

# Natural Disasters and the Dynamics of Intangible Assets

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Sustainable Development Network  
Global Facility for Disaster Reduction and Recovery Unit  
March 2009



## Abstract

Empirical evidence suggests that the higher-order effects of natural disasters, which affect intangible assets, may be even more important than the material inter-industry effects. However, most existing general equilibrium models ignore higher order effects concerning human capital. Moreover, it is recognized that natural resource dependence increases vulnerability to natural disasters. Recent studies have indeed shown the potential importance of subsistence traps caused by asset losses in low-income economies from a partial equilibrium perspective.

This paper presents an analysis that allows for endogenous investments in real assets (physical capital) as well as in human capital, explicitly considering the potential for subsistence traps arising from minimum consumption and minimum natural resource irreversibility thresholds. The general equilibrium

ramifications of subsistence traps are developed. The main issue is that the economy may be subject to hysteresis: A temporary shock such as a natural disaster may leave permanent consequences for the economy. An obvious permanent effect of a one-time disaster shock is that physical man-made and natural assets owned especially by poor households may end up completely wiped out. The disaster may not be the direct cause; it may be that poor households would have to obtain minimum subsistence consumption out of depleted assets. However, not all permanent effects of a one-time shock are negative. Under certain conditions, the destruction of man-made physical and natural capital may have general equilibrium effects that increase the incentives to invest in human capital and may even propel a formerly stagnating economy into a virtuous path of continuing growth.

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This paper—a product of the Global Facility for Disaster Reduction and Recovery Unit, sustainable Development Network Vice Presidency—is part of a larger effort in the department to disseminate the emerging findings of the forthcoming joint World Bank-UN Assessment of the Economics of Disaster Risk Reduction. Policy Research Working Papers are also posted on the Web at <http://econ.worldbank.org>. The team leader—Apruva Sanghi—can be contacted at [asanghi@worldbank.org](mailto:asanghi@worldbank.org), and the author of this paper at [rlopez@arec.umd.edu](mailto:rlopez@arec.umd.edu). We thank Apruva Sanghi and participants at the World Bank for useful comments.

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**Natural Disasters and the Dynamics of Intangible Assets**

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# Natural Disasters and the Dynamics of Intangible Assets

A growth theoretic understanding of the long-run impacts of natural disasters is still at an early stage. In a recent survey paper, Okuyama (2009a) concluded that the lack of theoretical formalization has been a factor preventing the integration of the economics of disasters into general development theory and has affected our ability to understand more comprehensively the implications of disasters. The present paper can be regarded as a contribution in this direction. The theoretical model proposed here incorporates important empirical stylized facts about disasters and integrates certain specific observations in the literature – which hitherto have remained as interesting but isolated insights – into a comprehensive macro growth framework.

This paper focuses on the dynamics of intangible assets in the aftermath of disasters. It shows that the dynamics of human capital and natural resources play an important role affecting the patterns of recovery and potential long-run growth effects of disaster shocks<sup>1</sup>. Recent studies have shown that in normal times public policy in a large number of countries, especially middle-income ones, tends to prioritize investments in physical assets to the detriment of investments in intangible assets (World Bank, 2000; López and Toman, 2006). These biases may be a source of economic inefficiency because, in contrast with tangible assets, intangible assets tend to be affected by serious market imperfections which reduce the incentives of the private sector to invest in such assets. A public policy bias in favor of tangible assets is particularly notorious in the allocation of government expenditures (López, Thomas and Wang, 2008). Governments tend to allocate a large share of government expenditures to private goods in the form of subsidies favoring either investment in tangible assets or consumption of the elites and insufficient expenditures to public goods including education, health care, R&D, environmental protection and other intangible assets. López and Islam (2008) have shown that these public spending biases are costly; countries that spend the most in private goods tend to grow much slower over the long run than countries that are less affected by such biases.

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<sup>1</sup> In a literal sense natural resources are tangible but we consider them intangible in the economic sense because they are often undervalued due to institutional and market failure.

A key consequence of this pro-tangible asset public policy bias is that over the long run a distortion in the asset composition of the economy emerges; the tangible/intangible asset stock ratio becomes too high. For reasons to be clarified below, this distortion further reduces the incentives to the private sector to invest in human capital and other intangible assets. But the fact that intangible assets grow little also implies that the incentives to invest in physical assets also decline over time. Growth then becomes increasingly dependent on continuous increases of government subsidies to promote tangible asset investment, which in turn forces the government to devote an ever increasing fraction of the expenditures to private goods. That is, the asset distortion may be self-reinforcing meaning that it tends to grow deeper over time ultimately becoming an obstacle for economic growth.

We show that a natural disaster that affects more tangible than intangible assets may have an important silver lining effect: It may reduce the asset distortion and thus promote faster economic growth. The issue is whether or not the same biases that affect public policy in normal times are present in the aftermath of major disasters. Some empirical evidence suggests that in some countries this has been the case but not in others. Thus, while natural disasters can have dramatic negative effects on the *level* of per capita income they can also represent an opportunity that nature provides to mitigate the effects of past policy distortions; natural disasters may correct a distorted asset structure created by misguided public policies. We show below that if governments do not insist in repeating the policy biases of the past, natural disasters that reduce the tangible/intangible asset ratio may trigger an increase of the rate of per capita income *growth* over the long run. By contrast, disasters that affect more intangible than tangible assets may exacerbate the asset distortion and thus be a loss-loss phenomenon by causing both a reduced level and reduced long run growth of income.

We show that disasters, even if they affect merely a segment of the economy, can have important economy-wide ramifications by affecting the post-disaster dynamics of both human capital and natural resources. An important finding mostly ignored in the literature is that the nature of capital markets is an important determinant of the effects of disasters. We alternatively consider two economies: (i) one with undeveloped capital markets and where the production of new human capital is mainly provided by the state (the “poor” economy); (ii) one with fully developed capital markets which allows the for-profit private sector to contribute to the production of new human

capital (the “middle-income” economy). The results of the analysis generally confirm at the economy-wide level the findings of recent empirical analyses at the micro level: The efficiency of capital markets (and labor markets) is a key determinant of the extent of the impact of productivity shocks on rural households’ income (Jayachandran, 2006; Gitter and Barham, 2008).

Several papers have emphasized the importance of system-wide impacts of disasters through material inter-industry relationships; these are the so-called higher order effects (Rose, 2004)<sup>2</sup>. Previous studies have provided indirect empirical evidence suggesting that higher order effects affecting intangible assets such as human capital may be even more important than the material inter-industry effects (Skidmore and Toya, 2002). However, most existing general equilibrium models ignore higher order effects concerning human capital<sup>3</sup>. Moreover, there is ample recognition that natural resource dependence increases the vulnerability of the economy to disasters (Benson and Clay, 2004). Recent studies have shown the potential importance of subsistence traps caused by losses of natural resources and productive capital in low income economies exclusively from a partial equilibrium perspective (Carter et. al., 2007).

Unlike previous studies the present paper evaluates the role of natural resource dependence and human capital investment from a general equilibrium dynamic perspective. We develop a dynamic general equilibrium model that provides a framework to rigorously analyze the behavior of an economy after a disaster shock. In contrast with standard computable general equilibrium models (CGEs), the model developed here is analytical and simple enough to be tractable, permitting the identification of the mechanisms at work and the derivation of comparative dynamic predictions about various effects of disaster shocks. The analysis allows for endogenous investments in “real” assets (i.e., physical capital) as well as investments in human capital explicitly considering the potential for subsistence traps arising from both minimum consumption and minimum natural resource irreversibility thresholds. The general equilibrium ramifications of subsistence traps are

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<sup>2</sup> For example if a power company’s production facility is damaged by a natural hazard, the production loss is specific to the production company. Other firms that use the electricity may not be directly damaged but may suffer large losses as a consequence of power disruptions.

<sup>3</sup> See Okuyama, 2008a for a critical review of the methodologies used for the literature for the estimation of the economic impact of disasters; also, Okuyama, 2008b uses input-output and social accounting matrix methodologies to analyze 10 disaster cases, none of which includes human capital.

emphasized. The paper summarizes certain key empirical stylized facts of disasters available in the literature, shows that the predictions of the model developed here are mostly consistent with these empirical stylized facts, and contributes to developing further explanations for some.

## I. EMPIRICAL EVIDENCE AND STYLIZED FACTS OF DISASTERS

In this section we present some of the empirical evidence available which is relevant to our analysis. The literature reports two types of empirical evidence: (i) Robust evidence on which there is a degree of consensus in the literature. (ii) Weak evidence on which there is no agreement in the literature; these are often contradictory findings across studies and across disasters. We use the robust evidence to provide certain empirical underpinnings that justify some of the assumptions used in the conceptual model provided in the next sections. Then the results and predictions of the analysis are used to shed light on the conditions under which we expect the various conflicting outcomes reported in the literature as part of evidence (ii) above.

The contradictory empirical evidence is in part due to the poor quality of the information available especially of the cross country data. These data is in general too blunt to allow us to identify effects of disasters which generally affect only a portion of the country. In other cases even micro based data provide decidedly inadequate indicators. This data inadequacy means that empirical studies are unlikely to elucidate certain effects of disasters. This gives even more prominence to the need for a rigorous theoretical analysis that can capture at least a subset of the key complexities of reality. Such a model could be regarded as complementary with empirical studies, especially of aspects on which the quality of the empirical information is rather poor.

*1. Long-run impact of disaster shocks on economic growth.* An important stylized fact is that disasters, while causing significant one-time reductions on assets and per capita income, do not necessarily reduce long-term economic growth. In fact, three of the greatest known disasters, the 1960 earthquake in Chile (9.5 Richter scale), the 1998 hurricane Mitch in Honduras, and the 2004 earthquake and Tsunami in the province of Aceh in Indonesia, have apparently had very different consequences for long-run economic growth. All three disasters affected a significant segment of the population and devastated an important part of the productive capital. While the Chile disaster caused no discernible

long-run effect on economic growth or on real wages over the next ten years (Coeymans, 1999; De Gregorio, 2005; Cenda, 2007), the post-disaster rate of economic growth in Honduras is somehow lower than the rates prior to the disaster, and the province of Aceh appears to have been able to increase economic growth over the three years after the Tsunami (Blanco Armas et al. 2008). Table 1 shows the vastly heterogeneous performance of per capita GDP growth before and after major disasters for selected countries.

Studies on the (ex-ante) impact of the expectation of periodic but not necessarily devastating disasters as opposed to the ex-post effect of one massive disaster as the cases mentioned above also provide contradictory findings. Skidmore and Toya (2002), for example, find that a higher probability of climatic disasters is associated with a faster rate of economic growth, a phenomenon that the authors attribute to “creative destruction” caused by disasters (an acceleration of the adoption of technologies embodied in physical capital caused by the need to replace such capital). However, Cuaresma et al. (2008) and Rasmussen (2004) found that this hypothesis appears to be relevant only to middle-income and developed countries. Still another study finds that the impact of disaster proneness on economic growth is mixed with large disparities depending not only on the level of development of the country but also on country size and type of disaster<sup>4</sup>.

A more recent study examines the effects of disasters on sector growth rather than merely on aggregate growth for the whole economy (Loayza et al., 2009). This is important because disaggregate sector output measures are likely to be more sensitive to disasters (which often affect more intensively particular sectors) than the usual aggregate GDP measures. Table 2 summarizes their findings; in general they find that disasters that reduce the capital/labor ratio are likely to be followed by faster sector growth while events that increase the capital/labor ratio are more likely to be followed by slower sector growth. The empirical association between the consequences of disasters for economic growth and for the asset ratio of the economy that these authors unearthed is particularly important; as can be seen below the model that we develop here predicts and explains precisely this outcome.

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<sup>4</sup> Meanwhile Bluedorn (2005) argues that the development of a country is inhibited by the constant exposure to hurricanes since these represent large negative capital shocks which can consistently impoverish a country.



2. *Long-run impacts on human capital.* The same degree of ambiguity plagues the analysis of the impact of disasters or disaster proneness on human capital. Certain empirical analyses have found that human capital increases as a consequence of disasters (Skidmore and Toya, 2002). However, other authors have reached opposite conclusions (Benson and Clay, 2004). Skoufias (2003) and Poop (2006) argue that human capital accumulation may decrease or increase after disasters depending on the role of the wage as a measure of the opportunity cost of potential students or as a measure of income affecting the ability of financially constrained households to afford human capital investments.

A possible reason for this disparity of empirical results is that the quality of the empirical proxies used for human capital is questionable at best. School attendance or years of education are woefully inadequate indicators of cognitive levels as recognized in the recent literature (Wößmann, 2003; De la Fuente and Doménech, 2006; Hanushek and Wößmann, 2008).

Another important issue concerns the magnitude of the losses of human capital. With the exception of mega disasters, direct losses of human life are not dramatic. However, in countries with a long tradition of international emigration (e.g., Central Americans in the USA), major disasters may cause a significant emigration response (UNDP, 2006, Benson and Clay, 2004). This is likely to have significant effects on human capital assets in the country especially given that migrants are often those with above average skill levels (Docquier and Marfouk, 2006, Mishra, 2006). Table 3 compares the post-disaster losses of human capital and physical capital for two cases for which these data are available, Japan (Kobe 1995) and Honduras (Mitch 1998). In Kobe the loss of population (due to deaths and out-migration) was minimal compared to the losses of physical capital. While in Honduras the human losses were much larger than in Kobe, still the losses of capital were much greater. That is, even in a country where the population has shown high proclivity to migrate mainly to the USA the losses of physical capital tend to be much greater than the labor losses<sup>5</sup>.

3. *Nature and distribution of damages.* Not all geographic areas of the countries are equally affected by disasters. The greatest effects tend to concentrate in particular areas which are more vulnerable to

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<sup>5</sup> Of course we are not claiming that this is always the case. As it is implicit in Loayza et.al. (2009), there are apparently cases where the human losses have been closer to those affecting physical capital.

disasters and where often most of the poor live (World Bank, 2003, Benson and Clay 2004). Disasters only rarely affect a whole country; Honduras Mitch is probably the one disaster that came closest to affecting the whole country's territory and population. But even in Honduras the effects were much more intense in certain rural areas than in the major cities. As can be seen in the sample of events presented in Table 4, with the exception of Honduras, even massive disasters have tended to affect less than 25% of the country's population. The greatest and most massive earthquake ever measured- Chile 1960- which caused damages and death in as far away as Japan and the Pacific Islands, affected mainly one-third of the country, while the rest was basically unscathed.

A related issue is that most disasters in rich and middle-income countries destroy much more physical capital than human capital. Human lives are usually spared in these countries because prevention mechanisms are in place to protect lives and physical capital tends to be highly concentrated to exploit economies of agglomeration which means that the potential for physical capital destruction is higher than in the case where it is more dispersed. By contrast, in poor countries the disasters affect human lives more with somehow lower damage to physical capital which is scarcer in the first place and is much more geographically dispersed than in developed countries (ADPC, 2005). Natural capital is affected in similar ways in both poor and rich countries but poor economies tend to be much more dependent on natural capital as a productive asset than rich countries.

Often the most serious impacts of disasters fall upon the poor, mainly the rural poor (World Bank, 2003, Benson and Clay 2004). Table 4 illustrates this tendency for selected cases where the information for the sector impact of disasters has been quantified. As can be seen in the table, most disasters have affected much more intensely the agriculture, fisheries and forestry sectors than the more modern enterprise sector. The rural poor tend to live in vulnerable areas and they are economically most dependent on natural resources for their survival. Several authors have pointed out that the vulnerability of the poor relates not only to their geographic location but also to the likelihood that the incomes losses caused by the disaster may propelled them into poverty traps ultimately rendering them destitute, unable to sustain themselves over the long run. Carter et al., 2007, provide micro empirical evidence for this phenomenon for Honduras and Ethiopia (see also IMF, 2003; Hallegate and Dumas, 2009).

4. *Government responses.* In general government responses in part depend on the extent of foreign aid that they receive. However, studies have shown that in most cases government reallocate expenditures in a major way for the next few years after the disaster (Table 5). Government expenditures are often redirected from recurrent to capital expenditures (Benson and Clay, 2004). This reallocation may cause significant disruptions in the provision of vital government services, especially in the provision of human capital services and other intangible assets (Molina et al., 2009). In general, governments emphasize infrastructure rebuilding as a top priority while human capital and natural capital rebuilding receive less attention. Graphic 1 illustrates this for the case of Aceh.

## II. POLICY BIASES IN NORMAL TIMES

In this section we look at certain public policies during normal times that in the end may significantly condition the economy's response to disaster shocks. In normal times public policy in a large number of countries, specially middle income ones, tend to prioritize growth in physical assets to the detriment of intangible assets (World Bank, 2000; López and Toman, 2006). These policies may exacerbate rather than reduce the losses associated with the most ubiquitous market failures such as those related to imperfect property rights and capital market imperfections. As shown by López and Islam (2008) these market imperfections tend to have a much greater impact on investments on intangible assets than on physical capital. As a consequence of these market failures countries tend to under invest in intangible assets and over investment in physical capital relative to intangible assets. Public policies biased in favor of physical capital thus exacerbate these asset distortions often magnifying the efficiency losses associated with market imperfections.

