Chapter 2 – Sustainable Development: Definitions, Measures and Determinants

1. Introduction

During the last decade, we have observed a remarkable upsurge of concern about the sustainability of economic development over the long run. As a result, considerable effort has been invested in the design of an analytical framework that can be used to think about policies that promote sustainable growth. This task has implied several methodological challenges, ranging from trying to define what is meant by sustainable development, to operationalizing the definition and designing indicators that can be used to monitor it.

This chapter has three objectives. The first is to introduce methodological issues about definitions and measurement of sustainable development. The second objective is to define a set of macro-flags that can be used to monitor sustainable development, and analyze their dynamics during the past two decades. The third objective is to better understand what are the factors that explain why some countries tend to make more intensive use of their natural resources base. This is a topic that has received little or no attention in the empirical literature, and yet is important for the assessment of sustainable growth.

The chapter is organized in five sections. Section 2 is concerned with definitions. Sections 3 and 4 are concerned with measurements. Finally, Section 5 is concerned with the empirical analysis of the dynamics of depletion rates.

2. What Do We Mean by Sustainable Development?

It is safe to state that there is not a single, commonly accepted concept of sustainable development, how to measure it, or even less on how it should be promoted. There are, in my opinion, two major views on the subject. On one hand, we have the ecologists' view that associates sustainability with the preservation of the status and function of ecological systems. On the other hand, we have economists that consider that sustainability is about the maintenance and improvement of human living standards. In the words of Robert Solow "if sustainability is anything more than a slogan or expression of emotion, it must amount to an injunction to preserve productive capacity for the indefinite future" (Solow, 1999). Hence, while in the ecologists' view natural resources have a value that goes beyond their productive use and cannot be substituted by other forms of capital, within the economics view natural resources can be consumed and substituted by other forms of capital, as long as productive capacity is maintained (see the discussion in Chapter 1, Section 2).

The World Commission on Environment and Development (Bruntland Commission) defined sustainable development as "development that meets the needs of the present without compromising the need of future generations to meet their own needs" (Bruntland Commission – see World Commission on Environment and Development, 1987). Toman (1999) better describes the reaction of both economists and ecologists to this definition:

"[...] If one accepts that there is some collective responsibility of stewardship owed to future generations, what kind of social capital needs to be intergenerationally transferred to meet that obligation? One view, to which many economists would be inclined, is that all resources - the natural endowment, physical capital, human knowledge and abilities - are relatively fungible sources of well being. Thus, large scale damages to ecosystems such as degradation of environmental quality, loss of species diversity, widespread deforestation or global warming are not intrinsically unacceptable from this point of view; the question is whether compensatory investments for future generations are possible and are undertaken. This suggest that if one is able to identify what are determinants of these "needs" and what types of resources are required to satisfy these needs, one should in principle determine [which] resources to transfer. An alternative view embraced by many ecologists and some economists, is that such compensatory investments often are unfeasible as well as ethically indefensible. Physical laws are seen as limiting the extent to which other resources can be substituted for ecological degradation. Health ecosystems, including those that provide genetic diversity in relatively unmanaged environments, are seen as offering resilience against unexpected changes and preserving options for future generations."

One approach to bring the views of economists and ecologists together is to assume that individuals derive welfare from, and have preference for, consumption, environmental quality, and social health, thus ruling out perfect substitution. This being the case, it is plausible to postulate the existence of a social welfare function that incorporates indicators of consumption, environmental quality and social stability. Then a sustainable development path can be defined as the one that maximizes the present value of the inter-temporal social function (see Gillis et al., 1992). In other words, a given set of economic, environmental, and social indicators would be aggregated into a single indicator that becomes a universal measure of sustainability. Policies could then be evaluated with respect to the impacts that they have on the indicator. An example of this type of indicator is the Human Development Index (HDI, see United Nations Development Program, 1991). This indicator essentially represents the average of life expectancy, literacy, and income per capita, and is published annually in the Human Development Report (see United Nations Development Program, 1995). The HDI is often used by national governments and international organizations to set policy goals and allocate public resources (see Murray, 1993). This implies that indicators like the HDI, in principle a positive or descriptive indicator, become normative or prescriptive indicators. Then, implicitly, the indicator is reflecting *some* set of "preferences". But given the way that indicators are usually constructed, these preferences are not likely to be "social preferences". Hence, maximizing the HDI may not be as desirable as maximizing some other weighted measure of life expectancy, literacy, and income per capita. Even worse, there may be other dimensions, currently omitted, that individuals consider important and that should therefore be included in any indicator of sustainable development. One of these dimensions is certainly the environmental dimension.

