GEOGRAPHICAL SPILLOVERS AND GROWTH

Jean-François Brun[*],
Jean-Louis Combes[**],
and Pascale Motel Combes[***].

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[*] CERDI (Centre d'Etudes et de Recherches sur le Développement International), 65 bd F. Mitterrand, 63000 Clermont-Ferrand, France. E-Mail : J-F.Brun@u-clermont1.fr

[**] University of Savoie, GAMMAP (Groupe d'Analyse des Marchés de Matières Premières), Université de Grenoble 2, B.P. 47, 38040 Grenoble Cedex 9, France. E-Mail : motelcom@club-internet.fr

[***] University of Grenoble 2, GAMMAP. E-Mail : Pascale.Motel@upmf-grenoble.fr

Abstract.

One of the main subjects in the theory of economic growth is to explain regional differences among rates of growth. In this paper, we address this issue through the notion of the "underdevelopment trap". Such a trap may be the result of strategic complementarities between investment decisions which generate multiple equilibria. The latter may be Pareto inefficient because of technological externalities. We test our model on international pooled data on the period 1970-90. The econometric analysis shows that economic growth rates depend on regional investment decisions. Moreover, it appears that such regional spillovers are channeled mainly through the physical rather than through the human capital stock.

Keywords.

Regional Spillovers, Growth, Strategic Complementarity, Technological Externalities, Underdevelopment Traps.

I. Introduction[1].

Between 1970 and 1990, developing countries had lower annual growth rates of GDP per capita than developed ones (cf. Appendix A). These growth differences have a strong regional flavor. African (1.3% between 1970 and 1980, 0.02% between 1980 and 1990) and Latin American (2.0% between 1970 and 1980, 0.8% between 1980 and 1990) countries grew systematically slower than Asian ones (3.3 % between 1970 and 1980, 3.6% between 1980 and 1990). Regional standard deviations in each developing countries regions are lower than the all-developing countries one. Africa is the most homogeneously and slowly growing region of the world over the 1980-90 period. Such a regional homogeneity and international diversity may be diagnosed as kinds of " regional underdevelopment traps ". The existence of regional traps is seldom theoretically and empirically documented while it may be an important matter for the history of economic development.

Two main pieces of explanation of regional underdevelopment are proposed in the existing literature. First, regional political instability can affect negatively a country economic performance (Ades and Chua, 1997) : regional instability disrupts trade flows and increases military expenses. Second, poor economic policy choices have contagious effects on neighboring countries (Sachs and Warner, 1997). Indeed, there may be positive and also negative policy imitation effects. The latter can be due to rent-seeking activities that can be favored by ethnic fragmentation (Easterly and Levine, 1998).

[1] Communication presented at the XIV èmes journées de l'Association Tiers-Monde 27-29 mai 1998, île de Bendor, Bandol Var, France.

In this paper, we propose an alternative explanation relying on the existence of strategic complementarities in investment decisions between neighboring countries. Investment decisions in one country are not only depending on local economic conditions but also on regional investment decisions. There thus exists geographical spillover effects. The latter can be the result of demand externalities in the sense that marginal productivity of capital depends on the beliefs of the country's investors about the demand in neighboring countries (Murphy, Shleifer, and Vishny, 1989). Trade externalities may also be created between neighboring trade partners in the presence of transaction costs (Howitt, 1985). But, we assume in the rest of this paper that these demand or trade externalities are negligible from a growth perspective and focus on technological spillover effects or externalities.

Geographical technological spillover effects have been well known since the pioneering work of Marshall (1919) on industrial districts. Indeed, an abundant literature has stressed the effects of human capital concentration in cities on factors productivities (Rauch, 1993). Moreover, knowledge spillovers are particularly effective in cities where communication is intensive (Glaeser et al. 1992). We think that this latter type of externalities may also occur within a regional group. Several reasons may explain this. First, the country may benefit from the knowledge accumulated by neighboring countries. Three channel of knowledge diffusion can be identified. When interacting opportunities are more available with neighbors than with the rest of the world, regional externalities are likely to be developed. Migrant workers also learn by doing when they are employed by regional foreign firms (Arrow, 1962). When a country invests in one project, the latter can be considered as a country-wide market study that improves the economic information needed by neighboring investors. Second, a country may benefit from the public capital goods provided by neighboring countries. Concretely, when a country invests in roads, telecommunications, airports and ports, neighbors are automatically

favored as price exclusion of foreign users is not possible. The same mechanism is at work concerning public investments in human capital, *i. e.* health and education.

In this paper, we venture a unified theoretical and testable framework of the channels of those regional spillovers. Our theoretical explanation relies upon the existence of a strategic complementarity between one country and its neighbors which generate multiple equilibria and coordination failure problems because of positive spillovers. Indeed, in some regions of the world, it can be assumed that regional conditions may generate positive technological spillovers that result in high or low growth rates of the countries belonging to the regional group, *i.e.*, proximity effects generate supply externalities that diffuse through one country's border to another one. We then test this hypothesis empirically on a sample of developed and developing countries.