The public policy bias in favor of tangible assets is particularly notorious in the allocation of government expenditures (López, Thomas and Wang, 2008). Governments tend to spend too much in private goods in the form of subsidies favoring either investment in physical capital or consumption of the elites and too little in public goods including education, health care, R&D, environmental protection and other intangible assets. Graphic 2 shows the shares of government spending in public goods broadly defined to include spending in human capital, environmental protection, knowledge creation, social subsidies, as well as other conventional public goods over the period 1985-2005 for a sample of middle income countries. As can be seen in the graphic, while

some countries such as Costa Rica, Uruguay and Chile devote a large fraction of government spending to public goods, most of the countries considered spend a much smaller fraction in public goods, many of them less than 50%. That is, they spend a large fraction of the government budgets in non-social subsidies which as shown by López, Thomas and Wang (2008) are mainly geared to subsidize large corporations and the income of the elites. Table 6 provides more details about the evolution of government spending for four countries, China, India, Brazil and Chile. The table shows the share of expenditures in items that can be clearly identified as subsidies to the elites (the “Type B” expenditures); all four countries spend a large fraction of the budget in such subsidies. Table 7 shows that in several countries just fuel subsidies absorbed an inordinate part of the government total expenditures. Government spending in private goods thus tends to crowd out spending in public goods.

The impact of these policy biases is reflected in the dynamics of the various assets over time. In general the development of asset growth accounting data is still in its early stage. However, with the limited information available one can at least get an idea of the asset growth for certain countries, especially middle-income and high income countries which tend to have a better informational base. Table 8 compares the growth rates of tangible versus intangible assets for a sample of countries in Latin America over the 1990-2001 period. The table shows that while in all but two countries tangible assets (physical capital) exhibit positive per capita growths, in all but two countries intangible assets have experienced declines. Obviously there is no reason to believe that asset growth should be balanced (although a key tenet of endogenous growth theory is to postulate balanced asset growth as an optimal equilibrium condition) but such a big disparity in asset growth over a relatively long period of time and for all countries is likely to reflect economic inefficiency.

Table 9 shows a more aggregate picture of the disparities between growth in physical versus human capital for a large sample of middle-income and high-income countries based on recent data of wealth indicators developed at the World Bank. The physical versus human capital gap is particularly large among lower middle income countries where the growth rate of physical capital almost doubles the rate of growth of human capital. These indicators tend to overestimate the true growth of human capital because they do not account for the qualitative aspects of education. In general countries are able to increase school enrollment quite often but the goal of education quality

improvements is much more elusive. Table 10 provides a glimpse at this issue. It presents data on international test scores for the six developing countries that have participated in such tests and six upper-middle-income countries. Of the 11 countries which have participated in the tests in 2000 and the year 2005 only four exhibit a significant test score improvement between the two years while the rest have either experienced pronounced declines or have remained basically stagnant. While this is a small sample, it does illustrate how seemingly successful countries when judged by the standard measures of economic growth such as Spain, Mexico, Ireland, Brazil and Greece do not seem to be making any progress in increasing the quality of education. This may reflect under investment in human capital, an important intangible asset.

The evidence provided above, while certainly not conclusive, seems to be consistent with the idea that a large number of countries appear to excessively focus in the accumulation of tangible assets to the detriment of intangible assets, particularly human capital and natural capital. Past distortions affecting the allocation of government spending as well as other public policies that tend to bias the incentives in favor of tangible assets materialize over time in a progressively more unbalanced asset composition of the economy. Many economies may reach a tangible to intangible asset ratio that is so distorted that becomes an obstacle to economic growth. López and Islam (2008) have in fact provided a vast volume of econometric evidence showing that these public spending biases are indeed costly. The higher the share of spending in public goods the higher is economic growth over the long run. This confirms the notion that, on average, countries overspend in private goods and under-spend in public goods. One can conclude that if the reason why growth decelerates in countries that overspend in promoting tangible assets to the detriment of intangible ones is the asset ratio distortion that such policies incubate, natural disasters that affect mostly the tangible assets may in fact contribute to reduce such distortion and hence allow for faster economic growth over the long run.

### **III. THE MODEL**

In Section I we have shown that the empirical evidence on the effects of disasters is in certain respects conflictive (i.e., facts 1 and 2 in Section I) while it is far more consistent in other aspects (i.e., facts 3 and 4). The structure of the model presented below reflects the later group of stylized

facts. At the same time the model is designed to be flexible enough to allow for alternative effects of disasters concerning the first group of stylized facts, trying to identify conditions that could be at the source of the empirical ambiguities and lack of robustness of existing empirical analyses.

We alternatively consider two types of economies: (A) A “*poor*” economy where the capital market is not well developed and where only the state is allowed to invest in human capital. The main implication of the former assumption is that the household-producer and enterprise sectors are only connected via the labor market. Capital flows between the two sectors are not possible or are severely restricted. (B) A “*middle-income*” economy which is identical to the poor one except that the capital market is assumed to be well developed and that the human capital sector is open to the for-profit private sector. It turns out that these two distinctions between poor and middle income are of great significance for the evaluation of the effects of shocks affecting the economy, including the effects of disasters<sup>6</sup>.

A main reason to allow for this dichotomy is based on recent empirical evidence which suggests that the impact of disasters is linked quite closely to the existence of capital markets. Micro studies of rural households by Carter et. al. (2007), Gitter and Barham (2007), and Jayachandran (2006), for example, have found that when capital markets are well developed the economic effects of disaster shocks tend to be smaller than when they are imperfect or non-existent.

The model considers the existence of three productive sectors in the economy, a *household-producer sector*, an *enterprise sector*, and a *sector producing human capital*. The *household-producer sector* has two characteristics: (i) it produces natural resource-intensive commodities using labor-intensive technologies; (ii) the household-producers are generally poor, many of them operating near a subsistence threshold caused by non-convexities associated with the existence of minimum subsistence consumption limits and/or with ecological irreversibility limits.

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<sup>6</sup> As can be seen in Table 11, there is a great diversity among developing countries on the participation of the private sector in the provision of education, from levels below 7% of the total school enrollment in countries such as Perú to over 33% in Korea.

Consistent with Stylized Fact 3, the household-producer sector is mainly located in rural areas spread across a wide geographic area. This means that a particular disaster may not affect all households with the same intensity. To capture this we assume that the  $N$  household-producers are distributed in two separate geographic regions. This allows for a disaster to have differential effects upon the households located in each of the two regions.

The *enterprise sector* constitutes the modern sector of the economy which produces industrial goods and services (i.e., financial services, retailing, etc.) that are mainly capital intensive. To sharpen the focus of the analysis, we assume that this sector is not directly dependent on natural resources. Moreover, consistent with empirical fact 3 in Section I, the enterprise sector tends to be much more concentrated geographically than the household-producer sector; to emphasize this important distinction, we assume that the enterprise sector is located in just one geographic area.

In the poor economy case the household-producer sector is linked to the enterprise sector exclusively through the labor market as household members work both on their own operations as well as salaried workers in the enterprise sector. In the middle income economy case the links between the household sector and the rest of the economy occur not only through the labor market but also through the capital market as in this case households may save in or borrow from the rest of the economy<sup>7</sup>.

In the poor economy the *human capital sector* is mainly in the hands of the state who invests part of the tax revenues on equipment and materials for schools, universities, hospitals and related activities and in hiring manpower. In the middle economy with effective capital markets, the private sector also contributes to the production of human capital in an important way. This sector produces new human capital, part of which replaces the human capital depreciated in each period and part of it may contribute to net increases in human capital. We follow Lucas (1988) and many others in assuming that human capital increases the effective manpower time. Increasing human capital is as if the number of effective hours of work of the labor force increased. That is, human capital is labor augmenting, with the effect of increasing the wage per hour if labor markets are competitive as we

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<sup>7</sup> In this case the household-producers can freely invest in bonds issued by the rest of the economy but their borrowing is subject to rationing (more on this issue below).

assume. To focus the analysis on the role of human capital, we assume that the total (physical) labor force is exogenous but the *effective* labor force is endogenous and may increase as human capital increases.

We assume that the economy is small and open to international trade in goods but not in primary factors of production. The main implication of this is that the prices of the various outputs produced as well as traded intermediate inputs are exogenously given. Domestic factor prices are, however, endogenously determined within the economy. International labor migration may occur but we assume that migration flows are constrained so that domestic factor prices are nonetheless endogenous.

### ***The household-producer sector***

*Production activities.* Households produce primary commodities ( $Q_A$ ) combining man-made capital and labor with natural resources:

$$(1) \quad Q_A = nF(k_A, hl_A),$$

where  $n$  is the stock of renewable natural resources;  $k_A$  and  $l_A$  are the levels of household capital and labor, respectively;  $h \geq 1$  is a labor efficiency (or labor “augmentation”) factor related to the level of human capital (see below for more details on this); the function  $F(k_A^1, hl_A^1)$  is assumed to be increasing, concave and linearly homogenous. The production function (1) corresponds to the specification often used in the literature of renewable natural resources (Schaeffer, 1957, Gordon 1954). For a given stock of natural resources,  $n$ , the level of production is proportional to the level of effort represented by  $F(k_A, hl_A)$ .

*Resource dynamics.* The stock of renewable resources is not necessarily constant; its dynamics is of course affected by the level of output extracted as follows:

$$(2) \quad \dot{n} = g(n) - \phi nF(k_A, hl_A),$$



where  $g(n)$  is the rate of natural renewal of the resource and  $1 > \phi > 0$  is a parameter reflecting the impact which production has on the natural resource. The natural renewal function is subject to threshold effect;  $g(n \leq \underline{n}) = 0$ , where  $\underline{n}$  is the minimum level of the natural resource stock that allows its regeneration. We use a generalization of the popular logistic specification of the natural resource renewable function that allows for irreversible threshold to occur at positive levels of  $n$  (Clark, 1990),

$$(2') \quad g = \gamma_1 n - \gamma_2 n^2 - \gamma_0,$$

where  $\gamma_i$  ( $i=1,2,3$ ) are all positive parameters. The logistic specification used in the literature assumes that  $\gamma_0 = 0$ , which seems like an innocuous assumption but effectively it precludes the possibility that the natural resource be affected by irreversible thresholds at positive levels of  $n$ . The natural resource renewable capacity (represented by the function  $g(n)$ ) becomes zero at two levels of  $n$ :

$$(2'') \quad \underline{n} \equiv \frac{\gamma_1 - [\gamma_1^2 - 4\gamma_0\gamma_2]^{1/2}}{2\gamma_2} \quad \text{and} \quad \bar{n} \equiv \frac{\gamma_1 + [\gamma_1^2 - 4\gamma_0\gamma_2]^{1/2}}{2\gamma_2},$$

where  $\underline{n}$  is the minimum threshold limit so that if  $n \leq \underline{n}$  the system cannot recover, and  $\bar{n}$  is the maximum carrying capacity. It is clear from (2'') that  $\bar{n} > \underline{n}$ <sup>8</sup>.

We assume that property rights on the natural resource are not defined which means that households exploit the resource in open access. This implies that households do not care about the impacts of their decisions on the evolution of the natural resource stock, but of course the evolution of the natural resource impacts their productivity.

*Household revenue.* Households maximize revenues conditional on a given stock of productive capital. Households' capital is fixed in the short run but they can affect capital stocks over the intermediate

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<sup>8</sup> In the conventional logistic specification (with  $\gamma_0 = 0$ ) it follows that  $\underline{n} = 0$  and  $\bar{n} = \gamma_1 / \gamma_2$ .

run through investment. The revenues obtained by the households are also affected by the stock of natural resources. Finally, households have access to the labor market and thus the opportunity cost of their labor (in efficiency units) is equal to the prevailing market wage rate,  $w$ . That is,  $w$  is the marginal value product per *efficiency* work time,  $hl$ , and thus the wage per actual time of work is  $wh$ .

We can now define a revenue function for the household-producer conditional on particular levels of  $n$  and  $k_A$  assuming that the household optimally chooses the level of labor used (which is not of course necessarily equal to its own labor supply as it can freely be a net buyer or seller of labor):

$$(3) \quad R \equiv \max_{l_A} \{ pnF(k_A, hl_A) - whl_A \} = r(np, w)k_A$$

where  $p$  is the commodity output price.  $R$  is thus the total revenue accruing to the stock of capital owned by the household.

Given that the function  $F(k_A, hl_A)$  is linearly homogenous, the revenue function is a linear function of the total capital stock,  $r(np, w)k_A$ . The function  $r(\cdot)$  can be interpreted as the returns per unit of capital, which must be increasing in the output prices and decreasing in the wage rate, homogenous of degree one and convex in its arguments (Diewert, 1981). We note the particular way in which the stock of the natural resources,  $n$ , enters into the revenue function, which means that the revenue function is increasing in the stock of natural resource.

*Geography and the aggregate revenue function.* Households are located in two regions. The sector's capital stock is thus distributed between say regions 1 and 2. The total number of households is  $N$  of which a proportion  $\varepsilon$  is located in region 1 and  $1-\varepsilon$  in region 2. Without loss of generality we pick the units so that  $N=1$ . Thus, we can represent the aggregate capital stock of the two regions as  $k_A = \varepsilon k_A^1 + (1-\varepsilon)k_A^2$ , where  $k_A^i$ ,  $i=1,2$  are the stocks of capital owned by the producers in each region. We assume that producers in each region have identical production functions and, prior to the disaster, have access to the same level of natural resources. This implies that the two functions

$r^i(\cdot)$  ( $i=1,2$ ) are identical across regions. Hence, the total revenue of the two regions combined,  $r^1(\cdot)\varepsilon k_A^1 + r^2(\cdot)(1-\varepsilon)k_A^2 = r(\cdot)k_A$ , is precisely equal to  $R$  as defined in (3).

*Output supply and the demand for effective labor.* As shown by Diewert (1981), the so-called Hotellings lemma applies, meaning that the optimal output supply and labor demand functions can be directly derived from the revenue function as,

$$(4) \quad Q_A = r_1(np, w)Ank_A$$

$$(5) \quad hl_A = -r_2(np, w)k_A,$$

where  $r_j(j=1,2)$  indicate first derivatives with respect to the corresponding argument. We note that  $hl_A$  is the total labor in efficiency units used by the households, which may be higher or lower than the total labor available in the household (which we denote as  $hL_A$ ) depending on whether the household is a net buyer or net seller of labor. However, the household sector as a whole must be a net seller of labor as it supplies the labor used by the rest of the economy. Thus, using the parable of the representative household we assume that  $L_A > l_A$ . Convexity of the revenue function implies that  $r_{ii} > 0$  which in turn means that the output supply functions are increasing in their respective output prices and that the labor demand is decreasing in the wage rate.

*Household income and capital accumulation.* The household's income is comprised by the returns to its capital ( $r(np, w)k_A$ ) plus the returns to its owned labor,  $whL_A$ , minus the net (lump-sum) taxes that it pays. The total labor time of the household is equal to the total household time,  $L$ , minus the portion of the household time that is devoted to acquiring new skills,  $l_H$ ; thus  $L_A = L - l_H$ . By the time being we consider  $l_H$  and hence  $L_A$  as given, but in the next section we study how  $l_H$  is determined. Thus, the total household income is

$$(6) \quad Y \equiv r(np, w)k_A + wh(L - l_H) - \eta T.$$

Where  $\eta T$  a lump-sum tax is collected on the household-producers;  $T$  is equal to the total lump sum taxes collected by the government throughout the economy, and  $\eta$  is the fraction of the total tax revenues which the household-producer sector is required to contribute. In (6) the term  $L - l_H$  is the total labor time that the households devote to work for the rest of the economy as salaried workers. That is,  $L - l_H = l_E + l_T + l_A$ , where  $l_E$  is the work time in the enterprise sector and  $l_T$  is the work time spent in the human capital producing sector. The household may use this income to consume and invest any surplus left to increase its capital stock,

$$(7) \quad \dot{k}_A = r(np, w)k_A + wh(L - l_H) - \delta_k k_A - \eta T - c,$$

where  $c$  is household consumption expenditure,  $\dot{k}_A$  is the net change of capital per unit of time, and  $\delta_k$  is the rate of capital depreciation<sup>9</sup>. The term  $wh(L - l_H)$  is the total wage income that the household obtains as salaried workers in the other two sectors of the economy.

We assume the following simple dynamic for  $h$ ,

$$(7') \quad \dot{h} = Bhl_H - \delta_h h,$$

where  $B > 0$  is a fixed parameter and  $\delta_h$  is the rate of depreciation of human capital. This is quite a standard formulation for the dynamics of human capital consistent for example with that in Lucas (1988).

*Subsistence.* Households need a minimum level of consumption expenditures to survive. The level of subsistence expenditures and the composition of the subsistence consumption bundle naturally depend on the commodity prices. We denote the subsistence expenditure as  $v(p, q)$ , where  $q$  is the price of industrial goods and services. This subsistence expenditure is of course increasing in the

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<sup>9</sup> The household is assumed to have no other instruments where to place its savings, so household savings can only be invested in its own physical capital. Below we see that when capital markets exist the households can also invest part or its entire savings in bonds issued by other sectors of the economy.

commodity prices. Thus, the household will strive to achieve a consumption level  $c \geq v$  and will be willing to disinvest in  $k_A$  to reach such critical level if necessary. Subsistence households may also resort to reduce investment in human capital by cutting  $l_H$  and thus increase  $L_A$  and consequently current labor income. That is, student household members may have to drop out of school in order to devote more time to work and thus allow the household extra income to prevent its consumption to fall below minimum consumption levels.

