4799	17.25655	1.413419	0.0267	45	8.18799	0.53676
Sri Lanka	0.00787	2.78419	1.954608	0.0004	35	NA	0.02783
Syrian Arab Republic	−0.03012	8.34434	1.938498	0.00038	28	7.64209	0.093
Taiwan	−0.03913	44.39935	2.133687	0.04069	NA	NA	NA
Thailand	−0.02139	20.99783	2.311424	0.00034	14	2.23987	0.05992
Austria	−0.01454	17.92698	0.636275	0.68797	52	9.64525	1.31864
Belgium	−0.1262	12.1722	0.497564	0.5518	75	11.31403	0.89292
Cyprus	−0.02425	9.81031	1.548202	0.00955	NA	0.83115	0.35769
Denmark	−0.00445	8.37586	0.291811	0.61986	83	14.74797	1.08145
Finland	−0.0136	11.14675	0.617724	0.40747	76	12.6407	1.48248
France	−0.01388	12.63764	0.497564	0.83617	56	14.15517	0.90951
Germany, FR	−0.00998	14.94543	0.376761	1.88835	NA	9.57263	1.04616
Greece	−0.02414	11.77689	1.559791	0.02065	49	8.66764	0.43288
Iceland	−0.00994	5.99709	0.480507	0.25709	NA	8.90109	2.2616
Ireland	−0.0094	10.60299	1.065748	0.11453	51	8.90848	0.6539
Italy	−0.01513	17.19436	0.865669	0.27332	47	10.99951	0.68367
Luxembourg	−0.00345	3.56475	0.214531	0.86896	NA	1.60547	3.50866
Malta	−0.04672	19.0655	1.712302	0	NA	4.27699	0.31891
Netherlands	−0.00936	7.70655	0.474815	1.02482	61	16.39529	0.9973
Norway	−0.151	16.40964	0.353865	0.43323	64	10.03569	4.24294
Portugal	−0.1993	9.78159	1.608089	0.00937	42	5.77013	0.33537
Spain	−0.01629	9.90846	1.110908	0.04136	38	8.55084	0.62635
Sweden	−0.00257	3.60212	0.343477	1.99619	62	14.47744	2.56918
Switzerland	0.00428	4.6522	0.092093	4.17212	37	7.48231	1.85351
Turkey	−0.00979	5.81326	1.749102	0.00096	16	4.97993	0.09455
UK	−0.00203	2.69202	0.371629	1.0756	66	7.95071	1.17921
Barbados	−0.0203	12.18278	1.332488	0.0081	NA	3.34321	0.24487
Canada	−0.00784	10.3476	0.172355	1.10597	56	25.7697	2.57163
Costa Rica	−0.00189	1.01352	1.469632	0.01563	24	10.76243	0.20208
Dom. Rep.	−0.01013	4.65792	2.034468	0.00274	12	4.41073	0.11985
El Salvador	0.015	6.13723	1.958499	0.00678	17	3.45468	0.07254
Guatemala	0.00488	3.17181	1.748298	0.00771	8	2.66203	0.04885
Haiti	0.01478	7.35594	2.484467	0.00533	5	0.52384	0.0168
Honduras	0.00865	6.95707	2.277795	0.00561	10	2.67575	0.04803
Jamaica	0.01555	4.63999	1.579345	0.00881	51	2.29967	0.26688
Mexico	−0.00819	5.86105	1.200579	0.02279	17	5.71479	0.18852
Nicaragua	0.01545	5.17495	1.561076	0.00985	14	3.51557	0.10911
Panama	−0.01115	8.31845	1.707051	0.02322	34	10.86345	0.26644
Trin. & Tob.	−0.00759	4.24361	0.737998	0.03151	36	1.65558	0.44156
U. States	0	NA	0	4.7682	NA	40.44696	2.19021
Argentina	0.01269	6.0782	0.866311	0.01914	28	16.06992	0.34692
Bolivia	0.00628	2.28701	2.053306	0.0087	18	6.31345	0.07061
Brazil	−0.0269	9.62825	2.045929	0.00398	16	6.15704	0.18169
Chile	0.01256	6.14067	0.94487	0.00725	34	8.24498	0.23821
Colombia	−0.01203	8.29306	1.730533	0.00457	17	4.7969	0.14591
Ecuador	−0.01724	7.38671	1.84833	0.00486	17	12.05167	0.09109
Guyana	0.0178	5.84581	1.605396	0.00258	NA	1.44823	0.20397
Paraguay	−0.01159	4.61156	1.989747	0.00178	13	3.08078	0.07133
Peru	0.00736	3.71848	1.541219	0.00506	25	8.80773	0.15034
Surinam	−0.1794	8.68464	1.519277	0	NA	NA	0.86354
Uruguay	0.00962	4.14647	0.816853	0.00871	44	8.4202	0.25211
Venezuela	0.02111	10.38418	0.648155	0.01442	27	10.61674	0.38752
Australia	−0.00072	0.89623	0.350579	0.34134	62	15.54973	1.40422
Fiji	−0.00643	2.86861	1.423498	0	NA	1.86082	0.14444
New Zealand	0.00569	5.43636	0.287269	0.20381	75	22.38139	1.5169
Papua N.G.	0.01409	7.07751	1.900526	0.0035	4	0.96177	0.07047