II. Regional Strategic Complementarity and Economic Growth: A Theoretical Analysis.

We consider a region as a group of countries where decisions taken in one country affect the welfare of others, *i. e.* positive geographical spillovers, and where countries behave strategically in the sense that there exists a strategic complementarity between them. Our formalization is an adaptation of the framework developed by Cooper and John (1988).

Each country decides to invest under the assumption that the action of other countries is given (Nash equilibrium). We consider *N* identical countries in a regional group. The decisions taken by each country are thus similar and the equilibrium is a symmetric Nash equilibrium. The main implication of this approach is to take only account of homogeneous regions.

The representative agent of the i^{th} country lives for two periods. At time, t he consumes c^i_t and derives inter-temporal discounted utility:

$$U_t^i = u\left(c_t^i\right) + (1+r)^{-1} \cdot u\left(c_{t+1}^i\right) \tag{1}$$

where r is the time discount rate of the consumer, U^i_t is its welfare at time t calculated as the discounted sum instantaneous utility u which is as usual non negative and concave increasing ($u' > 0$, $u'' < 0$). The representative agent produces in both periods of his life, his per capita production function is given by:

$$y_t^i = y_t^i\left(k_t^i, k_t^j\right) \tag{2}$$

where k^i_t is the per capita physical capital of country i and k^j_t is the regional per capita productive capital at time t (excluding country i) [2]. Assume the production function is twice differentiable with respect to its arguments:

$$\frac{\partial y(\cdot)}{\partial k_t} > 0 \ , \ \frac{\partial^2 y(\cdot)}{\partial\left(k_t\right)^2} < 0 \ , \ \frac{\partial^2 y(\cdot)}{\partial k_t^i \partial k_t^j} > 0 \tag{3}$$

The last derivative means that capital inputs are complements within the production process. Thus, there exist technological externalities within the regional group in a manner reminiscent of Romer (1986).

[2] k^i_t and k^j_t can also be regarded as composite capital including human capital. We consider in appendix A a restatement of the basic model to take into account the effect of human capital in a model where the two forms of capital are not perfect substitutes.

The representative agent consumes part of his first period income and invests the rest (s_t). In the second period, there is no investment. We suppose zero depreciation and no uncertainty. Thus, the maximization program is:

$$\max_{s_t^i} U_t^i = u\left(y_t^i\left(k_t^i, k_t^j\right) - s_t^i\right) + (1+r)^{-1} \cdot u\left(y_{t+1}^i\left(k_t^i + s_t^i, k_t^j + s_t^j\right)\right) \text{ such that, } s_t^j = \bar{s}_t \qquad (4)$$

From this maximization program, we derive a reaction function $s_t^i(\bar{s}_t)$ which describes the optimal investment response of country i when $s_t^j = \bar{s}_t, \forall i \neq j$. The symmetric Nash equilibrium is $s_t^i(\bar{s}_t) = \bar{s}_t$: if all other countries are choosing $\bar{s}_t$ it is obvious that the remaining countries select $\bar{s}_t$.

The first order necessary condition for s^i_t to be an optimum is:

$$\frac{\partial U_t^i}{\partial s_t^i} = 0 \Leftrightarrow -\frac{\partial u_t}{\partial c_t^i} + (1+r)^{-1} \cdot \frac{\partial u_{t+1}}{\partial c_{t+1}^i} \cdot \frac{\partial y_{t+1}^i}{\partial k_{t+1}^i} = 0 \qquad (5)$$

and the second order condition for an optimum is:

$$\frac{\partial^2 U_t^i}{\partial\left(s_t^i\right)^2} < 0 \qquad (6)$$

We derive now the slope of the reaction function of the Nash equilibrium in the $\left(\bar{s}_t, s_t^i\right)$ plane. We can calculate the slope $ds_t^i / d\bar{s}$ from the following expression set to 0:

$$d\left(\frac{\partial U_t^i}{\partial s_t^i}\right) = \frac{\partial^2 U_t^i}{\partial\left(s_t^i\right)^2} \cdot ds_t^i + \frac{\partial^2 U_t^i}{\partial s_t^i s_t^j} \cdot ds_t^j = 0 \qquad (7)$$