*Household utility function.* We assume that the household's utility function is increasing, strictly concave, and homothetic in the consumption of the three commodities (including the industrial good produced by the enterprise sector). The indirect household utility function can thus be represented as  $u[(c-v(p,q))/e(p,q)]$ , where  $e(p,q)$  is a cost of living index which transform consumption expenditures into real consumption (Diewert, 1981). Note that  $u$  has to be non-negative which requires that  $c \geq v$ , that is, that the household must at least be at the subsistence level.

*The household's choice of investment and consumption.* The household is assumed to choose an optimal investment path given initial conditions. This is equivalent to choosing the consumption path over time by maximizing the present value of its utility function,

$$(8) \quad \max_c \int_0^{\infty} \left\{ u \left[ \frac{c - v(p, q)}{e(p, q)} \right] \exp(-\rho t) \right\} dt$$

Subject to: Equations (7) and (7'); and to the initial levels of the assets,  $k_A(0) = \bar{k}_A$ ;  $n(0) = \bar{n}$ ;  $h(0) = \bar{h}$ , where  $\rho$  is the household discount rate.

We note that the dynamics of the natural resource is not considered in this optimization due to the fact that the natural resources are subject to open access. Of course the evolution of the natural resource will affect the future choices, but the issue is that current choices are not affected by the future state of the natural resource.

Household capital, unlike natural resources, is subject to well-defined property rights so the household has tenure security over it. Also, the evolution of household capital, unlike the evolution of human capital, depends on the household investment decisions. The Hamiltonian of this problem is,

$$(9) \quad \mathfrak{R} = \max_c u \left[ \frac{c - v(\cdot)}{e} \right] + \lambda [r(\cdot)k_A + whL_A - \delta_k k_A - \eta T - c] + \mu [Bhl_H - \delta_h],$$

Where,  $\lambda$  and  $\mu$  are the co-state variables representing the shadow values of physical and human capital, respectively. First order conditions are the following:

$$(10) \quad (i) \quad u'(\cdot)/e = \lambda \text{ if } c > v(\cdot); \text{ or } c = v(\cdot), \text{ otherwise}$$

$$(ii) \quad \mu B - \lambda w \leq 0; \quad l_H (\mu B - \lambda w) = 0; \quad l_H \geq 0$$

$$(11) \quad (i) \quad \dot{k}_A = r(np, w)k_A + whL_A - \delta_k k_A - \eta T - c \text{ if } c > v(\cdot); \text{ or}$$

$$\dot{k}_A = r(np, w)k_A + whL_A - \delta_k k_A - \eta T - v(\cdot), \text{ otherwise}$$

$$(ii) \quad \dot{h} = Bhl_H - \delta_h h \text{ if } c > v(\cdot); \text{ or } \dot{h} = -\delta_h h \text{ and } l_H = 0, \text{ otherwise}$$

$$(12) \quad (i) \quad \dot{\lambda} = \lambda [\rho + \delta_k - r(np, w)] \text{ if } c > v(\cdot); \text{ or } \lambda = \dot{\lambda} = 0, \text{ otherwise}$$

$$(ii) \quad \dot{\mu} = \mu (\rho + \delta_h - Bl_H) - \lambda w (L - l_H) \text{ if } c > v(\cdot); \text{ or } \mu = \dot{\mu} = 0, \text{ otherwise.}$$

If  $l_H > 0$  then from (10ii) we have that  $\mu B = \lambda w$  in which case we can write (12ii) as

$$(12iii) \quad \dot{\mu} = \mu (BL - \rho - \delta_h).$$

Also by differentiating (10ii) with respect to time it follows that the rates of growth of the two co-state variables,  $\hat{\lambda} = \hat{\mu}$ , should be identical if households do invest in human capital, that is if  $l_H > 0$ . That is, using (12i) and (12iii) we have that

$$(13) \quad r(np, w) - \delta_k = BL - \delta_h \text{ if } l_H > 0$$

In addition, we have that the dynamics of the natural resource will influence the evolution of  $k_A$  and household income and consumption. Using (4) in (2), we obtain,

$$(14) \quad \dot{n} = g(n) - \phi k_A r_1(np, w)n \text{ if } n > \underline{n}; \text{ and } \dot{n} \leq 0 \text{ if } n \leq \underline{n}$$

We first consider the solution for the steady state and then we analyze the out-of-steady-state dynamics of the system

*Steady state solution.* We first consider the case where the household is able to achieve consumption levels above subsistence and the stock of the natural resource is above its threshold limit ( $c > v$  and  $n > \underline{n}$ ). A natural definition of the steady state is the state when the following conditions hold:  $\dot{n} = 0$  and  $\hat{\lambda} = \hat{\mu}$ . Thus in steady state we need that

$$(15) \quad r(n^* p, w) - \delta_k = BL - \delta_h$$

That is, in steady state the marginal rate of return to physical capital net of depreciation should be equal to the marginal returns to human capital. There is a unique level of the resource stock,  $n^*$ , at which the above condition is satisfied. Suppose that initially  $n_0 > n^*$  so that  $r(n_0 p, w) - \delta_k > BL - \delta_h$ . This would be a signal to continue expanding  $k_A$  (and not investing in  $h$  so that the savings to spend in physical capital investment is higher) but as  $k_A$  rises production of the commodity increases and the stock of  $n$  falls, which in turn reduces the returns to physical capital,  $r$ . This process continues until the above condition is satisfied as equality. This relationship is graphically depicted in the lower panel of Figure 1. The second vertical line in the top panel of Figure 1 shows the  $\dot{k} = 0$  schedule.

From equation (14) it follows that  $\dot{n} = 0$  if

$$(14') \quad \frac{g(n^*)}{n^*} = \phi k_A^* r_1(n^* p, w).$$

This equation when evaluated at the steady state level of  $n$  yields a unique level of capital,  $k_A^*$ , which is consistent with a stable level of the natural resource. If households were to increase  $k_A$  beyond  $k_A^*$ , for example, the stock of  $n$  would fall which in turn would cause the rate of return to capital to decrease upsetting condition (15), which would induce households to disinvest in physical capital. The stock of physical capital would thus return to its equilibrium level. From (14) and (14') it is clear that the steady state levels of the stock of physical capital and stock of natural resources are functions of the output prices and of the wage rate. Since we assume throughout that the output prices are fixed, we just write the steady state stocks for each region as explicit functions of  $w$ ,

$$(14'') \quad \begin{aligned} & \text{(i) } k_A^{i*} = \psi(w) \text{ or } k_A^{i*} = 0 \text{ if } c = v \text{ (if subsistence applies) for } i=1,2; \\ & \text{(ii) } n^{i*} = \Omega(w) \text{ or } n \neq n^{i*} \text{ if } c = v \text{ (if subsistence applies) for } i=1,2 \end{aligned}$$

From (14) and (15) it follows that the steady state capital stock is decreasing in  $w$  and the steady state level of natural resource is increasing in  $w$ ; that is,  $\psi'(w) < 0$  and  $\Omega'(w) > 0$ .

Finally, evaluating (11i) at the steady state levels of the assets stocks (and thus using  $\dot{k}_A = 0$ ) we can solve for the steady state level of consumption expenditures,

$$(16) \quad c^* = r(n^* p, w)k_A^* + wh(L - l_H) - \eta T - \delta_k k_A^*.$$

The steady level of household consumption defined in (16) is conditional on the level of  $h$  as well as on the level of household time spent in building human capital ( $l_H$ ). Since, as we shall see, even when the steady state  $h$  is increasing, labor income is growing indefinitely and therefore over the long run the households are able to increase consumption over time. That is, the actual household consumption may not be constant over the long run. Note, however, that Equations (15) and (14') are not affected by  $h$  and  $l_H$ , which means that, unlike  $c^*$ , the levels of  $n^*$  and  $k_A^*$  are in fact fixed over the long run.



*Convergence.* We first assume that the initial endowment of physical and natural capitals of the household sector economy is initially above the SS subsistence curve and sufficiently to the right of the  $\underline{n}$  vertical line (Figure 1). It is easy to show that given a level of  $w$  the system converges to the long run equilibrium described above (we defer the discussion of the determination of  $w$  and  $l_H$  which of course depends on economy wide conditions). Suppose that initially  $n > n^*$  then we have that  $r(n, p, w) - \delta_k > BL$  and consequently  $k_A$  will be increasing. As  $k_A$  rises over time production of the commodity expands increasing the extraction of the natural resource eventually overcoming its capacity to renew itself. At this point the natural resource declines over time; but as  $n$  falls the rate of return to capital falls and hence the incentives to continue expanding capital decline and the stock of the resource approaches the long run equilibrium level,  $n^*$ . This transitional dynamics and convergence is illustrated in Figure 1. We note that the main reason why the system converges towards a zero output growth steady state is that the natural resource is fixed in the long run. This causes the rate of return to capital to fall as long as the natural resource declines towards its fixed long run equilibrium level. Any further expansion of the household production levels becomes unsustainable as it reduces the resource stock below the required level to make the rate of return to household capital attractive enough to continue investing.

We say that natural resources are abundant (scarce) when  $n > n^*$  ( $n < n^*$ ). Then we have the following important result for the out-of-steady dynamics: *When natural resources are abundant (scarce) the households net invest only in physical capital (human capital).* Thus, natural resources are complement with physical capital and substitutes with human capital. Human capital abundance acts as a disincentive to invest in human capital and as an incentive to expand physical capital. Of course in the steady state (i.e., when  $n = n^*$ ) the household continues to increase human capital while keeps the stock of physical capital constant.

*Subsistence equilibrium.* The above is the solution assuming that the household is able to achieve consumption levels above the subsistence level. Here we look at the subsistence equilibrium. The subsistence steady state is depicted by the subsistence line characterized by  $\dot{k}_A = l_H = 0$  even if  $r - \delta_k > BL - \delta_h$ . That is, a subsistence household is not able to invest in neither form of capital. Investment is constrained by the capacity of the household to save, not by the profitability of

investment. The boundary between subsistence and non-subsistence equilibrium is given by the curve depicting the budget constraint evaluated at  $\dot{k}_A = l_H = 0$  and  $c = v(\cdot)$ :

$$(17) \quad r(np, w)k_A + whL - \delta_k k_A - \eta T - v(\cdot) = 0$$

with slope,

$$(18) \quad \left. \frac{dk_A}{dn} \right|_{SS} = -\frac{r_1 p k_A}{(r - \delta)} < 0 \text{ if } r > \delta.$$

This downward sloping curve is shown as the line SS in Figure 1. This line shows all the possible combinations of  $n$  and  $k_A$  that allow for the household consumption level to be exactly equal to its subsistence level, i.e, for  $c = v$ . The position of the subsistence curve SS is not necessarily fixed. If, for example,  $h$  increases the SS curve would shift down. Figure 1 also shows the Ecological Fragility Zone (EFZ) defined as the area when the level of the natural resource is between  $\underline{n}$  and  $[\gamma_o / \gamma_2]^{1/2}$  and above the  $\dot{n} = 0$  curve. If the system is in EFZ the subsequent dynamics of the system may lead to levels of  $n$  below  $\underline{n}$  which implies the eventual extinction of the resource.

Any point along the SS curve implies that consumption is exactly equal to the subsistence level and that both physical and human capitals are constant. If the initial combination of the stock of physical capital and natural resources is at or below this line the household would not be able to achieve the steady state  $(k^*, n^*)$  discussed earlier. If initially the household availability of assets is along line SS the household would remain at subsistence as long as exogenous conditions do not change. If the resource endowment falls below the SS line the household falls into a spiraling poverty trap; the household becomes destitute and is condemned to subsist out of social programs or charity. Similarly, any point below  $\underline{n}$  implies that the ecological system cannot resist any resource extraction because it is unable to renew itself. Also any point within the EFZ may lead to extinction of the resource which means that eventually a household may fall into the poverty trap even if initially the system is above the SS curve. The arrows in Figure 1 illustrate this process.

**Summary:** *The representative household of the economy supplies labor to the household production sector as well as to the rest of the economy (the enterprise sector and the human capital production sector). In addition, the household sector devotes part of its time to schooling and other learning activities which enhance the future stock of human capital ( $l_H$ ). The main finding so far is that non-subsistence households reach a fixed long-run level of physical capital and that the dynamics of the natural resource and household behavior lead to an also fixed level of the natural resource over the long run. A long-run equilibrium condition is that the net marginal returns to investing in physical capital should be equal to the net marginal returns investing in human capital. However, the solution to the household optimization problem does not explicitly determines the optimal level of  $l_H$  (except of course when the household is in state of subsistence in which case we have shown that  $l_H = 0$ ) and also we have taken  $w$  as given.*

To determine the equilibrium levels of the investment in human capital ( $l_H$ ) and of the wage rate per efficiency labor we need to explicitly consider the rest of the economy and the equilibrium of the labor market. We now turn to these issues.

### ***The Enterprise Sector***

The enterprise sector is constituted by the modern sector producing mainly industrial goods and services which are assumed to be not directly dependent of natural resources as factors of production. In contrast to the household-producer sector, this sector is dominated by capitalist firms. The production function in this sector is

$$(19) \quad Q_M = g(k_M, Z, hl_M),$$

where  $Q_M$  and  $k_M$  are output produced and capital owned by the enterprises respectively,  $Z$  are imported intermediate inputs used by this sector,  $hl_M$  is labor in efficiency units. We assume that production is subject to constant returns to scale or, equivalently, that the function  $g(k_M, Z, hl_M)$  is linearly homogenous.

The returns to capital or profits in this sector are defined as,

$$(20) \quad \Pi = \max_{k_M, Z} \{ qg(k_M, Z, hl_M) - zZ - whl_M \} = k_M \pi(q, z, w),$$

where  $q$  and  $z$  are the prices for output and intermediate goods, respectively. Given the constant returns to scale assumption optimal profits in this sector are linear in  $k_M$  and there is a unit profit function,  $\pi$ , which is linearly homogenous, increasing in  $q$  and decreasing in  $z$  and  $w$ , and convex in its arguments (Diewert, 1981). Moreover Hotellings lemma applies which means that

$$(21) \quad (i) Q_M = k_M \pi_1(q, z, w); \quad (ii) Z = -k_M \pi_2(q, z, w); \quad (iii) hl_M = -k_M \pi_3(q, z, w),$$

where  $\pi_i (i = 1, 2, 3)$  denote first derivatives with respect to the corresponding argument.

Like household producers, capitalists are assumed to choose their investment and consumption patterns optimally to maximize the expected present value of their utility, which in turn is an increasing and strictly concave function of their consumption,  $c_k$ . We assume that, in contrast with the household producers, the capitalists in the enterprise sector rely exclusively on hired workers (or that their own work time is a negligible fraction of the total labor force).

$$(22) \quad \max_{c_k} \int_0^{\infty} \left\{ u \left[ \frac{c_k}{e(p, q)} \right] \exp(-\rho t) \right\} dt$$

Subject to:

$$\dot{k}_M = \pi(q, z, w)k_M - \delta_k k_M - (1 - \eta)T - c_k$$

$$k_M(0) = \bar{k}_M$$

where  $(1 - \eta)T$  is the contribution to the total tax revenues of the enterprise sector (the policy coefficient  $\eta$  is of course positive and less than one). Firms take  $q, z$  and  $w$  as given. The first order conditions are:

$$(23) \quad u'(\cdot)/e = \lambda_k$$

$$(24) \quad \dot{k}_M = \pi(q, z, w)k_M - \delta_k k_M - (1-\eta)T - c_k$$

$$(25) \quad \dot{\lambda}_k = [\rho + \delta_k - \pi(q, z, w)]\lambda_k,$$

where  $\lambda_k$  is the shadow price of capital.

This problem can be called a **pseudo Ak** type as the solution to the above problem allows firms to immediately reach a steady state path without transitional dynamics (see below however why we call it a pseudo Ak model). If the economy is sufficiently productive and if input prices are not too high and constant over time, the steady state may be consistent with a permanent increase in the stock of capital, output and consumption as in the conventional Rommer's Ak model (Romer, 1986, 1987). Differentiating (23) with respect to time and using (25) we obtain the optimal growth rate of capital and consumption,

$$(26) \quad \hat{c}_k = \hat{k}_M = \frac{1}{a} [\pi(q, z, w) - (\rho + \delta_k)],$$

where  $a \equiv -\frac{u''c_k}{u'} > 0$  is the elasticity of marginal utility assumed positive and constant and a “hat” above the symbols represents growth rates over time. Also, given that industrial output is  $Q_M = \pi_1(\cdot)k_M$ , we have that the rate of growth of output is also constant as long as output and input prices are constant,

$$(27) \quad \hat{Q}_M = \hat{k}_M$$

That is, consumption of capitalists, the stock of capital and production in the enterprise sector all grow at a constant rate which is positive provided that the economy is sufficiently productive so that

the marginal value product of capital,  $\pi$ , is above the opportunity cost of capital,  $\rho + \delta$ . This is in sharp contrast to the primary or household-producer sector which over the long run the steady state is one of a constant level of output, capital and consumption. The main reason is that the household-producer sector is dependent on a natural resource with a given renewal capacity. This means that unlike the enterprise sector, capital and production in the household-producer sector cannot expand indefinitely.