Therefore, coming up with a social function that aggregates social preferences may be an impossible task. The existence of such a social function depends on strong assumptions regarding agents' preferences and functional forms (see Harsanyi, 1953; Arrow, 1963; Bailey et al., 1980; Atkinson, 1980; and Lambert, 1993), and as suggested by Goodin (1986) in most cases may not exist. But even if it does, how do we go about measuring its components? In an attempt to approximate what could be interpreted as a set of universal social values about an indicator of sustainable development, I conducted a simple e-mail survey. The survey asked questions about individuals' preferences for three dimensions of sustainable development: economic growth, environmental quality, and income redistribution. The summary of weights that individuals place on each of these three dimensions is summarized in Appendix 8.1. Although the sample of individuals is not representative of the population, the results illustrate the high variance in individual preferences and give an idea of how difficult it would be to come up with a consensus regarding what is the appropriate social function to assess sustainable development.

These results convinced me to abandon the use of a social welfare function and opt instead for a measure that could be more transparent, and enjoy almost universal acceptance. In his work on common values, Bok argues that a minimalist set of social values is needed for societies "to have some common ground for cross-cultural dialogue and for debate about how best to cope with military, environmental, and other hazards, that, themselves, do not stop at such boundaries" (see Bok, 1995). Common values are not simply the values of the majority. Rather, they are a set of minimal values that nearly everyone in a society recognizes as legitimate for their own, but that have never been universally applied in society. Minimal values constitute a set of values that can be agreed upon as a starting point for negotiation or action. They represent the "chief or more stable component" of what individuals can hold in common. As stated by Murray (1993) "if many individuals after deliberation hold a preference or value then this value should be considered seriously".

Serageldin and Steer (1994), and Toman (1999) suggested a set of common views about sustainable development. The idea is that sustainability is about preserving and enhancing the opportunities available to people in countries around the world, and that these opportunities depend on a nation's accumulation of wealth. This wealth has three components: the stock of produced capital, the stock of natural capital, and the stock of human capital[1]. The main difference with this approach and Solow's is that a sustainable path needs not only to preserve productive capacity, but also access to a *minimum* level of environmental services and ecological diversity.

Within this framework, an indicator of sustainability is the *genuine savings* rate (see Section 4 for a discussion) of the economy given by:

$$s_t = \frac{GDP_t * (1-c_t) - K_t\delta_k + (N_t R - n_t) + h_t}{GDP_t}, \tag{2.1}$$

where c_t is the share of GDP that goes to consumption, $K_t\delta_k$ is the depreciation of the stock of produced capital during period t, n_t is the amount of natural resources and environmental services consumed during period t, R is the regeneration rate, and h are investments in human capital. As we discuss in the next section, data is now available to compute s_t.

On the basis of (2.1) I can provide a first (weak), definition of a sustainable growth path.

Definition 2.1: Weak sustainable growth path. I call weak sustainable growth path a path that converges to a state where s_t is non-negative.

This definition provides a heuristic to evaluate how well countries are preparing for the future. Along a sustainable path in the weak sense, the economy is generating enough resources to substitute for the depletion of natural resources. Hence, productive capacity is preserved. In other words, total wealth is constant or rising. If a country has a gross savings rate of 15% of GDP, a depreciation rate of 10%, a depletion rate of 10%, and no investment in human capital, it will be reducing its wealth by 5% per year (i.e., s_t=-0.05). This does not necessarily imply that the country is outside a sustainable path. Indeed, it may be the case that a high depletion rate is optimal during a given period of time, if stabilization follows. Nonetheless, a negative s_t can be interpreted as a *red flag*. This flag indicates that the current growth strategy can not be maintained forever and that stabilization will be necessary.

In the absence of damages, full depletion of the natural resource base is not necessarily inconsistent with sustainability. However, in the presence of damages, intuitively, we can see that sustainability will require the stabilization of the stock of natural capital above the threshold δ_1.

A second, (strong), definition of a sustainable growth path acknowledges that there may be several paths that generate sustainability in the weak sense. Among these paths, however, there are those that generate a maximum level of consumption per capita. It is ultimately this consumption that is a proxy for standards of living or social welfare. Several functions can be used to measure the utility that individuals derive from consumption. Here, I use one that is common in macroeconomic studies (see Pizer, 1998). The function is given by:

$$U(C_t) = L_t \frac{(C_t / L_t)^{1-\tau}}{1-\tau}, \tag{2.2a}$$

where C is consumption, L represents population, and τ is the coefficient of risk aversion.