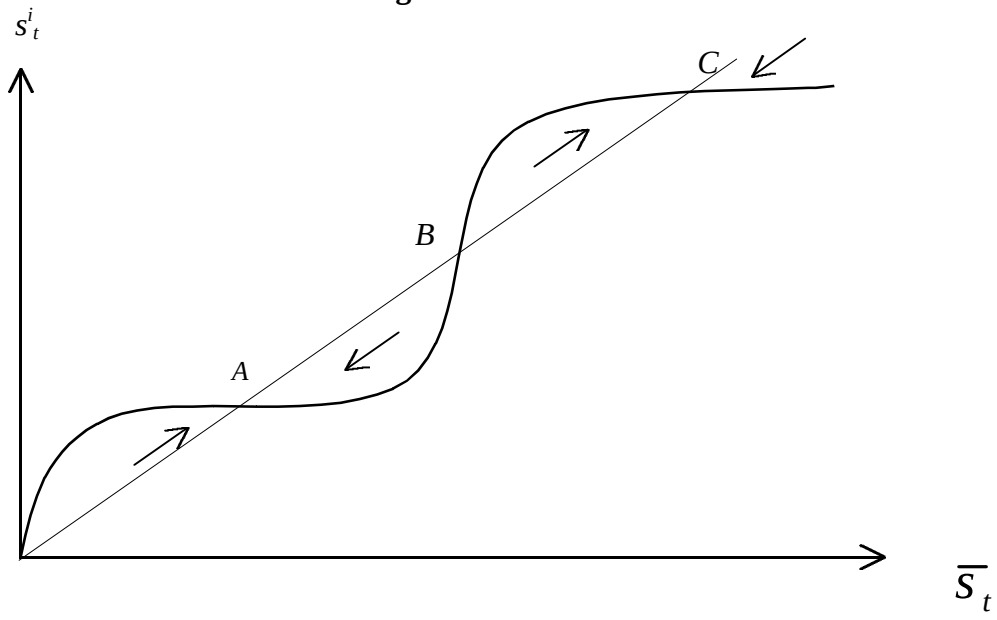
The slope of the reaction function is positive if the following cross derivative of the expected utility $\frac{\partial^2 U_t^i}{\partial s_t^i \partial s_t^j}$ is positive:

$$\frac{\partial^2 U_t^i}{\partial s_t^i \partial s_t^j} = (1+r)^{-1} \cdot \left(\frac{\partial y_{t+1}^i}{\partial k_{t+1}^i} \cdot \frac{\partial^2 u_{t+1}}{\partial (c_{t+1}^i)^2} \cdot \frac{\partial y_{t+1}^i}{\partial k_{t+1}^j} + \frac{\partial u_{t+1}}{\partial c_{t+1}^i} \cdot \frac{\partial^2 y_{t+1}^i}{\partial k_{t+1}^i k_{t+1}^j} \right) \tag{8}$$

This latter quantity is positive if capital inputs are highly complementary to compensate for the concavity of the utility function.

Suppose now that the reaction function is continuous everywhere and belongs to the interval]0;*A*] where *A* is a strictly positive constant. The reaction function crosses the first bisecting line an uneven number of times excluding tangency points (figure 1). We shall observe multiple equilibria when the slope of the reaction function is somewhere greater than unity. We can interpret this as a strong complementarity effect which overcomes the declining marginal productivities :

Figure 1.



Obviously *A* and *C* are stable equilibria while *B* is unstable.

In the presence of positive externalities, the equilibrium with a high investment level (*C*) is preferred by all countries. But if there does not exist a mechanism for countries to coordinate their own investments, they can reach a low investment equilibrium (*A*). This is a coordination failure problem. The optimal strategy for each country depends on his anticipation about the bordering countries' investments decisions. A regional low investment rate trap may exist. The main empirical implication of this model is the positive link between the regional investment rate and the growth rate of each country within a regional group[3].

III. An Empirical Analysis of Supply Externalities in a Cross Section of Data.

The Data Set.

The empirical framework derived from Barro and Sala-I-Martin (1996). The growth rate of GDP per capita is regressed on two sub categories of variables which are (*i*) the initial value of state variables, *i. e.* physical and human capital stocks and (*ii*) international environmental and control variables which themselves depend on the public and private decisions.

The physical capital stock is unknown and is hence approximated by the log-value of the initial real GDP per capita ($LGDP_0$). Because of diminishing returns, the expected effect of the initial capital stock on the dependent variable is negative. Thus, poor countries grow faster than richer countries (β-convergence).

The level of human capital may be approximated by health and education indicators. The former is measured by life expectancy at birth ($LIFE_0$) and the latter by initial primary ($PRIM_0$) and secondary (SEC_0) school enrollment ratios.

International environmental and public and private decisions variables allow one to control for different steady states between countries. Growth is thus conditional on these variables (β conditional convergence). The international environment is captured by the current terms of trade growth rate ($GRTT_t$).

The regional variables hence belong to the set of international environment variables. Among them we have (*i*) the regional investment rate ($REGINVEST_t$), (*ii*) the regional primary ($REGPRIM_t$) and secondary ($REGSEC_t$) school enrollment ratios, (*iii*) the regional GDP per capita growth rate ($REGGRGDP_t$), (*iv*) the investment rate of commercial partners ($COMINVEST_t$) and (*v*) the regional initial GDP per capita ($REGGDP_0$). Regional groups are defined as bordering countries and islands[4]. Regional variables are calculated as simple averages.

The national investment rate ($INVEST_t$) is supposed to have a positive effect on the steady state. The current inflation rate ($INFLA_t$) is supposed to have a negative effect as it introduces a bias into the structure of relative prices and generates a positive transfer towards the government which can engage unproductive expenditures. Commercial openness ($OPEN_t$) has a positive impact on the steady state in so far as a country can benefit from its comparative

[3] Another empirical implication, is that, around the two stable equilibria, when the slope of the reaction function is near one, a small exogenous shock can cause a great change in investments. This multiplier effect is a well known property of this kind of coordination failure model. The investment instability can be very large (Romer, 1996).

advantage. It favors the competitiveness and extends the scope of markets, promotes the access to better intermediate goods and increases the saving rate. Two control variables rely on demographic variables : the log value of potential working age population *i. e.* population between 15 and 64 years old ($LWPOP_t$) and the population growth rate ($GRPOP_t$). The former is supposed to affect the economic growth rate positively as a positive scale effect can be observed. The latter is a proxy for the fertility rate. If fertility decisions are endogenous, the expected effect is negative if a higher fertility rate is the result of a substitution effect between outside work time and time devoted to raise children with a constant cost per child. We also take into account an index of financial development approximated by the ratio of the money supply to GDP ($MONEY_t$). War damages are also introduced (WAR_t)

The data set covers 147 countries[5]. Due to missing observations we restrict the empirical analysis to a sub sample of 70 countries. Each country is described by two observations relating to average values on 1970-80 and on 1980-90. Temporal heterogeneity is eventually captured by a dummy (*DUM70*).