*Growth vs stagnation of the enterprise sector.* Even the enterprise sector can be subject to limits to growth if the wage rate per unit of efficiency labor,  $w$ , increases over time. As can be seen in (26) if the expansion of the enterprise sector leads to increasing  $w$ , the returns to capital,  $\pi$ , will progressively fall (remember that  $\pi$  is decreasing in  $w$ ) eventually becoming equal to the opportunity cost of capital at which point the enterprise sector would also stagnate and therefore the economy as a whole would stagnate as well. However, stagnation can be prevented under certain conditions, allowing the growth process to remain positive and constant as in the so-called **AK** model. This is why we called this model a pseudo **AK**. Below we examine the conditions for preventing the growth rate to decline towards zero over time.

**Summary:** *Unlike the case of the household physical capital investment and output levels, physical capital investment and production levels of the enterprise sector can under certain conditions continuously expand over the long run. Whether or not the enterprise economy stagnates depends on whether or not the increased demand for labor (in efficiency units) generated by the enterprise sector is off-set by a constant increase in the supply of labor efficiency. That is, the rate of growth of human capital as a source of increasing supply of labor efficiency is a key factor. If human capital grows at a sufficiently rapid pace to off-set the increased demand for efficiency labor then the efficiency wage rate does not need to increase and a constant growth rate of the enterprise sector and for the economy can be supported indefinitely. Otherwise, the economy will slow down and eventually stagnate.*

Thus, the key aspects of growth are to be found in the labor market and in the supply of new human capital. We first consider the issue of the supply of new human capital.

At this point we need to distinguish the two types of economy considered, first the case of a *poor economy* which has imperfect capital market with the state producing all new human capital and,

subsequently the *middle income economy* with perfect capital markets and where the private sector may produce new human capital.

## A. The Poor Economy

### *The human capital sector*

We assume that new human capital for the labor force is provided by the state. The state uses part of the tax revenues to produce human capital. The state uses a proportion  $\beta$  of the total tax revenues to provide new human capital. Governments of course use many types of taxes; most of them cause distortions by affecting investments and other forms of resource allocation. Since the focus of this analysis is not on the consequences of taxes, we assume that taxes are raised via lump-sum taxes applied to both the household-producers and to the enterprise sector. In the context of small open economies where final good prices are fixed, the lump sum tax resembles a consumption tax. The total tax revenue devoted by the government to produce human capital is  $\beta T$ , where  $0 < \beta < 1$  is a policy parameter.

The *supply* of new human capital is postulated to follow the following dynamic,

$$(28) \quad \dot{h}^S = H(Z_h, hl_T) - \delta_h h,$$

where  $H(\cdot)$  is a production function for new human capital as a function of the materials and effective labor used in the production of human capital ( $Z_h$  and  $hl_T$  respectively) and  $\delta_h$  is the rate of depreciation of human capital. Thus,  $l_T$  is the teacher time as provided by the households that are (partly) employed by the human capital sector.

Using the expenditures  $\beta T$  the government buys the services of labor as well as imported materials and equipment to produce human capital. We assume that the materials and equipment components

are imported by the government<sup>10</sup>. We note that the production of human capital, unlike the production of other goods and services, tend to have a very low elasticity of substitution between equipments and labor. To capture this we assume that production of human capital can be characterized by a fixed proportions or Leontief technology<sup>11</sup>. Thus, we have

$$(29) \quad H = \theta \min\left(\frac{Z_h}{\alpha_1}, \frac{hl_T}{\alpha_2}\right),$$

where  $Z_h$  are the specialized imported materials used in human capital production,  $l_T$  is the labor used producing human capital,  $\theta$  is a parameter reflecting total factor productivity in producing human capital, and  $\alpha_i$  ( $i=1,2$ ) are fixed coefficients. Thus, efficient production of human capital requires that  $Z_h = (\alpha_1 / \alpha_2)hl_T$ . This means that the total cost of producing human capital is,

$$(30) \quad whl_T + zZ_h = (w + (\alpha_1 / \alpha_2)z)hl_T$$

The total cost of producing human capital is equal to the government's budget for education,  $\beta T$ . Equalizing government expenditures in education and the education budget solves for the level of labor used in education,

$$(31) \quad hl_T = \frac{\beta T}{w + (\alpha_1 / \alpha_2)z}$$

The level of imported materials used can also be obtained using the condition  $Z_h = (\alpha_1 / \alpha_2)hl_T$  presented above. Using (31) in (29) we get,

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<sup>10</sup> We also assume that there is a mass of people, mainly children outside the labor force, that are available to receive instruction which eventually replaces part of the retiring component of the labor force once their education process ends.

<sup>11</sup> This assumption simplifies the ensuing analysis but it does not condition the results.



$$(32) \quad H = \theta h l_T / \alpha_2 = \theta \frac{\beta T}{\alpha_1 z + \alpha_2 w}$$

Hence, from (28) it follows that the rate of growth of the *supply* of new human capital is,

$$(33) \quad \hat{h}^s = \theta \frac{\beta T}{h[\alpha_1 z + \alpha_2 w]} - \delta_h.$$

Equation (33) provides a very reasonable representation of the supply of new human capital by the government: it is increasing in the volume of financial resources that the government devotes to human capital ( $\beta T$ ) and in the productivity of such resources ( $\theta$ ) and is decreasing in the prices of the inputs needed to produce human capital ( $w$  and  $z$ ).

Equation (33) represents the supply of new human capital. Earlier we considered the *demand* for new human capital by households, Equation (7') which we now write it explicitly as a demand condition,  $\hat{h}^D = B l_H - \delta_h$  (to remind,  $l_H$  represents the household student time). Equilibrium needs that  $\hat{h}_H^D = \hat{h}^S$ . This equilibrium takes place via adjustments in the levels of student enrollment vis-à-vis the level of teachers. Thus, the student-teacher ratio ( $l_H / l_T$ ) is adjusted until supply of new human capital equals demand. In fact, equalizing (33) and (7') using (31) we obtain that there is a fixed student/teacher ratio that allows for equilibrium,

$$(33') \quad \frac{l_H}{l_T} = \frac{\theta}{\alpha_2 B}$$

Since  $h l_T$  is given by (31) we have that (33') allows us to solve for the equilibrium level of  $h l_H$ . Thus the total level of effective time that households devote to the human capital sector including teachers and students is,

$$(33'') \quad (h l_H + h l_T) = \left( 1 + \frac{\theta}{\alpha_2 B} \right) \frac{\beta T}{(\alpha_1 / \alpha_2) z + w}$$

**Summary:** *The human capital production sector in poor economies is assumed to be in the hands of the government, which uses part of the tax revenues to buy the necessary materials and teaching time to produce new human capital. Households provide both the teaching manpower as well as the student time. The total labor and student time used by the human capital sector is increasing in the budget allocated by the government to the sector, and is decreasing in the cost of the inputs used in producing human capital; it is also affected by certain key efficiency parameters.*

### **Labor market equilibrium**

The labor market is assumed to clear at all times. That is, the wage rate per efficiency labor time,  $w$ , is flexible to allow the demand in efficiency units of labor to be equal to the supply of labor in efficiency units. The total physical labor force of the economy,  $L$ , is assumed fixed, so that the supply of labor efficiency units,  $hL$ , may change only if human capital rises over time. The total labor demand is comprised of the labor demand from the enterprise sector plus the demand from the household-producers sector and plus the demand for labor from the human capital production sector. Using the representations of labor demand in the enterprise and household-production sectors (equations (5) and (21.iii), respectively) and the labor demand from the human capital sector (equation (31)) we have that,

$$(34) \quad -r_2(n^* p, w)k_A^* - \pi_3(q, z, w)k_M + \left(1 + \frac{\theta}{\alpha_2 B}\right) \frac{\beta T}{(\alpha_1 / \alpha_2)z + w} = hL.$$

Where  $k_A^* = \varepsilon k_A^{1*} + (1 - \varepsilon)k_A^{2*}$ . Remember that from (14'') both  $k_A^*$  and  $n^*$  are functions of  $w$ . Thus, for given levels of  $k_M$  and  $h$ , equilibrium in the labor market requires a unique level of  $w$  which we denote by  $w^e$ . In addition to  $k_M$  and  $h$  the level of  $w^e$  also depends on the tax rate chosen by the government. Thus equation (34) solves for the remaining endogenous variable,  $w$ , as a function of  $k_M, h$ , and the policy variable  $T$ . We can write the equilibrium wage rate as a function,  $w^e = w(k_M, h, T; X)$ , where  $X$  is a binary variable equal to 1 if neither of the household-producer regions are in the subsistence regime, and  $X=0$  if at least one of the household regions is under a

subsistence regime, and hence at least one of the  $k_A^{i*} = 0$ <sup>12</sup>. It is natural to expect that  $w(k_M, h, T; 1) > w(k_M, h, T; 0)$ .

All left-hand-side terms in (34) are decreasing in  $w$  so the effect of  $w$  on the total labor demand is of course negative. It is easy to see from (34) that this implies that the equilibrium wage rate is increasing in  $k_M$  and decreasing in  $h$  (it is also increasing in  $T$ ),  $\partial w^e / \partial k_M > 0$  and  $\partial w^e / \partial h < 0$ .

A key issue is whether or not the resulting equilibrium value of  $w^e$  allows the enterprise sector to expand. From (26) it is clear that if the marginal value product of capital when evaluated at  $w^e$  is above its marginal cost, that is if  $\pi(q, z, w^e) > \rho + \delta_k$ , then growth in the enterprise sector and hence in the economy will be positive. The question is whether this growth rate can be supported over time. As we have just seen,  $k_M$  in this case increases over time, meaning that the demand for labor from the enterprise sector may continuously increase in a growing economy. Thus to keep the wage rate constant and hence for growth to remain positive it is necessary that  $h$  increase at a sufficient pace. Below we consider the conditions necessary to preserve a positive growth rate.

***Preserving a positive and constant growth rate: The required rate of growth of human capital***

Equilibrium (34) with constant  $w^e$  can only be preserved if  $h$  is growing at a sufficiently fast rate. To determine this required rate of growth of human capital ( $\hat{h}^R$ ) we differentiate (34) with respect to time (assuming  $w$  constant) to obtain the following condition,

$$(35) \quad -\pi_3(\cdot)k_M \hat{k}_M = hL\hat{h}^R,$$

which using (21.iii) can be written as:

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<sup>12</sup> The level of  $w^e$  also depends on output and intermediate input prices which we omit from the equilibrium wage function because these are parameters which we assume constant.

$$(36) \quad \hat{h}^R = s_M \hat{k}_M,$$

where  $s_M = -\frac{\pi_3}{L} \frac{k_M}{h} = l_M / L$  is the share of the labor force employed by the industrial sector which is increasing in  $k_M / h$ .

From (36) it is clear that  $\hat{h}^R < \hat{k}_M$  and, since  $s_M$  is an increasing function of the ratio  $k_M / h$ , the required rate of growth of human capital must be increasing over time getting closer to  $\hat{k}_M$  but never quite reaching it. The required rate of growth of  $h$  needed to sustain the rate of growth given by (26) is therefore:

$$(37) \quad \hat{h}^R = \frac{s_M}{a} [\pi(q, z, w^e) - (\rho + \delta_k)]$$

Thus, while human capital needs to grow at a slower rate than physical capital in the enterprise sector, the rate of growth of human capital needs to be increasing over time as  $s_M$  grows.

From (33) it is clear that the rate of growth of human capital can increase over time only if the tax  $T$  or the share of government revenues devoted to human capital,  $\beta$ , or both, increase over time. Equalizing (33) and (37), we obtain the required tax revenues that the government must spend in the production of human capital to sustain economic growth,

$$(38) \quad (\beta T)^e = \frac{h(\alpha_1 z + \alpha_2 w^e)}{\theta} \left[ \frac{s_M}{a} (\pi(q, z, w^e) - \rho - \delta_k) + \delta_h \right].$$

Thus, if the initial rate of growth is to be preserved, it is necessary that  $\beta T = (\beta T)^e$  and must be constantly increasing over time. Expression (38) provides a very sensible rule for government expenditure allocation to human capital: the needed government expenditure in human capital is increasing in the rate of growth of physical capital and in the unit cost of human capital production,

$(\alpha_1 z + \alpha_2 w^e)$  and in the rate of depreciation of human capital. It is also decreasing in the level of efficiency of production of human capital ( $\theta$ ).

The previous analysis shows that sustaining a faster rate of physical capital growth requires a faster human capital growth rate as well. That is, human capital and physical capital are complements rather than substitutes.

**Summary:** *Given initial stocks of physical and human capital, the equilibrium wage rate in the short run is determined by a policy decision regarding the level of tax revenues devoted to human capital production,  $\beta T$ . This, in turn, determines whether or not the enterprise sector will be able to grow and at what rate. It is clear from (34) that  $w^e$  is increasing in the tax level chosen by the government. Hence, if the government chooses a tax that is too high it may choke growth in the short run by inducing too high a wage rate. However, a higher level of tax revenues if government waste does not increase (e.g., if  $\beta$  does not fall) may allow for a faster growth rate of human capital which over time increases the effective labor supply. This, in turn, may allow for a decline in the wage rate per unit of efficiency time which eventually will make investment in the enterprise sector attractive again. Thus, the government spending in human capital is between two evils: Too high spending may cause too high wages in the short run which may dissuade investors thus risking stagnation; too little spending in human capital, on the other hand, may allow for lower wages in the short run and hence rapid investment in physical capital, but at the cost of too slow a rise in human capital which may cause wages over the long run to increase enough to choke growth.*

## External equilibrium

So far we have not explicitly referred to the required balance of trade equilibrium. In fact given the small open economy condition, the external equilibrium is already guaranteed by the satisfaction of the budget constraints of the household-producers and enterprise sectors that we assume (plus the assumption that tax revenues are equal to government expenditures). See, for example, Dixit and Norman (1980) for a detailed discussion of these issues.

## *B. The Middle-Income Economy*

As discussed in the introduction of the model section, the middle income economy is assumed to have a well-developed capital market and the human capital sector is fully open to for-profit private enterprises. The capital market is well developed in the sense that there are financial instruments by which the household-producer sector can invest in bonds issued by the enterprise sector. This does not necessarily mean that the household-producer sector can borrow from the enterprise sector without limits; in fact the literature has shown the widespread prevalence of credit rationing affecting households and poor producers even in developed countries (Grant, 2007; Hayashi, 1987). We assume that the household-producers as a group cannot be net borrowers from the rest of the economy<sup>13</sup>. In any case we focus in the case where before the liberalization of the capital market the rate of return to capital in the household-producer sector is below the rate of return to capital in the enterprise sector,  $r < \pi$ . This is of course the interesting (and realistic) case. Given this the household-producer sector will want to invest in bonds, not borrow, so the assumption of credit rationing for the household-producer sector is really innocuous.

If initially  $r < \pi$  the household-producers devote all their savings to invest in bonds issued by the enterprise sector and nothing to invest in its own capital stock. This causes their physical capital to decline and consequently natural capital rebuilds which, in turn, raises the returns to household capital over time until  $r = \pi$ . At this point new steady state equilibrium for the sector is reached. Figure 2 illustrates this process. As shown in Figure 2 capital market liberalization induces a long run equilibrium characterized by a more abundant stock of natural resources.<sup>14</sup>

We also assume that the government still invests in basic education just enough to prevent the human capital sector to fall (that is, the government contribution to human capital is equal to  $\delta_h h$ ). In doing this the government uses a portion of the labor force,  $\xi hL$ , where the parameter  $0 < \xi < 1$  is possibly quite small. Otherwise the middle income economy is structurally identical to the poor economy.

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<sup>13</sup> This assumption is extreme but does not affect the results as long as there is binding credit rationing.

<sup>14</sup> Here we are comparing equilibrium positions evaluated at identical wage rates.

*The capital markets.* As discussed above a main implication is that now the net rates of return to capital in the household-producer sector and enterprise sector are equalized in the long run. That is, in long run equilibrium we have<sup>15</sup>,

$$(39) \quad r(np, w) = \pi(q, z, w)$$

In addition we have that the household equilibrium allocations (15) and (14') are still valid which for the sake of clarity we repeat here,

$$(15) \quad r(n p, w) - \delta_k = BL - \delta_h$$

$$(14') \quad \frac{g(n)}{n} = \phi k_A r_1(n p, w).$$

Equations (15) and (39) solve for the long run levels of the stock of natural resources and wage rate,  $n^*$  and  $w^*$  and condition (14') solves for the long-run equilibrium level of  $k_A^*$ . Evaluating condition (14') at the levels  $w^*$  and  $n^*$  yields the long run equilibrium level for the stock of capital in the household-producer sector,  $k_A^*$ .

Thus, the household-producer sector follows a path that is akin with the standard Swan-Solow model where output growth ceases over the long run. By contrast, the enterprise sector may reach long run equilibrium with positive output and physical capital growth like in endogenous growth models. The main reason for this asymmetry in dynamic behavior is that the household-producer sector, unlike the enterprise sector, is constrained by the availability of the natural resources which has a limited capacity to regenerate itself. Ultimately, the natural resource is fixed and this puts limits to output growth in that sector. Importantly, this does not mean that the household sector does not benefit out of the ensuing process of economic growth. What happens is that once the

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<sup>15</sup> The net returns are  $r - \delta_k$  for the household-producer sector and  $\pi - \delta_k$ . Since the depreciation rates are assumed identical in the two sectors we get (14') below.

level of physical capital  $k_A$  stops growing the households shift their savings to invest in financial assets issued by the enterprise sector obtaining a net rate of return equal to  $\pi - \delta_k$  (of course this assumes that there are no financial intermediaries; in the real world households get a somehow lower return by paying intermediation fees).