Definition 2.2: Strong sustainable growth path. Strong sustainable growth path is a path that maximizes the inter-temporal value function given by:

$$V(C_t) = \sum_t (1+r)^{T-t} \left\{ L_t \frac{(C_t / L_t)^{1-\tau}}{1-\tau} \right\} , \tag{2.2b}$$

where r is a discount rate and T is the end of the planning horizon. Maximizing consumption over the infinite time horizon implies that productive capacity needs to be preserved over that infinite time horizon. The optimal inter-temporal allocation of natural resources will be a necessary condition.

From these definitions, two caveats are worth noticing. First, by linking optimality exclusively to consumption per capita and stability of wealth per capita, we ignore several issues that are important in order to assess sustainability. These issues include, for example, the way income is distributed across individuals in a given society, or the level of access of different segments of the population to basic needs such as health and education. Nonetheless, the approach sets boundaries on a nation's possibilities to improve these standards of living.

A second caveat is that the definitions ignore other dimensions related to quality of life and social health, such as the utility that individuals derive from living in societies with low crime rates or strong political and civil rights. Unfortunately, the shortcut is necessary for simplicity and fundamentally to keep policy recommendations independent of functional and parametric choices. Still, by considering the stability of the stocks of natural, produced, and human capital the definitions acknowledge the importance of investments in education, health, and environmental protection. Furthermore, it has been extensively documented that measures of social health and quality of life are correlated with GDP per capita (see Klitgaard and Fedderke, 1995).

The next two sections of this chapter assess sustainability in the developing world on the basis of the weak definition. The last chapter of this research will be concerned with the strong definition.

3. Measuring the Wealth of Nations

To assess sustainability on the basis of our weak definitions, we need information on stocks and flows (i.e., investments or consumption) of produced, human, and natural capital. Measuring the stock of produced, human, and natural capital in countries across the world is an extremely difficult task. The World Bank undertook this task during 1995 and came up with estimates of total wealth for a group of 108 countries. Figure 2.1 summarizes these results for twelve sub-regions of the world.

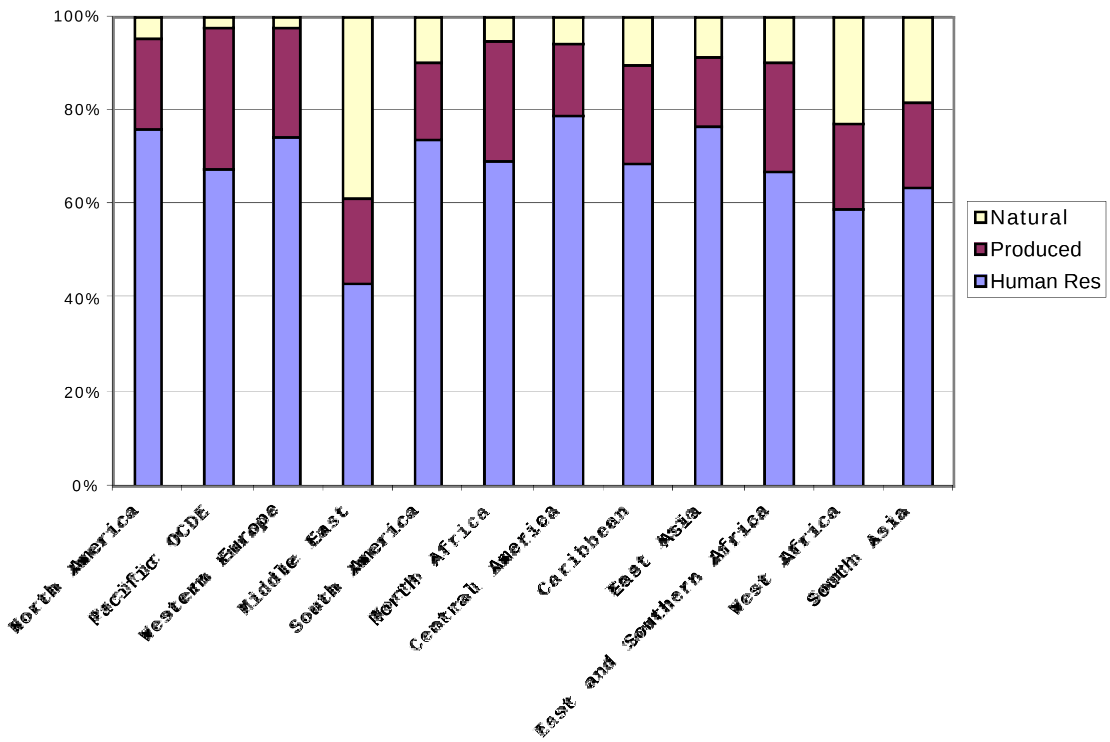

Figure 2.1: Composition of the Wealth of Nations in the World.