The Estimation Method.

All variables except for $LIFE_0$, SEC_0 , $PRIM_0$ and $GRTT_t$ are instrumented. Four justifications can be given for doing so (*i*) several variables are measured with errors, (*ii*) the economic growth rate may alter some variables (*iii*) international instability may be correlated with the independent variables and (*iv*) an instrumental variable estimator is robust even if

[4] Cf. Appendix C for the neighboring countries' list which is derived from Chua (1993).

[5] Our data are constructed from different sources. Variables using the GDP are from the Summers and Heston (1993) Penn World Tables, except GDP per capita growth rate which is taken from World Bank databases following Nuxoll (1992). Other variables are from the World Bank databases, war damages is taken from Easterly and Rebelo (1993).

some pertinent variables are omitted. The instruments relate to initial and former period values. The Hausman specification test rejects at the 5% level the exogeneity hypothesis and validates the use of two stages least squares[6].

The White tests reject at the 5% level the null of homoskedasticity and thus the variance and covariance matrix are corrected according the White's method. Econometric robustness is evaluated with the Ramsey Reset and Chow tests. We propose three breakpoints : industrialized countries versus developing countries (*CHOW #*1), sub Saharan countries versus the rest of the world (*CHOW #*2), and African countries versus Latin American and Asian countries versus industrialized countries (*CHOW #*3).

[6] A test of over-identification restrictions as proposed by Hausman (1983) has been implemented by regressing the residuals of the two-stage-least-squares equation on all the predetermined variables in the equation. The test statistic is T times the uncentered R^2 of this regression, where T is the number of observations, appears to be non significant at the 5% level.

The Results.

Table 1.

Dependent Variable : GDP per capita growth rate				
Regression	1	2	3	4
Observations	140	140	140	138
Intercept	5.127 (1.99) **	5.849 (2.14) ***	10.120 (0.87)	6.792 (2.54) **
DUM70	1.396 (3.88) ***	1.183 (3.02) ***	1.392 (3.26) ***	1.346 (2.81) ***
$LGDP_0$	-1.532 (-3.71) ***	-1.729 (-3.99) ***	-1.593 (-3.92) ***	-1.945 (-3.80) ***
$OPEN_t$	0.016 (3.06) ***	0.012 (2.66) ***	0.010 (2.23) **	0.013 (2.79) ***
$LWPOP_t$	0.503 (2.99) ***	0.273 (1.80) *	0.252 (1.37)	0.298 (1.71) *
$GRPOP_t$	-0.628 (-2.19) **	-0.484 (-1.61) *	-0.563 (-2.00) **	-0.354 (-0.84)
$LIFE_0$	0.125 (3.04) ***	0.120 (2.93) ***	0.109 (2.86) ***	0.134 (2.61) **
$INFLA_t$	-0.009 (-2.42) **	-0.010 (-2.38) **	-0.009 (-2.33) **	-0.005 (-1.03)
$GRTT_t$	0.187 (4.83) ***	0.185 (4.69) ***	0.177 (4.51) ***	0.187 (4.42) ***
$REGINVEST_t$		0.088 (1.74) *	0.082 (1.50) *	0.106 (1.67) *
$COMINVEST_t$			-0.169 (-0.39)	
$REGPRIM_t$				-0.017 (-0.95)
$REGSEC_t$				0.012 (0.54)
Adjusted R^2	0.39	0.40	0.41	0.41

Table 2.

Regression	1	2	3	4
F Hausman Test p (H_0)	3.84 (0.00)	3.59 (0.00)	2.58 (0.02)	2.38 (0.03)
F White Test p (H_0)	2.02 (0.02)	2.25 (0.01)	1.75 (0.04)	1.79 (0.03)
F Reset Test p (H_0)	0.14 (0.93)	0.50 (0.68)	0.53 (0.66)	0.90 (0.42)
F Chow Test #1 p (H_0)	0.34 (0.95)	0.48 (0.89)	0.58 (0.84)	0.40 (0.93)
F Chow Test #2 p (H_0)	1.19 (0.30)	1.17 (0.32)	1.30 (0.23)	0.63 (0.81)
F Chow Test #3 p (H_0)	0.53 (0.94)	0.90 (0.59)	0.96 (0.51)	0.94 (0.55)

Table 1 reports four regressions, t-tests are between brackets[7]. Regression 1 is our benchmark regression, the following regressions test the influence of the regional physical capital investment rate on economic growth (regression 2), of the commercial partners' investment rate (regression 3), and regression 4 tests the hypothesis of the influence of the regional human capital influence on economic growth. Table 2 summarizes the main econometric tests results, p-value are between brackets.