*Labor market equilibrium.* Labor market equilibrium now defines the equilibrium level of  $l_H$  because equilibrium in the capital market already defines a unique wage rate consistent with it. The labor market condition thus needs to be interpreted differently,

$$(34') \quad -\pi_3(q, z, w^*)k_M - r_2(n^* p, w^*)k_A^* + hl_H = (1 - \xi)hL,$$

We note in (34') that  $(1 - \xi)hL$  is the effective labor supply to the private sector once the government employment is deducted. Given  $k_M$  and  $h$ , which are fixed in a particular point of time (the economy can affect the rates of change of these assets but not their level at a point in time), the level of  $l_H$  is determined. This means that given an initial level of the level of  $h$  the rate of change of human capital is determined; which using (7') is equal to  $Bl_H - \delta_h$ . But it is possible that the levels of initial asset endowments,  $k_M$  and  $h$  as well as  $n$ , are such that (34') does not satisfy the non-negativity constraint in which case  $l_H = 0$ . In this case the economy is unable of investing in new human capital (just the replacement human capital is produced by the government)<sup>16</sup>.

This means that for human capital to be increasing over time we need that  $h$  be greater than a critical level,  $h^c$

$$(40) \quad h > -\frac{1}{(1 - \xi)L} [\pi_3(q, z, w^*)k_M + r_3(n^* p, w^*)k_A^*] \equiv h^c$$

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<sup>16</sup> If the government provided less than the replacement of human capital  $l_H > 0$  would not be sufficient for human capital to grow.



### ***Bifurcation and state dependence***

In part depending on initial state conditions (i.e., factor endowments) the system bifurcates into two possible long run equilibrium solutions:

(i) An ***interior solution*** with equations (14'), (15) and (39) uniquely solving for the long run constant levels of  $n^*$ ,  $k_A^*$  and  $w^*$ . If the initial endowments of  $k_M$  and  $h$  are favorable, that is if such endowment allow condition (40) to be satisfied, the labor market equation (34') evaluated at  $n^*$ ,  $k_A^*$  and  $w^*$  may solve for a unique *temporary* value of  $l_H > 0$ . If when evaluated at the equilibrium wage rate  $\pi(q, z, w^*) > \rho + \delta_k$  then  $k_M$  and  $h$  will both grow continuously over time and  $l_H$  will adjust accordingly as required by the labor market clearing condition (34'). The expansion of both  $k_M$  and  $h$  may allow the economy to continuously grow over time.

(ii) A ***corner solution***, where evaluating the labor market equilibrium (34') at  $n^*$ ,  $k_A^*$  and  $w^*$  would only be consistent with a negative value for  $l_H$  in which case the non-negativity constraint for  $l_H$  is binding and we have a corner solution  $l_H = 0$ , implying that human capital cannot grow. This is the case when the initial level of  $k_M$  is too high vis-à-vis the level of  $h$  so that condition (40) is not satisfied. When the non-negativity constraint for  $l_H$  is binding it effectively means that the wage rate must increase above  $w^*$  to clear the labor market. Let's denote this higher wage by  $\tilde{w}$  and denote as  $w^0$  the wage rate that makes  $\pi(q, z, w^0) = \rho + \delta_k$ . If  $\tilde{w} < w^0$  then at  $k_M$  will be increasing which given that  $\dot{h} = 0$  means that the labor demand will increase over time while the efficiency labor supply remains constant. That is, if condition (40) fails at the initial factor endowments it will also subsequently fail as  $k_M$  increases and  $h$  does not. The wage rate continuously increases over time until it reaches  $w^0$ . At that point  $k_M$  stops growing and we get a new equilibrium altogether with solution  $n^0$ ,  $k_A^0$ ,  $k_M^0$  and  $w^0$  (and  $l_H = 0$ ) obtained solving (39), (14'), (34'), and the new condition

$\pi(q, z, w^0) = \rho + \delta_k$ <sup>17</sup>. The capital market condition (15) does not hold anymore as  $l_H = 0$  which means that (15) becomes an inequality  $(r(n^0 p, w^0) - \delta_k) > BL - \delta_h$ . The economy is in the long run unable to expand both  $h$  and  $k_M$  which means that it stagnates. Moreover, it can easily be shown that the long run equilibrium level of natural resources in a stagnant economy is higher (lower) than in a growing economy, that is,  $n^0 < n^*$ , if the household-producer sector production is more labor intensive than the enterprise sector production.

*The human capital paradox.* If the corner solution equilibrium is reached the system cannot escape it unless exogenous changes happen. Here is the apparent paradox: since  $w^0 > w^*$  the corner solution equilibrium implies that the rate of return to investing in human capital is high (as human capital is scarce) and above the rate of return to investing in physical capital (that is, condition (15) is in this case an inequality). Yet rational investors do not invest in new human capital. The reason is that potential investors in human capital know that if human capital starts accumulating the rate of return to human capital would gradually have to fall in the future as the wage rate falls towards  $w^*$ . But this implies large capital losses to investors in human capital. In fact, given an initial equilibrium  $n^0, k_A^0, k_M^0$  the wage rate would have to shoot up above  $w^0$  in the short run to accommodate a positive level of  $l_H$  that investing in new human capital needs. This additional wage increase and hence additional expected capital losses for human capital investors is what tilt the balance against investing in new human capital<sup>18</sup>.

*Long-run stagnation.* The corner solution described above show the conditions under which the system converges towards stagnation. The higher is the initial stock of  $k_M$  and the lower is the

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<sup>17</sup> The reader can verify that if  $\tilde{w} \geq w^0$  then  $\hat{k}_M \leq 0$  until the wage rate reaches  $w^0$  at which point the system also reaches a no growth steady state.

<sup>18</sup> The human capital paradox is not merely an intellectual curiosity. High rates of return to human capital especially in middle income countries (way above rates of return to physical or financial assets) are frequently reported in the literature (Psacharopoulos and Patrinos, 2002; Palacios-Huerta, 2003; and Jacobs 2007) and yet these countries seem to systematically under invest in human capital as shown, for example, by high and increasing international cognitive test score gaps with developed countries (López and Miller 2008, López and Islam 2008).

initial stock of  $h$ , the more likely is that condition (40) does not hold; that is, the more likely is that the economy be unable to increase human capital. A human capital stagnation trap ensues, which subsequently leads to economic stagnation. In fact, this process causes excess demand for effective labor (the labor markets ceases to clear at  $w^*$ ) which is solve by an equally continuous rise of  $w$  until  $\pi(q, z, w^0) = \rho + \delta_k$ , where  $w^0 > w^*$ <sup>19</sup>. At this point the whole economy stagnates.

*Long-run growth.* The interior solution described above steers the system to permanent growth. If the initial asset endowments are favorable, in the sense  $h$  is higher and/or  $k$  is sufficiently low so that condition (40) is met, then the labor market equilibrium would be consistent with  $l_H > 0$ . In this case the economy is constantly able to increase human capital. It can be shown that the economy continues increasing human capital indefinitely. That is, if initially the asset endowments allows for a net growth of human capital a state of accumulation of human capital with a constant growth rate will persist indefinitely. The economy is able to reach long run equilibrium with permanent growth.

**Summary:** *An economy that in the past has over invested in physical capital and under invested in human capital faces a high risk of becoming unable to maintain a positive rate of economic growth. By contrast, a relative abundance of human capital vis-à-vis physical capital increases the likelihood that the economy will be able to sustain a positive rate of economic growth over the long run.*

#### IV. EFFECTS OF A DISASTER SHOCK

Disasters can affect this economy through a variety of channels, including the levels of productivity of each sector, it could cause disruptions in the provision of intermediate inputs and materials causing increases of their prices,  $z$ , affecting primarily the enterprise and human capital sectors.

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<sup>19</sup> The fact that the wage per efficiency labor increases is of course due to the scarcity of human capital that the lack of net investment in human capital induces. Compared to a case where human capital does expand workers may be better off in the latter case as the wage per actual work time,  $wh$ , would be increasing. In both cases the wage per actual time increases over time, but the difference is that when human capital does not grow the wage growth is merely temporary stagnating over the long run, while the wage increases are permanent in the case where human capital expands.

The disaster can also devastate the stocks of productive assets,  $k_A$ ,  $n$ , and  $k_M$  which affect not only the productive capacity of the various sectors but also the demand for labor pushing down real wages. The fall in wages, or more generally of incomes, can have significant and contradictory implications for the medium term growth of the economy: Lower wages may be an incentive for the enterprise sector to increase its investment rate which may contribute to off-set or more than off-set capital losses in such sector. *Thus, in the short run we may expect an acceleration of economic growth.*

However, the fall of incomes can have dramatically negative effects over the intermediate run. Governments are likely to receive political pressures to cut taxes to alleviate the affected sectors and at the same time to allocate more government expenditures towards infrastructure. In the absence of significant foreign aid, the government may be forced to reduce the share of spending in the operation of the human capital production sector (although part of the increased spending in infrastructure could go to the human capital sector). As is illustrated in Table 5, governments often change their public spending patterns in a dramatic way after disasters. The tendency towards crowding out operational expenditures in favor of capital spending has been empirically documented by Benson and Clay (2004) among others. This reallocation of government expenditures often result in significant disruptions in the provision of human capital (Molina et al., 2009). That is, often both  $T$  and  $\beta$  fall which cause a deceleration of the rate of accumulation of human capital. After a few years this may be reflected in a reduction of the stock of human capital which will, in turn, imply that the initial increases in the rate of physical capital accumulation in the enterprise sector cannot be supported and such rate may fall to levels even below those prior to the disaster.

Moreover, the initial fall in wages may cause part of the household sector to fall into a poverty trap which eventually may disappear as a production sector and hence be unable to retain workers. The workers released by the household-producer sector would put further pressures on wages as they become landless workers. These are just examples of the many mechanisms by which a disaster can affect this economy. The complexity of the issue forces us to focus on particular mechanisms that we consider important to highlight or that are especially useful to shed lights on certain important issues that concern the literature on disasters.

### ***A rural disaster concentrated in one region: The case of a poor economy***

As shown in Section 1 the available empirical evidence suggests that most disasters tend to be concentrated in particular geographic areas of the countries, they rarely affect whole countries. We consider here a disaster that is geographically concentrated (say a mayor drought or storm) affecting part of the rural area of a country but not directly the rest of the country<sup>20</sup>. The disaster reduces both the capital assets owned by the household-producers (say, it wipes out part of the livestock herd) as well as the natural capital (i.e., affect the stock of underground water or the stock of biomass used as a source of natural fertility of soils in the context of slash-and-burn agriculture) of the area affected. In the context of the model the disaster affects one of the regions where the household-producer sector is established, say Region 1, where  $k_A^1$  and  $n^1$  are drastically reduced. In addition, depending on the type of disaster it is possible that the total factor productivity in Region 2 also falls as a consequence of damage affecting local infrastructure and access to markets.

*Direct effects.* The direct effects are those affecting directly the household-producer sector of Region 1. Depending on the intensity of the disaster and on how far are initially the households from the subsistence boundary (SS in Figure 1) the fall of  $k_A^1$  may or may not be reversible. It may also leave the natural capital below the extinction threshold (that is, the level of  $n$  after the disaster may end up below  $\underline{n}$ ). If the disaster is not large enough, the asset destruction may leave the households still above the SS boundary and to the right of the  $\underline{n}$  vertical line such as point  $d_1$  in Figure 2 and thus the process of asset reconstruction is feasible; the system is economically and ecologically reversible and the same initial long run asset equilibrium (point 0 in Figure 2) is eventually reestablished. That is, the fall in household incomes is merely temporary and the rebuilding of assets will require them to temporarily reduce consumption to invest in  $k_A^1$ .

By contrast, if the asset destruction is greater the households' asset endowment may fall to a point below the SS curve and/or to the left of the  $\underline{n}$  line such as points  $d_2$  or  $d_3$  in Figure 3. At any of

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<sup>20</sup> In Honduras the hurricane Mitch caused elevated damages and losses to the “primary” sector (resource dependant); in Aceh the relative damage to the primary sector are also higher than to the enterprise sector. Table 4 provides evidence about the distribution of damages for other countries as well.

these points the dynamics of the system, as shown by the arrows, is towards continuous consumption of the capital left and continuous loss of natural capital; that is, the household falls into spiraling reduction of income and of  $k_A^1$ . In Figure 3 the point  $d_4$  reflects a reduction of factor endowments to a point that is still above the economic and ecological thresholds but at a level of  $n$  below  $(\gamma_0 / \gamma_2)^{1/2}$ . In this case, it is possible that the subsequent dynamic of the system may push the sector first into the ecological trap (below  $\underline{n}$ ) and subsequently below the SS curve as well. This is a case where irreversible ecological loss, not directly the disaster, leads to the poverty trap. Eventually, the households cease to be viable as a production entity and must emigrate either to the other rural region not affected by the disaster (Region 2) and/or to the enterprise sector (in this case the second equality is valid in Equation (15'.i)). The subsistence trap is the most interesting case because it has important secondary effects which over the long run may affect the growth patterns of the entire economy.

*Short-run secondary effects.* The secondary effects are in part linked to the labor market. The wiping out of  $k_A^1$  and the consequent elimination of Region 1 as a source of jobs cause downward pressures on wages and eliminates a source of tax revenues. From Equation (34) it is clear that if  $k_A^1$  is eliminated the demand for labor falls, which in turn causes  $w$  to decrease. The fall of  $w$  has implications for capital accumulation in both the Region 2 and the enterprise sector. The lower  $w$  will increase the rate of return to capital in both Region 2 and the enterprise sector.

In Region 2 the wage reduction may have two very different effects. The fall in wages will move the subsistence curve (SS) upwards and if such a movement is large enough it may lend the old equilibrium asset endowment in Region 2 below subsistence as illustrated in Figure 4. In this case the collapse of Region 1 could spill over into the permanent collapse of at least some of the households in Region 2 as well. Alternatively, if households in region 2 were initially wealthier the upward shift of the SS curve would still leave the households above subsistence. The Region 2 in this case would accumulate more physical capital in the short run as the returns to capital increase. This would reduce natural capital, if such reduction is not large enough to put the household below the ecological threshold, Region 2 would be able to achieve a new long-run equilibrium with more

physical capital and less natural capital. The net effect of the disaster is thus to reduce the long-run levels of natural capital.

The enterprise sector also increases its rate of investment as  $\pi$  rises and consequently the  $\pi - (\rho + \delta_h)$  gap increases (see Equation 26). Thus, the economy as a whole will experience a faster rate of capital accumulation at least over a period of time. Output (GDP) will also grow faster than prior to the disaster. This is consistent with some empirical studies that have documented an acceleration of growth after disasters (Albala-Bertrand 1993). Moreover, this higher rate of investment and faster growth are not merely a catching up process. In fact, the accelerated investment takes place in sectors that are not directly affected by the disaster and it is possible that even accounting for the reduction of capital in the Region 1, the net effect on investment be still positive.

*Long-run secondary effects.* The fall in wages and the disappearance of Region 1 as a productive sector, however, erodes the tax base for the government which, in turn, barring a reallocation of government expenditures is likely to cause a deceleration of the rate of investment in human capital. As seen in Equation (33) a fall in  $w$  reduces  $\hat{h}$ . So  $\hat{k}_M$  increases and  $\hat{h}$  falls. From (37) it is clear that this may upset the balanced growth process as  $\hat{h}$  falls below its required rate of growth necessary to support the new rate of physical capital investment. Thus, over the long run, once the effects of a lower level of  $h$  start to be felt in the economy  $w$  will start increasing and the rate of growth of the enterprise sector decelerates. Moreover, the household-producers in Region 2 start disinvesting. The economy's rate of growth over the long run is reduced. But as wages recover, tax revenues and, consequently, the human capital sector growth rate also recover until  $\hat{h}$  reaches the new required rate that sustain the capital growth in the enterprise sector.

### ***A rural disaster concentrated in one region: The case of a middle-income economy***

As in the previous case we assume that prior to the disaster the economy is in steady state, which means that the households sector has reached asset levels  $k_A^*$  and  $n^*$  which implies that  $r(np, w) = \pi(q, z, w)$ . We consider here two alternative initial steady state scenarios: (i) one that

entails positive long run growth prior to the disaster. That is, where the capital market is in full equilibrium (all rates of return to capital are equalized) and  $h > h^c$  (see Equation (40)) with the enterprise sector, therefore, able to grow permanently. (ii) The economy is stagnated where investments in human capital are insufficient to permit continuous growth of the enterprise sector (i.e.,  $h \leq h^c$ ). In this case  $\hat{k}_M = 0$ .