Source: Author calculations based on World Bank data (1999).

The figure displays the stock of total wealth per capita and its composition. By and large, the main contributor to the stock of total wealth is human capital, and usually represents between 60% and 80% of total wealth. On the other hand, the relative importance of natural capital with respect to produced capital varies widely across regions. While for OECD countries produced capital represents more than 90% of non-human wealth, in less developed regions, particularly Middle East, Africa and Asia, natural resources represent half of the stock of total non-human capital.

The distribution of wealth in the world is highly skewed. Few countries surpass levels of wealth per capita higher than USD 200,000 and the majority have levels of wealth per capita below USD 50,000 (see Figure 2.2).

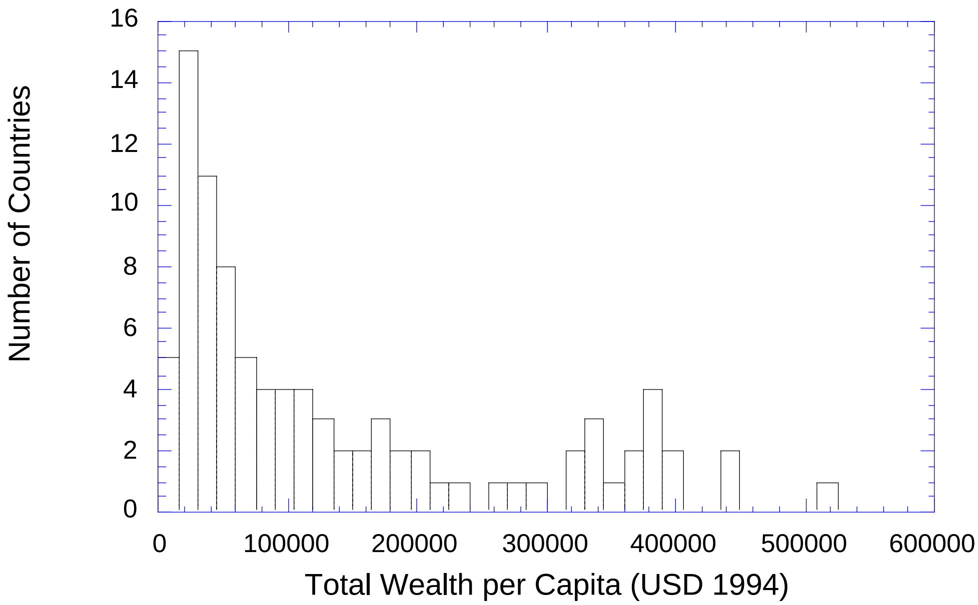

Figure 2.2: The World Distribution of Wealth.

Source: Author calculations based on World Bank data (1999).

This is a source of concern given that available income per capita is tightly related to wealth per capita. To see this, I plot in Figure 2.3 the relationship between the logarithm of the stock of wealth per capita and the logarithm of Gross National Product per capita for countries where the information is available. A simple linear regression suggests that a 1% increase in the total stock of capital per capita is associated with a 1.5% increase in GNP per capita.