The benchmark regression.

Our results share some common features with previous work. First, in all regressions the coefficient of initial per capita GDP is significantly negative as in the works of Barro, 1991 and of Mankiw, Romer and Weil, 1992, so we cannot reject the hypothesis of conditional β-

[7] *** implies the null hypothesis is rejected at the 1% level, ** at the 5% level and * at the 10% level.

convergence between countries. Second, school enrollment ratios are not significant. This result confirms the diagnosis of Barro and Sala-I-Martin (1996) that these variables are not good proxies for the education level. Third, international environment and control variables do have the usual significant effect on economic growth. But, the financial development indicator and the war damages appear non significant.

Regional spillovers effects on economic growth.

The regional investment rate (regression 2) has the expected sign indicating that we cannot econometrically reject our hypothesis of regional spillovers channeled by neighboring physical capital (at the 8% level). Regional economic growth thus has a positive effect on a given country's economic growth. This result is robust and the explanatory power is quite high when compared to similar studies using pooled data. It may not be suspected of being altered by the presence of non exogenous variables as many of the variables are instrumented. The usual econometric tests, given in table 2, show that the main econometric hypotheses are not rejected.

Our results confirm the role played by regional environmental variables on economic growth. Indeed, Chua (1993) also finds that the regional investment rate affects economic growth positively but he does not use an instrumental variables method. The robustness of his results may thus be questioned. In a related line of research, Ades and Chua (1997) find that a regional variable like regional instability does have a significant negative impact on growth. But the theoretical reasons advanced seem to be weaker than those proposed here.

We have noticed that introducing the national investment rate does not add any explanatory power to the regressions. This result is also reported by Barro and Sala-I-Martin (1996) and should be given some explanations. First, the national investment rate is instrumented showing that the authors who obtain a positive correlation between the economic growth and the investment rate using non instrumental methods detect the influence of economic growth on investment and not the reverse (De Long and Summers, 1991). Second, as additional variables are taken into account, the influence of the investment rate on economic growth may be captured by the former variables.

With regression 3, we try to capture the effects of the investment rate of commercial partners. The variable has no effect on economic growth and on other coefficients. It is interesting to note that this result holds even when we eliminate the regional investment rate. This result is consistent with the idea that we really capture the effects of geographical proximity rather than commercial proximity. The former relates economic growth performance to the fact that a country belongs to a specific region and thus may be locked into a low regional economic growth regime. It specifically exists within a regional ensemble. The latter may explain a difference in the performances between countries by the economic impetus stemming from trade flows. It is not specific to a group of countries achieving similar economic growth performances as it can also explain discrepancies between countries experiencing quite significantly different growth rates.

Regional spillovers through regional human capital.

Regression 4 includes the effect of regional school enrollment ratios which are non significant. Two reasons can explain this result. First, the variables are bad proxies for the

level and for the accumulation of human capital. Second, there seems to exist a specific spillover effect channeled by productive capital which contradicts the results of some previous works (Chua, 1993)[8]. Human capital may generate externalities abroad only if it is mobile. Our result favors thus the hypothesis of a limited mobility of human capital within a region[9].

Concluding Remarks.

We have shown that the regional environment may affects the economic growth rate and may results in an undesirable effect identified as a regional underdevelopment trap. This fact can be put forward within a rather general theoretical framework allowing for the existence of multiple equilibria. From an empirical point of view, we have originally shown that regional environment effects are mostly channeled through the investment in physical capital rather than in human capital. Our results are plausible under the hypothesis of the absence of mobility of human capital.

Some policy insights can be inferred. Our results argues in favor of the constitution of regional institutions which may help one country to take advantage of the benefits of regional influence. A regional institution like a regional development bank may be devoted to the design of policies favoring the coordination between investment decisions that can permit to attain a higher steady state corresponding to the high level equilibrium.

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[8] Moreover, this author uses ordinary least squares which quests doubts on his results.

[9] We have also found that the regional economic growth rate does not introduce any additional explanatory power. This result is however not contradicting Easterly and Levine's (1998) who find that the neighbors growth rate affects positively the country growth performance. Indeed, they do not control their results with the neighbors' growth rate. In fact, the non significant effect of the neighbors' growth rate variable seems to show that regional spillovers are mainly transmitted by growth factors like physical capital. The explanatory power of the regional initial GDP per capita depends crucially on whether we introduce it with or without the regional investment rate. When it is introduced alone, it becomes significant as in Barro and Sala-I-Martin (1996). This result reflects the narrow theoretical grounds on which the effect of such a variable is justified.

Appendix A: Regional Per Capita Growth Statistics.

Countries	Period	SSA	LAM	ASIA	DEV	OECD	ALL
Number	70-80	36	29	15	94	24	115
	80-90	44	32	18	110	24	131
Average (%)	70-80	1.271	1.973	3.342	1.968	2.679	2.048
	80-90	0.017	0.772	3.639	0.554	2.305	0.813
Standard Deviation	70-80	2.934	2.288	2.622	3.131	1.457	2.859
	80-90	2.238	3.368	2.890	3.480	1.555	3.251

SSA: Sub Saharan Africa, LAM: Latin America, ASIA: South and East Asia, DEV: Developing Countries.