*(i) The case of a growing economy*

*Direct and short-run effects.* A key difference with the poor economy is that now the wage rate of the economy may not be affected. The direct effect which causes a discrete fall on  $k_A^2$  leads to a temporary reduction on the demand for labor. However, any slack in labor demand is picked up by the human capital sector (see (34')). That is,  $hl_H$  increases, which means that the rate of growth of human capital will rise<sup>21</sup>. This may in turn prevent a fall in the wage rate even in the short run.<sup>22</sup>

The negative short run effects of a geographically concentrated disaster mainly stay within the region where the disaster happens. Moreover, in an economy with integrated capital markets the household-producer sector is less likely to fall into the poverty trap than in a poor economy. The main reason is that the wage rate does not fall and therefore the income of household-producers falls less than in the poor economy. At least the wage component of their income does not decrease. Moreover, even if Region 1 falls into the extreme poverty trap this will not have negative spillover effects into Region 2 because the main mechanism by which these spillovers take place is via the fall in the wage rate. Thus, a localized disaster tend to remain much more contained within the locality when capital markets work and the private sector is allowed to invest in human capital production than when the capital markets are not developed.

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<sup>21</sup> Note that condition (40) is now weaker as  $h^c$  falls and therefore if the economy was before the disaster increasing its level of human capital will continue to do so after the disaster.

<sup>22</sup> Empirical evidence for Brazil is consistent with the positive effect of a weakening labor market on human capital investment; a study by Duryea and Arends-Kuenning (2003), shows that falling wages and employment conditions cause an increased enrollment in education and a fall in high school dropouts which, in turn, ameliorate the fall in wages.



The fall of  $n$  in the Region 1 will reduce the rate of return to capital in the region creating a gap between  $\pi(q, z, w^*)$  and  $r(np, w^*)$  thus upsetting the long run equilibrium condition that calls for equalization in the rates of return to physical capital. This would induce pressures to mobilize part of the household-producer sector capital towards the enterprise sector. However, the capital stock may not be easily converted from  $k_A$  into  $k_M$  in the short run. The transfer of capital must occur gradually over time by allowing  $k_A$  to depreciate for a while and by the household-sector investing all their savings in bonds issued by the enterprise sector instead. This allows for a faster recovery of the natural resource stock than in the poor economy where the household can only invest its savings in its own productive capital. Eventually  $n$  returns to the same steady state level  $n^*$  at which point the rate of return to capital in the household sector becomes again equal to that of the rest of the economy again. An important implication of this is that when capital markets are well developed the economy will be able to recover the natural capital destroyed by a disaster more rapidly than an economy where capital markets do not exist.

*Medium-term effects.* The expansion of  $hl_H$  that takes place in the short run causes a faster human capital accumulation. But as  $h$  now grows faster the effective supply of labor increases more rapidly which in turn causes incipient reductions of  $w$ . Any small decrease in  $w$  improves the rate of return to  $k_M$  which in turn induces an increase of the demand for labor in the enterprise sector thus allowing to cancel any such wage decrease. The fall of wage rate below  $w^*$  is thus only ephemeral.

In the meantime the Region 2 recovers its stock of natural resources to the level  $n^*$ . At that point it starts rebuilding its stock of physical capital until the old steady state is reestablished with  $k_A = k_A^*$ . The long run rate of growth of this economy will not be affected. This follows from the fact that  $\hat{k}_M$  remains unchanged over the long run. In fact, given that  $w$  remains constant at  $w^*$  it follows from (26) that  $\hat{k}_M$  returns to its pre-disaster level.

**Summary:** *Disaster shocks in a growing middle-income economy cause a temporary acceleration of economic growth but over the long run the economy grows at the pre-disaster rate. The household-producer sector is less likely to fall into*

*a poverty trap and thus over the long run is more likely to fully recover than in the case of the economy with undeveloped capital markets.*

*(ii) The case of a stagnated economy*

The economy is initially stagnated because the labor demand from the household and enterprise sectors do not leave enough space to the human capital sector to produce new human capital to allow positive growth. That is, prior to the disaster the stocks  $k_M, k_A, n$  are too high vis-à-vis  $h$ , making the combined demand for efficiency labor from the household and enterprise sectors too large to allow human capital to experience net growth. This implies that initially the wage rate per unit of efficiency labor has become too high to support net growth of both  $k_M$  and  $h$ . As shown earlier, this equilibrium wage rate is  $w^0$ , defined by the wage rate that makes  $\pi(q, z, w^0) = \rho + \delta_k$ . Moreover, this equilibrium wage rate is higher than the wage rate that would prevail if the economy were able to accumulate human capital (i.e.,  $w^0 > w^*$ ). At the stagnating equilibrium the economy does not invest in human capital not because its rate of return is low (in fact, it is easy to see that at  $w^0$  we have that  $r^H \equiv BL - \delta_h > \pi(q, z, w^0) - \delta_k$ ) but because the composition of the asset endowments do not allow for any residual labor to be invested in the human capital sector. Importantly, the fact that the wage per efficiency time,  $w^0$ , is greater in a stagnated economy than the wage rate that would prevail in a growing economy,  $w^*$ , does not mean that the wage per unit of actual time worked is lower. In fact, the actual wage of a growing economy,  $w^*h(t)$  eventually would overcome the actual wage of a stagnating economy at some point in time,  $\tilde{t}$ .

A disaster causes a temporary reduction of  $k_A$  and  $n$ . This lowers the demand for efficiency labor leaving space for the human capital sector to use some of the labor left available to produce human capital. The human capital sector will increase its use of the surplus labor partly off-setting the labor demand reduction. The wage rate nonetheless needs to fall in the short run towards  $w^*$  before the human capital becomes competitive and employ the surplus labor being generated. At that point short run equilibrium is reached where now human capital starts growing and the economy expands. If the household-producer sector does not fall into the subsistence trap, the levels of  $k_A$  and  $n$

eventually recover to the same pre-disaster levels. Once this happens the asset composition of the economy is likely to be more favorable than prior to the disaster in the sense that it may then be more amenable to allow the human capital sector to grow while keeping the wage rate pegged at  $w^*$ . Over the intermediate run both  $h$  and  $k_A$  have been increasing. If  $h$  has grown at a sufficiently faster pace than  $k_A$  it is possible that the condition  $h > h^c$  be maintained (see (40)). In this case what was a stagnant economy prior to the disaster becomes a growing one after the disaster<sup>23</sup>.

**Summary:** *A disaster that affects more intensively the stock of physical capital than human capital may propel a middle-income economy from chronic economic stagnation to permanent economic growth.*

This result is consistent with empirical studies that have shown that some countries tend to grow faster over the long run after disasters than before them (Albala-Bertrand 1993). Moreover, certain empirical studies have also shown that growth expansion after disasters tends to happen more often in middle-income countries than in poor countries (Cuaresma et al. 2008). The previous analysis predicts precisely this; we showed that this phenomenon may occur in countries where the private sector plays an important role in providing human capital and where capital markets are well developed which are often middle-income countries.

Some authors including Popp (2006) and Skoufias (2003) have recognized that the destruction of physical assets may promote greater investment in human capital and Duryea et.al. (2003) has even provided rigorous empirical documentation of it for Brazil. What has not been recognized in the literature is that this effect could cause *permanent* growth effects and can make the difference between stagnation and continuous economic growth over the long run. Under certain conditions facilitated by the existence of well developed capital markets and full participation of the private sector in the

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<sup>23</sup> This phenomenon is consistent with and illustrated by the following observation: Anyone familiar with academics knows that the number of applications for entering universities both to undergraduate and graduate programs shoot up during recessions. Most of the increased university applicants come from the labor force or would have entered the labor force instead of pursuing further studies if the labor market were in better shape. Also, in times of recession it is much easier to retain faculty members and to attract new ones which otherwise would be employed in the private commercial sector. Effectively, the “real” sector of the economy competes with the human capital sector for both potential students and teachers which otherwise could be employed by the commercial sector of the economy. This competition becomes much less intense in times of recession, which may have the effect of promoting a more rapid expansion of the human capital of the economy.

production of new human capital there this a potential for a qualitative shift of the economic regime from stagnation to growth.

*Migration.* If the disaster triggers significant migration it may have an opposite effect: increasing migration could upset the economy's asset composition against growth. If a significant part of the labor force emigrates, the critical level of human capital that makes possible the growth process to continue,  $h^c$  in (40), could increase. As can be seen in (40) a reduction in  $L$  increases  $h^c$ ; this leaves open the possibility that an economy where  $h$  was prior to the disaster above the critical threshold might end up below it and, hence, unable to continue expanding its human capital and possibly stagnate.

Thus, disasters prompt two opposing forces: on the one hand they reduce the demand for labor from the productive sector which is a force that promotes greater investment in human capital and hence is pro-growth. On the other hand, it may induce migration which reduces the supply of human capital and thus reduces the human capital available for human capital accumulation and hence is growth depressing.

A prediction from the analysis is that countries where the migration response elasticity is large (say Honduras or El Salvador which by been close to the US magnet and by having a large portion of its population abroad may facilitate further migration in difficult times) are more likely to fall into stagnation after a disaster than countries where the migration elasticity is smaller due to geographic isolation and low historical rates of migration (say Chile or Argentina). The diverse migration responsiveness between Chile and Honduras may contribute to explain the big contrast between the experiences of Honduras after the massive disaster brought by hurricane Mitch and Chile after the 1960 equally massive earthquake. Chile post 1960 suffered relatively modest losses of lives and experienced negligible emigration as a consequence of its isolation and lack of migration experience at the time. The dramatic disaster in Chile caused no perceptible deceleration of economic growth over the next ten years. By contrast, there is hard evidence that emigration from Honduras dramatically increased after Mitch and there is also evidence showing that the rate of growth in

Honduras after Mitch suffered a prolonged dip (see Table 1 for a comparison between Chile and Honduras)<sup>24</sup>.

**Summary:** *A disaster that directly or indirectly reduces human capital more than physical capital may cause an initially growing economy to fall into a stagnation trap or may not help an initially stagnant economy to become a growing one.*

As shown in section I the empirical evidence suggests that most disasters tend to affect more the physical capital basis than the human capital level. Loayza et.al. (2009) are able to find certain empirical regularity concerning the effects of disasters on growth that is consistent with our findings: Disasters that reduce the capital labor ratio of the economy tend to cause faster growth while disasters that increase such ratio cause the opposite effect.

## V. PRONENESS TO DISASTERS

So far we have considered mainly how an economy evolves in response to one (possibly unexpected) major disaster. Another issue is how an economy evolves when people know ex-ante that smaller but recurrent disasters periodically occur. The literature that considers this issue has concluded that a possible response to expected recurrent disasters is to cut back investments on physical assets which are usually more vulnerable to disasters and to expand investments on assets such as human capital that are less vulnerable (Skidmore and Toya 2002). Empirical corroboration of this hypothesis, however, is extremely difficult to satisfactorily implement mainly because of inadequate data on assets, particularly human capital (Mulligan and Sala-i-Martin 1997, 2000). So the existing empirical evidence is rather weak. Below we provide some further conceptual probing of this story in the context of an economy that has well developed capital markets.

The simplest way of capturing the ex-ante disaster expectation effect is to assume that such expectation increases the expected asset depreciation rate of the vulnerable assets ( $\delta_k$  in the context

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<sup>24</sup> In addition, Benson and Clay (2004), discuss the cases of Dominica and Montserrat, where migration has meant a significant loss of human capital and has contributed to the impoverishment of poor households and communities.

of the model). At the beginning of each period investors consider the expected return for the period that one extra dollar invested in the asset yields. Assume that the asset flow yield is accrued at the beginning of the period but you need to keep your money tied until the end of such period during which there is a risk of losing part of the principal (you milk your cow early in the morning but there is a small probability of losing the cow at the end of day, say as a consequence of a lightning). This means that the expected net rate of return to one dollar of physical capital is  $\pi - (\delta_k + \nu)$ , where  $\delta_k + \nu$  is the effective rate of depreciation ( $\nu$  is of course the probability of losing the capital stock which in turn depends on the probability of disaster)<sup>25</sup>.

Assume that unlike physical capital, human capital is not exposed to disaster risk. Then, assuming that the economy is diversified (i.e., it produces new human capital), equations (14'), (15) and (39) imply,

$$(39') \quad \pi(q, z, w^d) - \delta_k - \nu = BL - \delta_h$$

Clearly, the equilibrium wage  $w^d < w^*$ ; that is, the expectation of disasters has the effect of reducing the wage rate that allows for the rates of return to investment in human capital production and elsewhere in the economy to equalize. It follows that the rate of growth of physical capital accumulation,

$$(26') \quad \hat{k}_M = \frac{1}{a} [\pi(q, z, w^d) - (\rho + \delta_k + \nu)],$$

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<sup>25</sup> A more elaborated example: You invest in a bond January 1 and receive on that day a coupon for the interests, equal to  $\tilde{r}$  for each dollar invested which you may redeem on that day but you need to leave your principal invested until the end of the year. There is a certain probability,  $\nu$ , of default within that year. The level of  $\nu$  used in ex-ante evaluating the net rate of return, in turn, may depend on the probability of a disaster. The more prone to disaster a country is the higher is  $\nu$ . This is your effective expected depreciation rate. Thus the ex-ante expected rate of return is  $\tilde{r} - \nu$ .

is affected by two effects: a direct one which reduces it and an indirect one via the fall in the wage rate that acts in the opposite direction. It can be shown, however, that the net effect is negative, that is, the direct effect dominates the indirect one<sup>26</sup>.

Thus, the first part of the hypothesis in the literature, that a higher probability of disaster reduces the rate of accumulation of physical assets is corroborated. What about the literature's second hypothesis: does the rate of human capital accumulation increase in more disaster prone countries? Consider the labor market equilibrium again now evaluated at  $w^d$  instead of  $w^*$ ,

$$(34'') \quad -\pi_3(q, z, w^d)k_M - r_2(n^* p, w^d)k_A^* + hl_H^d = (1-\xi)hL$$

For given levels of  $k_M$ ,  $k_A$ , and  $h$ , it is clear that the fact that  $w^d < w^*$  implies that  $l_H^d < l_H^*$ ; that is, the rate of human capital accumulation as shown in (28') is also reduced by the expectation of disasters. This contradicts the second hypothesis in the literature. But of course the fact that  $k_M$  grows at a lower rate could imply that, given enough time,  $l_H^d$  could become larger than  $l_H^*$  and thus, eventually the rate of human capital accumulation could become faster than in the case where there is less probability of disaster. Could this effect allow human capital to grow faster?

A way of probing this is to perform the following experiment: Suppose a country that is experiencing positive growth is affected by an increased probability of disaster. Scientists in a particular country credibly conclude that climate change is likely to cause a greater frequency of periodic disasters in the future. How would the economy with initial levels of assets  $k_M(0), k_A(0), n(0)$  and  $h(0)$  respond to such a prediction? The level of  $\nu$  increases and thus the impact effect is to decrease  $w$  which, in turn, causes an increase in the demand for labor from the enterprise and household-producer sectors. The increased demand for labor from the productive sectors will crowd-out the human capital sector causing the rate of human capital accumulation to fall. In addition, the rate of accumulation of physical capital would be decreased because as before the direct negative impact of a higher  $\nu$  on the returns to capital dominates the indirect wage effect.

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<sup>26</sup> A formal proof available from the author.

Thus, the impact effect is to reduce both the rate of investment in physical capital as well as the rate of investment in human capital. Unlike the popular hypothesis in the literature, physical capital and human capital are dynamic complements not substitutes over the long run<sup>27</sup>.

An implication of this is that the hypothesis that proneness to disasters causes faster human capital accumulation is at least questionable. Further empirical probing of this assumption is needed using better data on human capital that is beginning to emerge. Students from many countries are now participating in standardized cognitive tests in various subjects. In fact, for some of these subjects (especially mathematics) there is by now a large number of score measures over the last decade and a half for many countries. As is recognized in the literature the test scores are a much better indicator of human capital than simply enrollment rates or numbers of schooling years. If the hypothesis that more frequent disasters are associated with increasing human capital is corroborated with these more elaborated estimates it would mean that the conceptual analysis above should be reconsidered. If the new estimates show that this is not the case it would mean that both empirical and conceptual analyses point in the some direction, enough cause to reconsider our premises.

## VI. CONCLUSION

This paper has developed a dynamic general equilibrium model that allows us to consider the long-run implications of disasters focusing on the interactive dynamics of intangible vis-à-vis physical assets. This paper brings a large number of important insights in the literature into a coherent general development theoretic framework. This allowed us to develop new hypotheses explaining seemingly contradictory findings in the empirical literature regarding the growth consequences of disasters. Below we summarize the two most vital specific contributions of this paper.

The first contribution of this paper is to show conditions under which disasters may trigger faster economic growth and alternative scenarios where disasters can lead to stagnation. More

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<sup>27</sup> In more standard balanced two assets growth models this dynamic complementary characteristic is even more evident. For example the Barro and Sala-i-Martin, 1995 (chapter 4) provides an analysis of one sector growth with human and physical capital where over the long run the capital/human capital ratio is constant. This obviously means that any reduction in the rate of growth of one of the assets must cause the other asset to also decrease its growth rate.



importantly, we have shown that under certain initial conditions a disaster may propel an economy from chronic stagnation into a consistent growth path over the long run. Economies that are too rich in physical capital relative to human capital tend to crowd out investments in human capital which, in turn, means that the accumulation of physical assets becomes unsustainable in the long run. This brings what we call the paradox of human capital where the scarcity of human capital causes a high rate of return to human capital investment yet the market allocation does not allow for greater investments in human capital. Thus long run stagnation is the natural outcome. Disasters commonly devastate physical assets but cause much less damage to human capital causing a change in the asset endowment of the economy in favor of human capital. This, in turn, may solve the stagnation problem allowing the economy to start greater investment in human capital prompting a virtuous cycle of economic growth. Disasters may solve the human capital scarcity trap by causing a somehow lower rate of return to human capital but also causing market conditions that prevent the crowding out of human capital investments.