APPENDIX B: THE CALCULATION OF THE N STATISTIC

In this Appendix, the procedure that was used to estimate the N statistic (or 'Cox' statistic) will be explained. As has been noted above, this procedure is taken from Pesaran and Deaton (1978). For the derivation of the formulas used in this paper, and for the application of the procedure to a multi-equation model, the reader is referred to this original source. The N statistic applies in the case where two alternative (non-linear and) non-nested equations, denoted by f and g, are tested against each other.

$$H_0\colon\ y = f(\beta_0, x) \tag{A1}$$

$$H_1\colon\ y = g(\beta_1, x). \tag{A2}$$

In this formulation, y is the dependent variable, x is a vector of independent variables, and β_i are vectors of parameters to be estimated. Throughout, hats above variables will, as usual, denote estimations.

Here, we will deal with the calculation of N for the maintained hypothesis that model H_0 is the correct one. The first step is then to estimate the two models (using the maximum likelihood method), and calculate the asymptotic (i.e. maximum likelihood) variance of the two regressions, denoted by $\hat{\sigma}_0^2$ and $\hat{\sigma}_1^2$, respectively. Step two is to calculate the predicted values of the estimated equation H_0, which we denote by $f(\hat{\beta}_0)$, and use these as the dependent variable in a regression estimation H_1. Then we define

$$\hat{\sigma}_{10}^2 = \hat{\sigma}_0^2 + \hat{\sigma}_*^2, \tag{A3}$$

where $\hat{\sigma}_*^2$ is the estimated variance of the regression $g[f(\hat{\beta}_0)]$.

Now we define

$$T_0 = \frac{n}{2}\ln\left(\frac{\hat{\sigma}_1^2}{\hat{\sigma}_{10}^2}\right). \tag{A4}$$

Now we proceed estimating the variance of T_0, denoted by $\hat{V}_0(T_0)$, as follows. We define the following function.

$$\hat{F} = \frac{\partial f}{\partial \beta_0}. \tag{A5}$$

Then we run a regression of $\hat{F}_{\beta_0-\hat{\beta}_0}$ on the residuals from the regression $g[f(\hat{\beta}_0)]$ and denote the residual sum of squares of this regression by e_*^2. Then we calculate

$$\hat{V}_0(T_0) = \frac{\hat{\sigma}_0^2}{\hat{\sigma}_{10}^4} e_*^2 \tag{A6}$$

Finally, we define

$$N_0 = \frac{T_0}{\sqrt{\hat{V}_0(T_0)}} \tag{A7}$$