Appendix B: The Role of Human Capital.

Consider a restatement of the basic model to take into account the effect of human capital. The countries now choose simultaneously their optimal levels of investments in material capital and in human capital. The countries allocate their human capital between production activities and human capital accumulation. This latter technology is capital specific, *i. e.* it only uses human capital. We define h^i_t (resp. h^j_t) the human capital of country *i* (of country *j*) at time *t* which is allocated between production activities and human capital formation $\tilde{h}^i_0$ (resp. $\tilde{h}^j_t$) in the country *i* (resp. country *j*).

The utility function of country *i* thus becomes:

$$\max_{s^i_t, \tilde{h}^i_t} U^i_t = u\left(y^i_t\left(k^i_t, k^j_t, h^i_t - \tilde{h}^i_t, h^j_t - \tilde{h}^j_t\right) - s^i_t\right)$$
$$+(1+r)^{-1} \cdot u\left(y^i_{t+1}\left(k^i_t + s^i_t, k^j_t + s^j_t, h^i_0 + H^i\left(\tilde{h}^i_0\right), h^j_0 + H^j\left(\tilde{h}^j_0\right)\right)\right) \qquad \text{(b1)}$$

such that $s^j_t = \bar{s}_t$ and $\tilde{h}^j_t = \bar{h}_t$.

The first order necessary condition for an optimum level of investment in human capital in country *i* is:

$$\frac{\partial U_t^i}{\partial \tilde{h}_t^i} = 0 \Leftrightarrow -\frac{\partial u_t}{\partial c_t^i} \cdot \frac{\partial y_0^i}{\partial \tilde{h}_t^i} \cdot (-1) + (1+r)^{-1} \cdot \frac{\partial u_{t+1}}{\partial c_{t+1}^i} \cdot \frac{\partial y_{t+1}^i}{\partial \left(h_{t+1}^i - \tilde{h}_{t+1}^i \right)} \cdot \frac{\partial H^i}{\partial \tilde{h}_t^i} = 0 \qquad \text{(b2)}$$

and the second order condition for an optimum is:

$$\frac{\partial^2 U_t^i}{\partial \left(\tilde{h}_t^i \right)^2} < 0 \qquad \text{(b3)}$$

From this maximization program, we derive a reaction function[10] $\tilde{h}_t^i\left(\bar{h}_t\right)$ which describes respectively the optimal investment in human capital response of country *i* when the other countries chooses their own investment in human capital levels $\tilde{h}_t^j = \bar{h}_t, \forall i \neq j$. The symmetric Nash equilibrium is given by $\tilde{h}_t^i\left(\bar{h}_t\right) = \bar{h}_t$. The sign of the slope of the latter expression is given by the following expression:

$$\frac{\partial^2 U_t^i}{\partial \tilde{h}_t^i \cdot \partial \tilde{h}_t^j} = \frac{\partial y_t^i}{\partial \tilde{h}_t^i} \cdot \frac{\partial^2 u_t}{\partial \left(c_t^i \right)^2} \cdot \frac{\partial y_t^i}{\partial \tilde{h}_t^j} + \frac{\partial u_t}{\partial c_t^i} \cdot \frac{\partial^2 y_t^i}{\partial \tilde{h}_t^i \partial \tilde{h}_t^j}$$

$$+ (1+r)^{-1} \cdot \frac{\partial H^i}{\partial \tilde{h}_t^i} \cdot \frac{\partial H^j}{\partial \tilde{h}_t^j} \left(\frac{\partial y_{t+1}^i}{\partial \left(h_{t+1}^i - \tilde{h}_{t+1}^i \right)} \cdot \frac{\partial^2 u_{t+1}}{\partial \left(c_{t+1}^i \right)^2} \cdot \frac{\partial y_{t+1}^i}{\partial \left(h_{t+1}^j - \tilde{h}_{t+1}^j \right)} + \frac{\partial u_{t+1}}{\partial c_{t+1}^i} \cdot \frac{\partial^2 y_{t+1}^i}{\partial \left(h_{t+1}^i - \tilde{h}_{t+1}^i \right) \partial \left(h_{t+1}^j - \tilde{h}_{t+1}^j \right)} \right) \qquad \text{(a4)}$$

[10] We could as well derive two other reaction functions $\tilde{h}_t^i(\bar{s}_t)$ and $s_t^i\left(\bar{h}_t\right)$. Their slope paths depend respectively on the sign of $\frac{\partial^2 U_t^i}{\partial \tilde{h}_t^i \partial s_t^j}$ and of $\frac{\partial^2 U_t^i}{\partial s_t^i \partial \tilde{h}_t^j}$. These latter expressions are positive if the complementarity effects given respectively by the positive second partial derivatives $\frac{\partial^2 y_{t+1}^i}{\partial \left(h_{t+1}^i - \tilde{h}_{t+1}^i \right) \partial k_{t+1}^j}$ and $\frac{\partial^2 y_{t+1}^i}{\partial k_{t+1}^i \partial \left(h_{t+1}^j - \tilde{h}_{t+1}^j \right)}$ dominate the concavity of the utility function.