The second specific contribution of this paper is showing the crucial role of the degree of development of capital markets in affecting the disaster consequences. We have shown that disasters concentrated in one region are less likely to cause significant real wage reductions in the economy when capital markets are well-developed than when they are not. This means that the existence of capital markets tends to prevent redistribution of income against workers as a consequence of disasters.

Moreover, the fact that wages are not affected also implies that the likelihood of disasters causing the households to fall below economic irreversible asset thresholds which lead to spiraling impoverishment is lower when capital markets are efficient than when they are not. Capital markets in general tend to also reduce the likelihood that the ecological thresholds be violated after a disaster. The main reason for this is that capital markets relieve pressures on natural resources allowing the economy to operate with higher levels of natural capital in normal times. Thus a disaster is likely to catch the economy in a better (less vulnerable) natural resource position when capital markets exist than when they do not. A similar disaster, therefore, is less likely to induce ecological threshold violation and, hence, subsistence traps when capital markets are efficient than when they are not.

In addition, capital markets also tend to prevent negative spillovers of disasters affecting one particular region into other regions not directly affected. This means that households not directly affected by disasters have no risk of falling into poverty traps. By contrast, when capital markets do not exist wage spillovers may easily lead to households in unaffected regions to fall into economic and subsequently ecological traps. An implication of the analysis is that perhaps one of the most effective means to reduce the negative impacts of disasters is the development of the institutions that allow the capital markets to work.

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TABLE 1  
PER CAPITA GDP GROWTH BEFORE AND AFTER A MAJOR DISASTER

Country	Total Damage (% GDP)	Real GDP per capita in disaster year (constant 2000 US\$)	Growth GDP per capita % (average 2 previous years)	Growth GDP per capita % (average 2 following years)	Growth GDP per capita % (average 4 previous years)	Growth GDP per capita % (average 4 following years)	Growth GDP per capita % (average 10 previous years)	Growth GDP per capita % (average of the following 10 years or until 2007)
Honduras (Huracan Mitch 1998)	73%	1,151	1.99	-0.12	0.45	0.55	0.89	2.42
El Salvador (Earthquakes in 2001)	10%	2,122	0.97	0.82	1.47	0.94	2.19	1.55
Nicaragua (Huracan Mitch 1998)	28%	715	3.07	3.85	2.65	2.13	-1.71	2.44
Dominican Republic (Huracan Georges 1998)	17%	2,000	5.75	6.32	4.17	4.33	1.80	4.21
Belize (Huracan Keith 2000)	34%	3,330	3.20	1.92	1.40	2.78	2.90	2.08
Maldives (Tsunami 2004)	78%	3,116	6.02	7.44	4.07	6.21 *	5.63	6.21
Indonesia (Tsunami 2004)	2%	904	3.25	4.30	3.08	4.57 *	1.97	4.57
Chile (Earthquake 1960)	13%	1,875	-2.47	2.11	0.43	1.94	1.26	1.97

Province	Total Damage (% GDP)	Real GDP per capita in disaster year (constant 2000 US\$)	Growth GDP per capita % (average 2 previous years)	Growth GDP per capita % (average 2 following years)	Growth GDP per capita % (average 4 previous years)	Growth GDP per capita % (average 4 following years)
Aceh, Indonesia (Tsunami 2004)*	97%	1,108	4.88	4.31	2.55*	4.18*

Source: Own elaboration based on data from WDI and from BPS (Provincial Statistic Bureau of Aceh)

\*Three year average (GDP per capita for 2008 hasn't been published yet)

\*The Real GDP per capita is in constant 2002 US\$ for Aceh

TABLE 2  
Impact of Droughts and Earthquakes on long run Sector growth  
(Based on Loayza et al., 2009)

Dependent variable	Droughts	Earthquakes
Growth Rate of GDP per capita	(-) <sup>***</sup>	(+)
Growth Rate of Agricultural Value-added per capita	(-) <sup>***</sup>	(-)
Growth Rate of Industrial Value-added per capita	(-)	(+) <sup>***</sup>

(-) negative impact on growth

+ positive impact on growth

\*significant at 10%; \*\*significant at 5%; \*\*\*significant at 1%

Source: own elaboration based on the results of the regressions of Loayza et. al. (2009)



TABLE 3  
CAPITAL STOCK AND HUMAN LIVES LOST DUE TO A DISASTER IN JAPAN AND HONDURAS

		Japan (Kobe Earthquake, 1995)	Honduras (Mitch Hurricane, 1998)
Damage in Stock of Capital	% of Country GDP	2.30%	12%
Lost Population (Deaths + migration)	Number of persons	106,500	65,745
	% of Total Population	0.08%	1.12%

Source: Horwich (2000), for Japan and Meza (2006) for Honduras.

**TABLE 4**  
**DAMAGES IN PRODUCTIVE SECTORS FOR SELECTED COUNTRIES**

Country	Affected Population (% of total Population)	Total Damage (% GDP)	Agriculture, Livestock, Fisheries, Forestry (% of Sectorial GDP)		Enterprises (% of Sectorial GDP)	
			Damage to assets*	Lossess of Production**	Damage to assets*	Lossess of Production**
Honduras (Huracan Mitch 1998)	86.6%	72.9%	99.9%	65.6%	7.4%	40.4%
El Salvador (Earthquakes in 2001)	18.3%	9.6%	3.7%	5.5%	5.2%	0.6%
Nicaragua (Huracan Mitch 1998)	9.7%	27.6%	18.3%	8.1%	2.0%	19.5%
Rep. Dom (Huracan Georges 1998)	19.0%	17.1%	46.8%	39.1%	9.5%	6.5%
Belize (Huracan Keith 2000)	24%	33.7%	31.7%	19.2%	37.8%	12.6%
Maldives (Tsunami 2004)	4.8%	77.7%	35.3%	9.9%	26.6%	37.0%
Aceh, Indonesia (Tsunami 2004)	24.0%	97.0%	20.3%	59.9%	7.5%	12.5%

\*Damage represents the total or partial destruction of physical assets, such as infrastructure, buildings, furniture and equipment. Damage occurs at the time of the disaster, and is measured at replacement value.

\*\*Losses are changes in economic flows that arise as a result of damage. They include decline in production and sales or increased production costs; lower revenues and higher production costs in the provision of services; and increased expenditures arising from the disaster. They occur after the disaster and over a relatively long period of time until full reconstruction and recovery has been attained

Source: Own elaboration based of assessment reports from ECLAC and ADPC, for macroeconomic values WDI and Central Bank of each country

TABLE 5  
COMPOSITION OF PUBLIC EXPENDITURE BEFORE AND AFTER DISASTERS IN SELECTED  
COUNTRIES  
(% of total government expenditure)

Country	SOCIAL			ECONOMIC SERVICES			OTHER SERVICES		
	Average of two previous years	Disaster year	Average of two following years	Average of two previous years	Disaster year	Average of two following years	Average of two previous years	Disaster year	Average of two following years
Honduras (Huracan Mitch 1998)	28.2	29.6	33.4	22.4	23.2	19.2	49.4	47.2	47.6
Aceh (Tsunami 2004)	46.3	34.6	38.3	10.7	9.9	8.0	43.2	55.6	53.7
El Salvador (Earthquakes in 2001)	36.2	41.5	37.6	12.1	12.3	10.2	51.8	46.2	52.3
Nicaragua (Huracan Mitch 1998)	37.0	33.7	40.6	22.0	26.7	28.9	41.1	39.6	30.5
Rep. Dom (Huracan Georges 1998)	38.3	35.5	39.1	34.5	31.8	26.2	27.2	32.8	34.6
Maldives (Tsunami 2004)	47.9	46.5	51.6	14.6	14.9	11.9	37.5	38.5	36.5

**Social public expenditure:** Housing and community amenities, Health, Education and Social Protection **Economic Services:** General economic, commercial, and labor affairs; Agriculture, forestry, fishing, and hunting; fuel and energy; mining, manufacturing and construction; transport; communication; other industries, R&D Economic affairs  
**Other Services:** General Public Services, Defense, Public Order and Safety, Recreation, culture and religion

Source: Own elaboration based on data from GFS, WDI and countries statistics

TABLE 6  
SPENDING ON PUBLIC VS PRIVATE GOODS: TRENDS IN FOUR COUNTRIES, 1985-2005

<b>Brazil- Federal and state government expenditure</b>	1985	1990	1995	2000	2004	2005	Average
Share of public goods expenditures in total gov't	42%	30%	47%	35%	37%	38%	41%
Share of private goods and subsidy in total gov't	24%	47%	36%	27%	32%	32%	34%
Ratio of type A over type B	1.80	0.64	1.31	1.30	1.16	1.18	1.27
<b>Chile - Central government expenditure</b>	1985	1990	1995	2000	2004	2005	Average
Share of public goods expenditures in total gov't	n.a.	70%	78%	80%	82%	83%	77%
Share of private goods expenditures in total gov't	n.a.	30%	22%	20%	18%	17%	23%
Ratio of type A over type B	n.a.	2.32	3.55	4.03	4.70	4.83	3.58
<b>China- General government expenditure</b>	1985	1990	1995	2000	2004	2005	Average
Share of public goods expenditures in total gov't	64%	60%	45%	50%	48%	48%	51%
Share of private goods and subsidies in total gov't	34%	26%	17%	15%	14%	14%	21%
Ratio of type A over type B	1.88	2.30	2.68	3.29	3.37	3.45	2.53
<b>India- Consolidated general government</b>	1985	1990	1995	2000	2004	2005	Average
Share of Public goods expenditures/Total exp & Net	32%	31%	29%	29%	29%	32%	30%
Share of Private goods expenditures/Total exp & Net	18%	18%	18%	18%	19%	18%	18%
Ratio of type A/ type B	1.77	1.71	1.63	1.62	1.49	1.82	1.63

*Source:* Lopez et al. 2008. The Quality of Growth: Fiscal Policies for Better Results. IEG-World Bank

**Public goods** are defined as: Public order and safety, Environment protection, Housing and community amenities, Health, Recreation, culture and Religion, Education, and Social protection. **Type A** interventions emphasize using the government expenditures to reduce the impact of market failure on the accumulation of assets, particularly human capital, knowledge and the environment. **Type B** intervention focuses on (non-social) subsidies to private goods which are often captured by the elites. Subsidies to private goods, including commodity subsidies, credit subsidies, grants to corporations, loan guarantees, marketing subsidies and others are much more easily appropriated by the most powerful interests that are able to lobby governments most effectively

TABLE 7  
FUEL SUBSIDIES in 2005

<b>Explicit subsidies</b>		
	% of Public Expenditure	% of GDP
Bolivia	3.0%	0.8%
Congo, Republic of	5.0%	1.0%
Dominican Republic	3.2%	0.5%
Ghana	2.0%	0.4%
Honduras	2.4%	0.4%
India 1/	4.6%	0.7%
Indonesia	20.2%	3.4%
Jordan	17.4%	5.6%
Lebanon	0.3%	0.1%

<b>Implicit subsidies</b>		
	% of Public Expenditure	% of GDP
Bangladesh	10.3%	0.9%
Egypt	19.9%	4.1%
Peru	0.4%	0.1%

*Source:* Own elaboration based on Lopez et al. 2008. The Quality of Growth: Fiscal Policies for Better Results. IEG-World Bank

TABLE 8  
PER CAPITA ANNUAL ASSET GROWTH RATES FOR SELECTED COUNTRIES (1990-2001)

Country	Growth of Physical Capital per capita	Growth of Human and Environmental Assets per Capita	Growth of Net Total Wealth per Capital
Mexico	2.0%	-0.6%	-0.1%
Paraguay	1.6%	-1.8%	-1.0%
Chile	3.0%	-0.6%	0.2%
Ecuador	3.5%	-2.6%	-1.3%
Costa Rica	1.4%	1.0%	1.1%
Peru	1.8%	-0.8%	-0.2%
Uruguay	0.0%	0.2%	0.1%
Argentina	0.0%	-0.5%	-0.4%
Bolivia	1.0%	-2.0%	-1.6%
Brazil	2.0%	-0.6%	-0.1%
Venezuela	1.5%	-4.0%	-1.5%
<b>Comparators</b>			
Korea	3.5%	1.2%	1.8%
Ireland	2.7%	1.7%	2.0%

Source: Lopez and Toman (2006)

TABLE 9  
Physical Capital and Human Capital Stocks for High and Middle Income Countries  
(2005 USD per capita)

	Produced Capital				Human Capital			
	Stock level 1995	Stock level 2000	Stock level 2005	Average Annual Growth for the whole Period	Stock level 1995	Stock level 2000	Stock level 2005	Average Annual Growth for the whole Period
Lower middle income	3,373	4,406	5,885	6.42%	6,885	7,433	9,444	3.50%
Upper middle income	13,644	15,376	15,802	1.55%	49,649	40,671	54,097	1.49%
High income	84,510	90,937	97,043	1.43%	371,268	412,935	446,637	1.94%

Source: Own elaboration based on data from Estimates of Wealth, World Bank.

TABLE 10  
 PERFORMANCE ON COGNITIVE TEST (PISA TEST)  
 FOR SELECTED COUNTRIES IN THE YEARS 2000 AND 2006

	Performance on the combined literacy scale	Performance on the combined literacy scale
	Year 2000	Year 2005
Mexico	422	410
Chile	410	442
Argentina	418	374
Brasil	396	393
Peru	327	*
Indonesia	371	393
<b>Comparators</b>		
Greece	474	460
Ireland	527	517
Korea	525	556
Poland	479	508
Portugal	470	472
Spain	493	461

\*not available in the publication

\*\*deflated by US CPI

Source: PISA 2003 and Education at a Glance 2007, OECD



TABLE 11

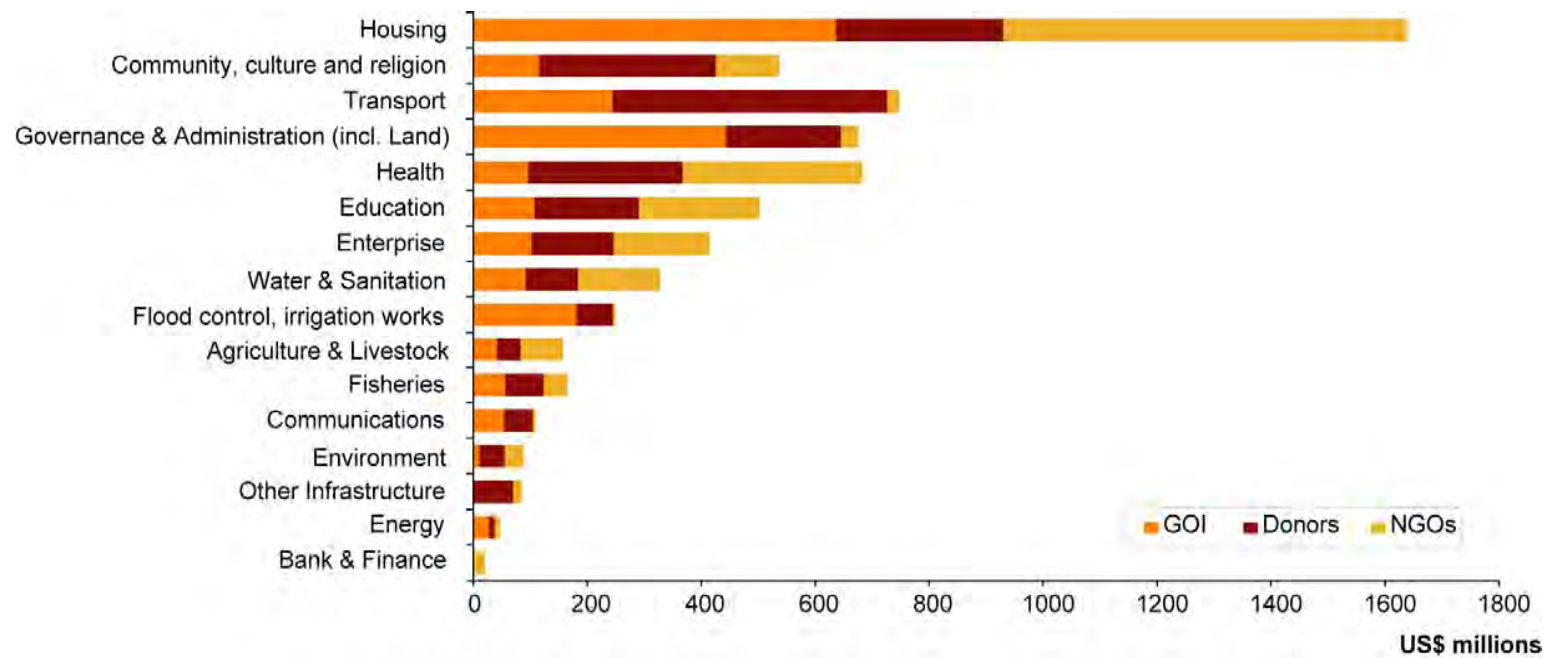
Private Education Enrollment in Primary and Secondary School, Private Education Expenditures, and Performance of the Private and Public Schools in the PISA test 2000 for selected countries.