This expression is positive if the complementarity effects compensate for the concavity of the utility function.

Appendix C: Neighboring Countries.

Countries	Neighbors							
Angola	Zaire	Zambia	Namibia	Congo				
Benin	Nigeria	Togo	Burkina Faso	Niger				
Botswana	South Africa	Zimbabwe	Namibia					
Burkina Faso	Mali	Niger	Ivory Coast	Ghana	Benin	Togo		
Burundi	Tanzania	Rwanda	Zaire					
Cameroon	Nigeria	Chad	CAF	Congo	Gabon	Eq Guinea		
Cape Verde	Senegal							
CAF	Zaire	Chad	Sudan	Cameroon	Congo			
Comoro	Mozambique	Madagascar						
Congo	Zaire	Gabon	Cameroon	CAF	Angola			
Ivory Coast	Liberia	Ghana	Guinea	Burkina Faso	Mali			
Djibouti	Ethiopia	Somalia						
Ethiopia	Sudan	Somalia	Kenya	Djibouti				
Gabon	Congo	Cameroon	Eq Guinea					
Gambia	Senegal							
Ghana	Togo	Ivory Coast	Burkina Faso					
Guinea	Mali	Sierra Leone	Ivory Coast	Liberia	Senegal	Bi Guinea		
Bi Guinea	Guinea	Senegal						
Eq Guinea	Gabon	Cameroon						
Kenya	Uganda	Ethiopia	Tanzania	Somalia	Sudan			
Lesotho	South Africa							
Liberia	Guinea	Sierra Leone	Ivory Coast					
Madagascar	Mauritius	Mozambique						
Malawi	Mozambique	Zambia	Tanzania					
Mali	Mauritania	Algeria	Burkina Faso	Guinea	Niger	Ivory Coast	Senegal	
Mauritius	Madagascar							
Mauritania	Mali	Senegal	Algeria	W. Sahara				
Mozambique	Malawi	Zimbabwe	Tanzania	South Africa	Zambia	Swaziland		
Niger	Nigeria	Chad	Algeria	Mali	Burkina Faso	Benin	Libya	
Nigeria	Cameroon	Niger	Benin	Chad				
Uganda	Kenya	Zaire	Sudan	Tanzania	Rwanda			
Rwanda	Burundi	Zaire	Tanzania	Uganda				
Sao Tome	Nigeria	Cameroon	Gabon	Eq Guinea				
Senegal	Mauritania	Gambia	Mali	Guinea	Bi Guinea			
Seychelles	Tanzania	Madagascar	Kenya	Somalia				
Sierra Leone	Guinea	Liberia						
Somalia	Ethiopia	Kenya	Djibouti					
Sudan	Ethiopia	Chad	Egypt	CAF	Zaire	Uganda	Libya	Kenya
Swaziland	South Africa	Mozambique						
Tanzania	Kenya	Mozambique	Malawi	Burundi	Uganda	Zambia	Rwanda	
Chad	Sudan	CAF	Niger	Cameroon	Libya	Nigeria		
Togo	Ghana	Benin	Burkina Faso					
Zaire	Angola	Congo	Zambia	CAF	Uganda	Sudan	Burundi	Rwanda
Zambia	Zaire	Angola	Malawi	Zimbabwe	Mozambique	Tanzania	Namibia	
Zimbabwe	Mozambique	Botswana	Zambia	South Africa				
Algeria	Morocco	Mali	Libya	Tunisia	Niger	Mauritania		
Saudi Arabia	Yemen	Jordan	Oman	United A.E	Iraq	Kuwait	Qatar	
Bahrein	Saudi Arabia	Qatar						
Egypt	Sudan	Israel	Libya					
United A.E	Saudi Arabia	Oman	Qatar					
Iraq	Iran	Syria	Saudi Arabia	Turkey	Kuwait	Jordan		
Iran	Iraq	Pakistan	Turkey	Ex Ussr	Afghanistan			
Jordan	Saudi Arabia	Syria	Israel	Iraq				