Country	% of students in the private sector	Private Education Expenditures as a Percentage of Total Education Expenditures	Performance of the Private Schools on the combined reading literacy scale	Performance of the Public Schools on the combined reading literacy scale
Argentina	6.5	12.1	498	381
Brasil	10.5	*	460	386
Chile	12.9	30	484	387
Indonesia	46.6	23.5	357	380
Korea	33.6	22.6	533	519
Mexico	14.9	16.9	491	413
Peru	6.7	40.7	428	314
Thailand	17.5	*	422	433

\*not available

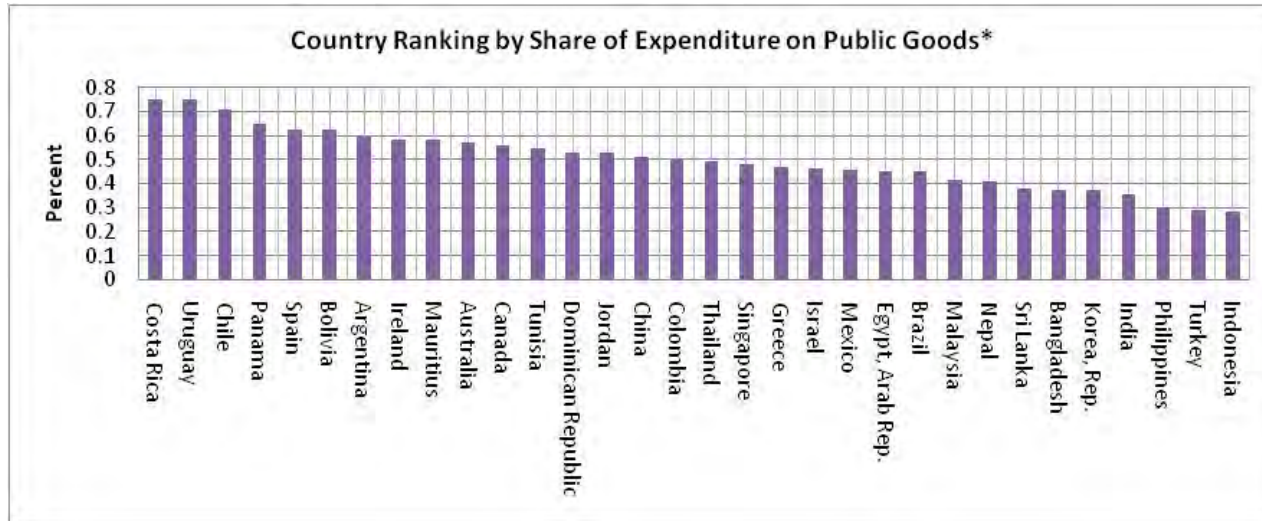
Source: World Bank EDSTATS for expenditures and OECD-PISA database, 2003. Table 7.13 for enrollment

Graphic 1  
 RECONSTRUCTION ALLOCATIONS DURING THE PERIOD IN ACEH (2005-2008)



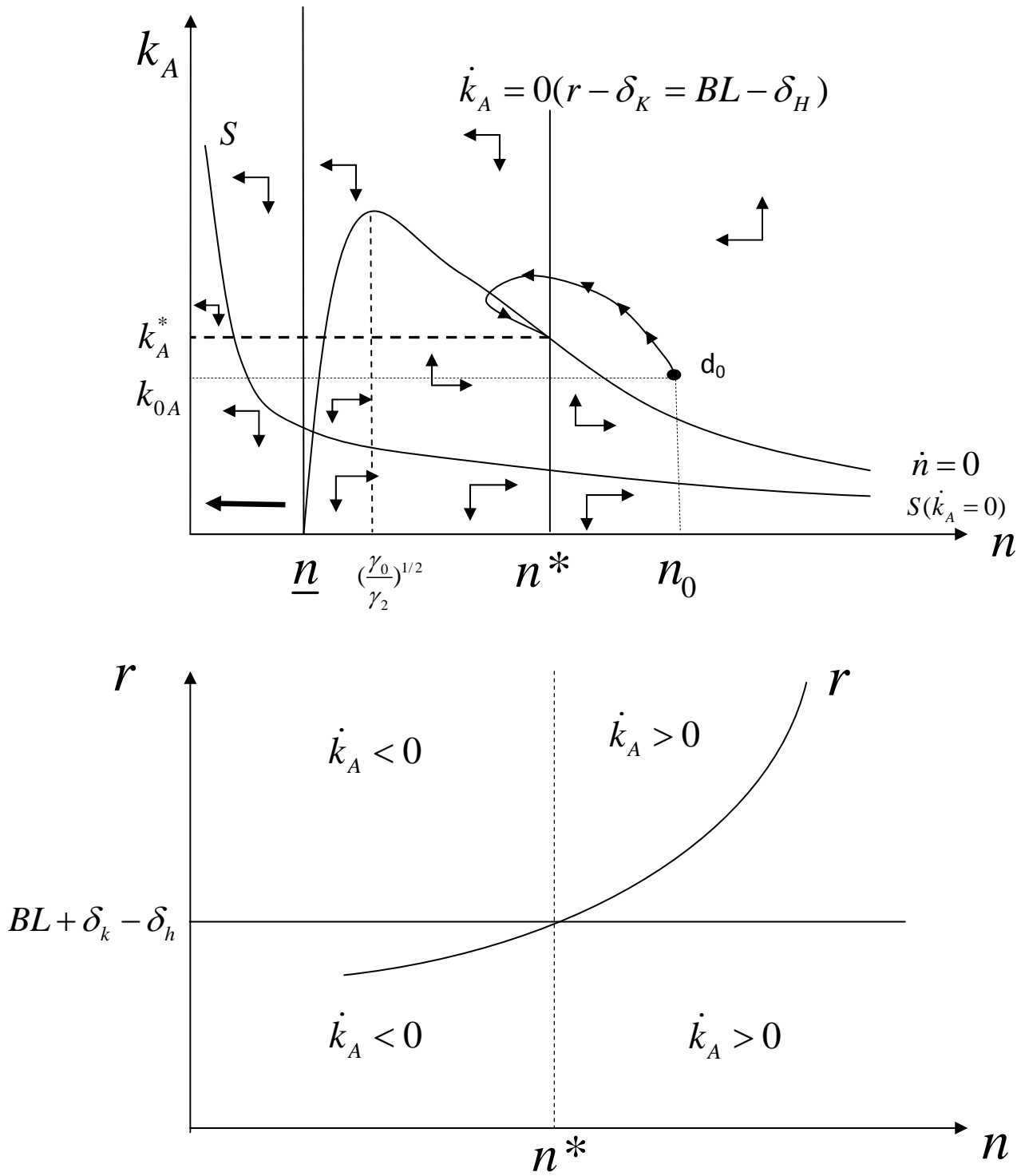
Source: Masyrafah, H. and McKeon, J. (2008). "Post-tsunami aid effectiveness in Aceh Proliferation and coordination in reconstruction"

Graphic 2

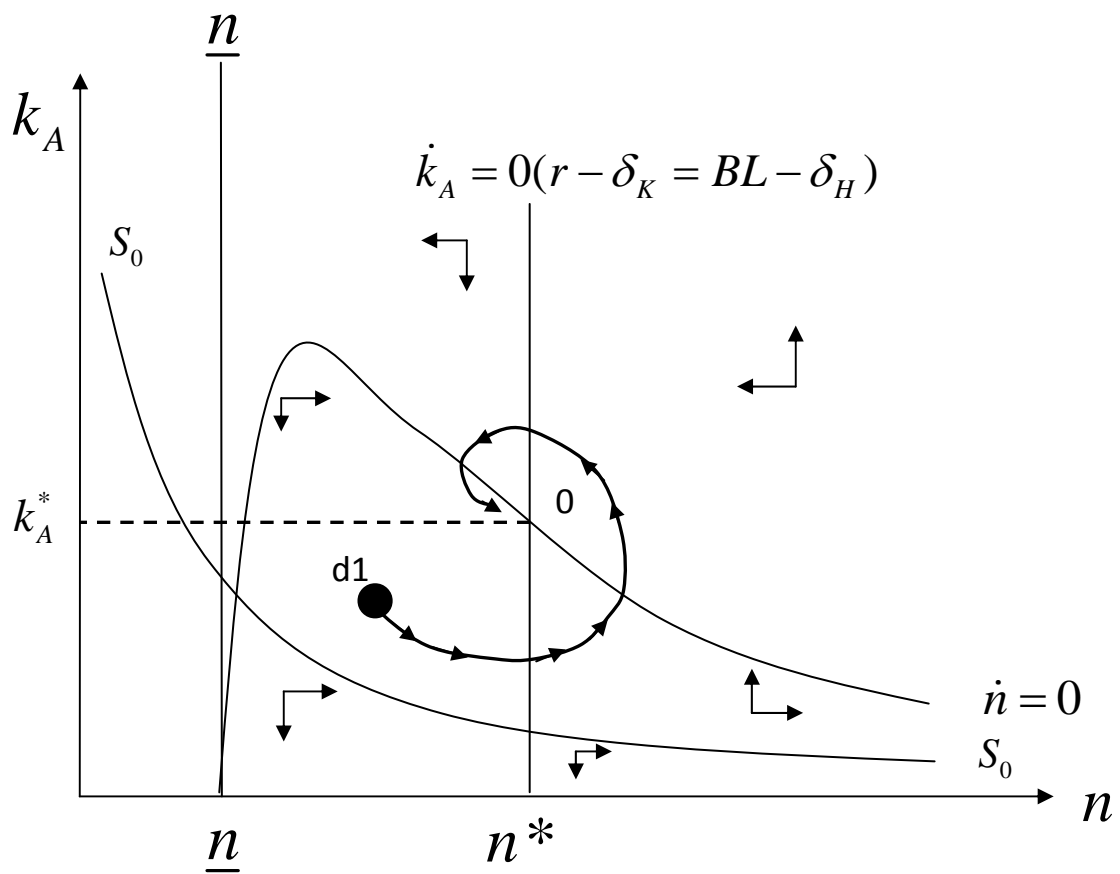


Source: Lopez et al. 2008. The Quality of Growth: Fiscal Policies for Better Results. IEG-World Bank

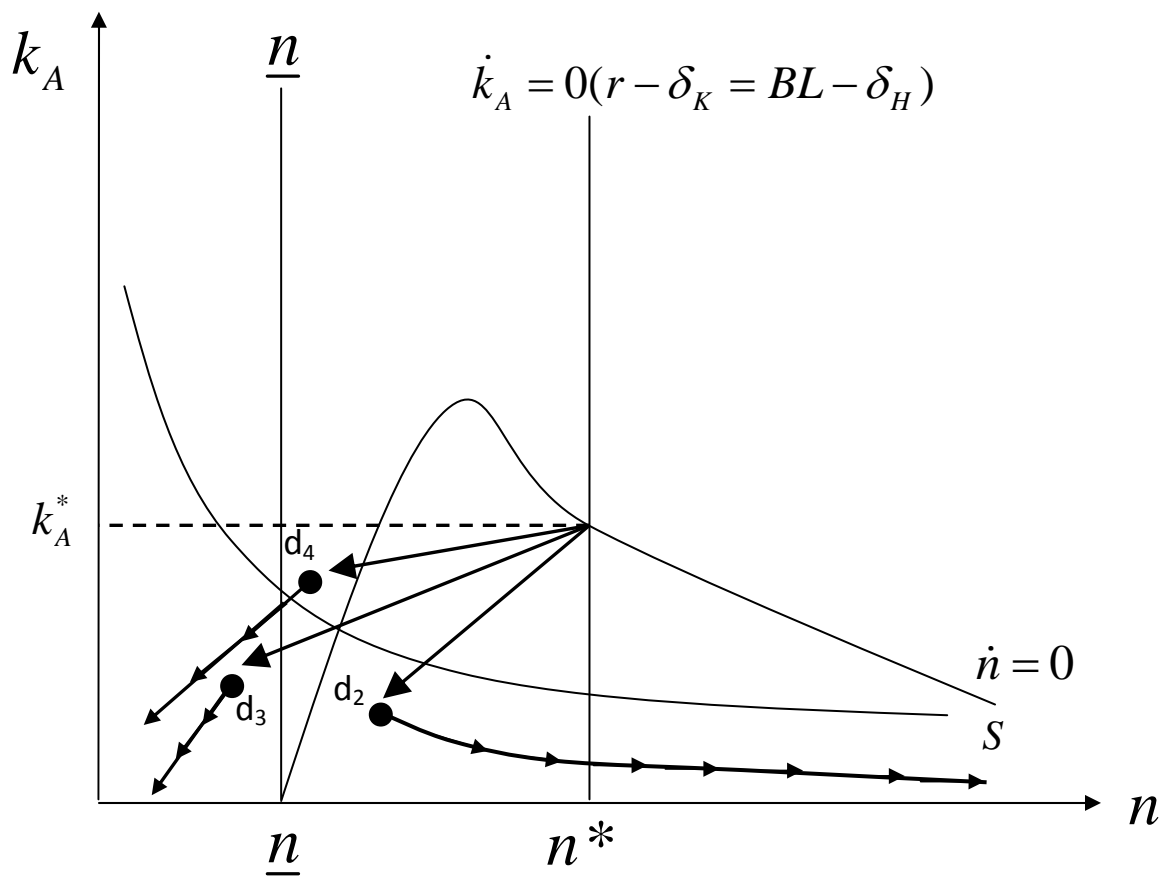
\* Public goods are defined as: Public order and safety, Environment protection, Housing and community amenities, Health, Recreation, culture and Religion, Education, and Social protection



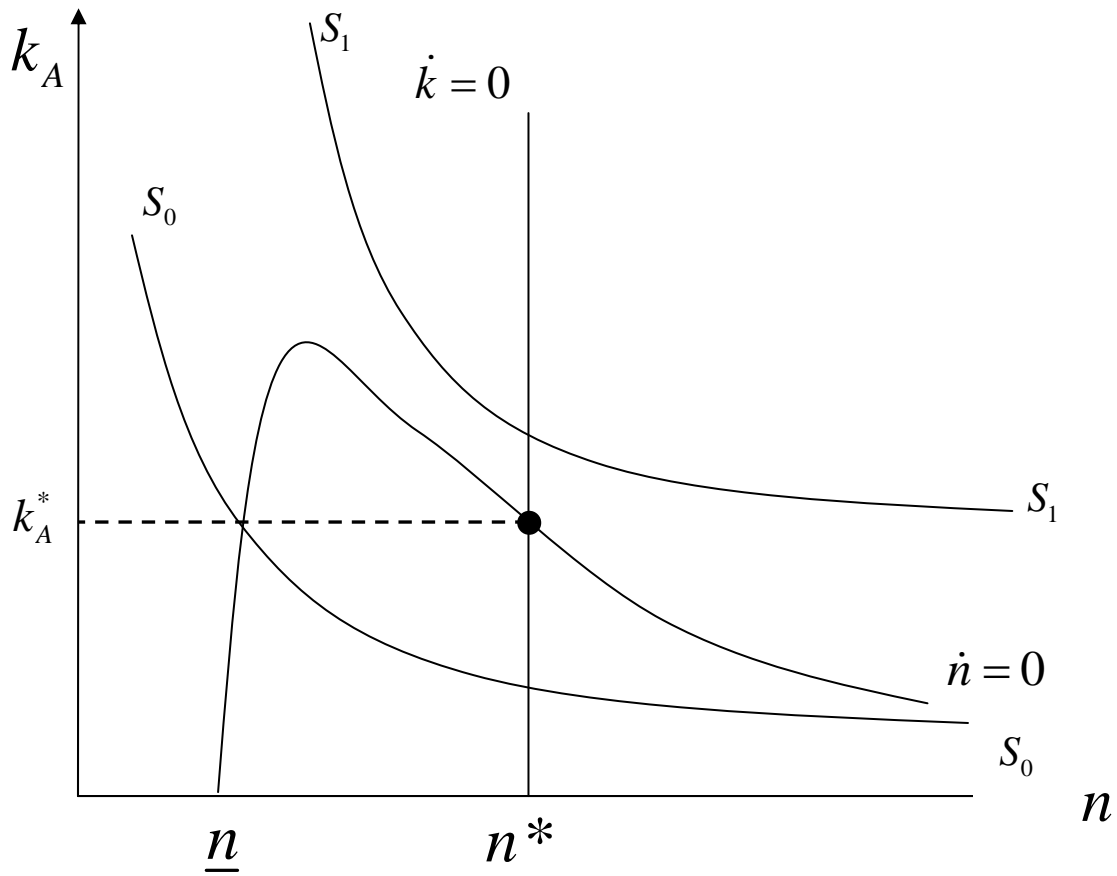
**FIGURE 1**  
Adjustment towards long-run equilibrium when there are no capital markets



**FIGURE 2**  
**Effect of a moderate disaster in Region 1: Reversible Damage**  
**(when there are no capital markets)**



**FIGURE 3**  
 Effect of a Major disaster in Region 1: Irreversible Damage  
 (when there are no capital markets)



**FIGURE 4**  
**Effects of a Disaster in Region 1 on Region 2**  
 Fall in wages displaces upwards the subsistence curve and some producers in Region 2 may fall into subsistence trap.  
 (when there are no capital markets)