Kuwait	Iraq	Saudi Arabia						
Lebanon	Syria	Israel						
Libya	Egypt	Sudan	Chad	Niger	Algeria	Tunisia		
Morocco	Algeria	W. Sahara						
Oman	Saudi Arabia	United A.E	Yemen					
Qatar	Saudi Arabia	United A.E						
Syria	Turkey	Iraq	Jordan	Israel	Lebanon			
Tunisia	Algeria	Libya						
Yemen	Saudi Arabia	Oman						
Afghanistan	Pakistan	Iran	China	Ex Ussr				
Bangladesh	India	Myanmar						
Bhutan	China	India						
Myanmar	Thailand	India	Laos	Bangladesh	China			
China	Mongolia	Afghanistan	Pakistan	India	Nepal	Bhutan	Myanmar	Laos
	Vietnam	Ex Ussr	North Korea					
Fiji	Papua N.G	Australia	New-Zealand					
Hong-Kong	China							
India	Bangladesh	China	Pakistan	Nepal	Myanmar	Bhutan		
Indonesia	Malaysia	Papua N.G	Philippines	Australia				
Macao	China	Hong-Kong						
Malaysia	Indonesia	Thailand	Singapore	Brunei				
Maldives	India							
Mongolia	China	Ex Ussr						
Nepal	India	China						
Pakistan	India	Iran	China	Afghanistan				
Papua N.G	Indonesia	Australia						
Philippines	Indonesia	Brunei	Vietnam					
Korea	Japan	North Korea						
Salomon Is	Papua N.G	Australia						
Samoa	Papua N.G	Australia	New-Zealand					
Singapore	Malaysia							
Sri Lanka	India							
Taiwan	China							
Thailand	Malaysia	Myanmar	Laos	Cambodia				
Tonga	Australia	New-Zealand	Papua N.G					
Vanuatu	Australia	New-Zealand	Papua N.G					
Antigua & Barbuda	Venezuela	Dominican Rep						
Argentina	Chile	Paraguay	Brazil	Bolivia	Uruguay			
Bahamas	USA							
Barbados	Trinidad & Tobago							
Belize	Mexico	Guatemala						
Bolivia	Brazil	Peru	Chile	Argentina	Paraguay			
Brazil	Bolivia	Venezuela	Colombia	Peru	Paraguay	Argentina	Uruguay	Surinam
	Guyana							
Chile	Argentina	Bolivia	Peru					
Colombia	Peru	Venezuela	Brazil	Ecuador	Panama			
Costa Rica	Panama	Nicaragua						
Cuba	USA	Mexico	Haiti	Jamaica				
Dominica	Venezuela	Dominican Republic						
El Salvador	Honduras	Guatemala						
Ecuador	Peru	Colombia						
Guatemala	Mexico	Honduras	El Salvador	Belize				
Guyana	Brazil	Venezuela	Surinam					
Haiti	Dominican Republic							
Honduras	Nicaragua	El Salvador	Guatemala					
Jamaica	Haiti	Cuba						
Mexico	USA	Guatemala	Belize					
Nicaragua	Honduras	Costa Rica						
Panama	Costa Rica	Colombia						
Paraguay	Argentina	Brazil	Bolivia					
Peru	Colombia	Brazil	Ecuador	Bolivia	Chile			
Puerto Rico	Dominican Republic							

Dominican Republic	Haiti							
St Christopher	Dominican Rep	Venezuela						
St Lucia	Dominican Rep	Venezuela						
St Vincent	Venezuela							
Surinam	Guyana	Brazil						
Trinidad & Tobago	Barbados	Venezuela						
Uruguay	Brazil	Argentina						
Venezuela	Brazil	Colombia	Guyana					
Cyprus	Turkey	Syria	Lebanon					
Turkey	Syria	Ex Ussr	Iran	Iraq	Bulgaria	Greece		
South Africa	Botswana	Namibia	Lesotho	Mozambique	Swaziland	Zimbabwe		
Germany	Austria	Netherlands	France	Switzerland	Belgium	Luxembourg	Denmark	Czekos
Australia	New-Zealand	Indonesia	Papua N.G					
Austria	Germany	Czekos	Switzerland	Hungary	Liechtenstein	Italy	Yugoslavia	
Belgium	France	Netherlands	Germany	Luxembourg	U.K			
Canada	USA							
Denmark	Germany	Sweden						
Spain	Portugal	France						
USA	Canada	Mexico						
Finland	Norway	Sweden	Ex Ussr					
France	Spain	Belgium	Switzerland	Italy	Germany	Luxembourg	Monaco	U.K
Greece	Turkey	Bulgaria	Yugoslavia	Albania				
Ireland	U.K							
Israel	Egypt	Jordan	Syria	Lebanon				
Italy	Switzerland	France	Austria	Yugoslavia				
Japan	Korea	China						
New-Zealand	Australia	Fiji						
Norway	Sweden	Finland	Ex Ussr					
Netherlands	Germany	Belgium	U.K					
Portugal	Spain							
U.K	Ireland	France	Belgium	Netherlands				
Sweden	Norway	Finland	Denmark					
Switzerland	Italy	France	Germany	Austria				

CAF: Central African Republic, Czekos:

Appendix D: Definition of Variables.

$LGDP_0$	Log of initial real per capita GDP
$LIFE_0$	Life expectancy at birth
$PRIM_0$	Primary school enrollment rate
SEC_0	Secondary school enrollment rate
$GRTT_t$	Current terms of trade growth rate
$INVEST_t$	National investment rate
$REGINVEST_t$	Regional investment rate
$REGPRIM_t$	Regional primary school enrollment rate
$REGSEC_t$	Regional secondary school enrollment rate
$REGGRGDP_t$	Regional per capita GDP growth rate
$REGGDP_0$	Regional initial per capita GDP
$INFLA_t$	Current inflation rate
$OPEN_t$	Commercial openness
$LWPOP_t$	Potential working-age population (15-65 years old)
$GRPOP_t$	Population growth rate
$MONEY_t$	Financial development (money supply /GDP)
WAR_t	War damages
DUM70	1970-80 : 1, 1980-90 :0

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