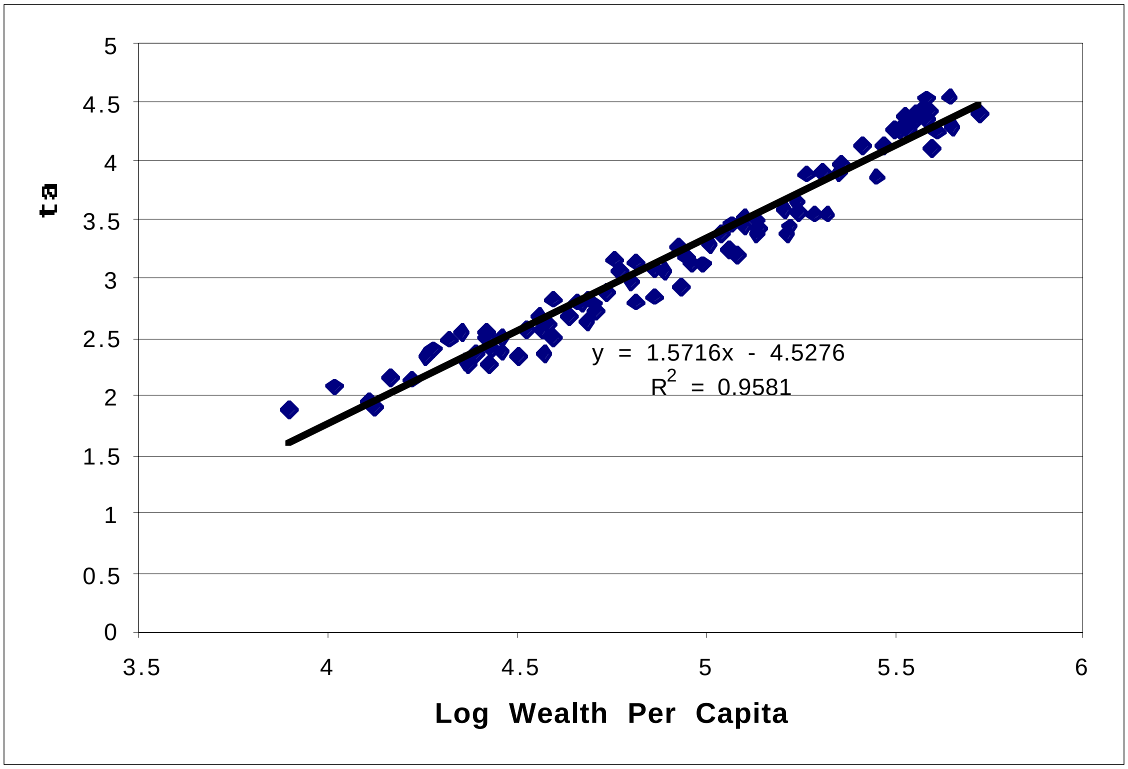

Figure 2.3: Total Wealth per Capita and GNP per Capita.

Source: Author calculations based on World Bank data (1999).

When I break-down the effects of total wealth into the marginal effects of each of its components, human capital per capita appears to be the most important contributor to economic growth. Indeed, using 1994 data, I estimated a "world production function". The results of this simple exercise are presented in Table 2.1. We observe that a 10% increase in the stock of human capital per capita can be associated with an 8% increase in total income per capita. The marginal effect of investments on produced capital is lower but still important. Indeed, a 10% increase in the stock of produced capital per capita, increases income per capita by 6%.

Models	**Coefficient**	**Std. Err**	**Significanc**
GNP/Capita			R2=0.95
Human Capital	0.824	0.085	Prob>F=0
Produced Capital	0.604	0.083	
Natural Capital	0.027	0.036	
Constant	-3.268	0.181	

Table 2.1: A World Production Function.

Source: Author calculations.

It is important to notice that once we adjust for differences in the stock of human and produced capital, the stock of natural capital does not have any explanatory power regarding differences in total income per capita. This apparently paradoxical finding is consistent with a well-known result in the literature on development economics, reported for example in Lal and Myint (1996): that countries with a high initial endowment of natural capital have had a tendency to implement policies that infringed on the efficiency of investment, and therefore growth. This was in essence due to inevitable politicization of the rents that natural resources yield. In his 1998 book, Lal refers back to his first study: "In many cases we found that natural resources had proven to be a "precious bone", as they led to policies which tended to kill the goose that laid the golden eggs" (see Lal, 1998). Yet, this is not always true, and this is why the coefficient for natural resources is not negative either. Indeed, a country such as Thailand, also abundant in natural resources, did a good job in transforming rent into long term growth.

3.1 Measuring Produced Capital and Human Capital

Produced capital and human capital have usually been considered as the main factors driving economic development. Produced capital refers to the orthodox concept of capital that includes buildings, machines, roads, bridges, transport equipment, and the like. In the World Bank study, this type of capital was computed on the basis of the perpetual inventory model, with the major inputs being investment data and an assumed life table for assets. On the other hand, human capital refers to human resources and the set of skills and knowledge that they incorporate. In the World Bank study, the value of human resources was obtained as a residual through the following calculation: researchers first multiplied agricultural GDP by 45% to reflect the return of the labor component, and then added all non-agricultural GNP net of rents from sub-soil assets and the depreciation of produced assets. This amount was then discounted over the average number of productive years of the population. The result gives the returns to human capital, produced capital, and urban land. These annual values are converted to a stock using a 4% discount rate. Human capital is then computed by subtracting from this stock the stock of produced capital and urban land.

Figures 2.4 and 2.5 show the distribution of produced and human capital in the world. Both figures display a very unequal distribution of both types of capital. As shown in Appendix 8.2, in the case of produced capital, while in countries like the United States each member of the population is endowed with roughly USD 76,000 of produced capital, in countries such as Zambia this number is less than USD 3,500. The same is true for human capital, which in essence reflects important differences in labor productivity between the developing and the developed world. Indeed, the majority of countries in the world have levels of human capital per capita below USD (1987) 50,000, while only a minority surpass levels of USD (1987) 200,000 per capita.

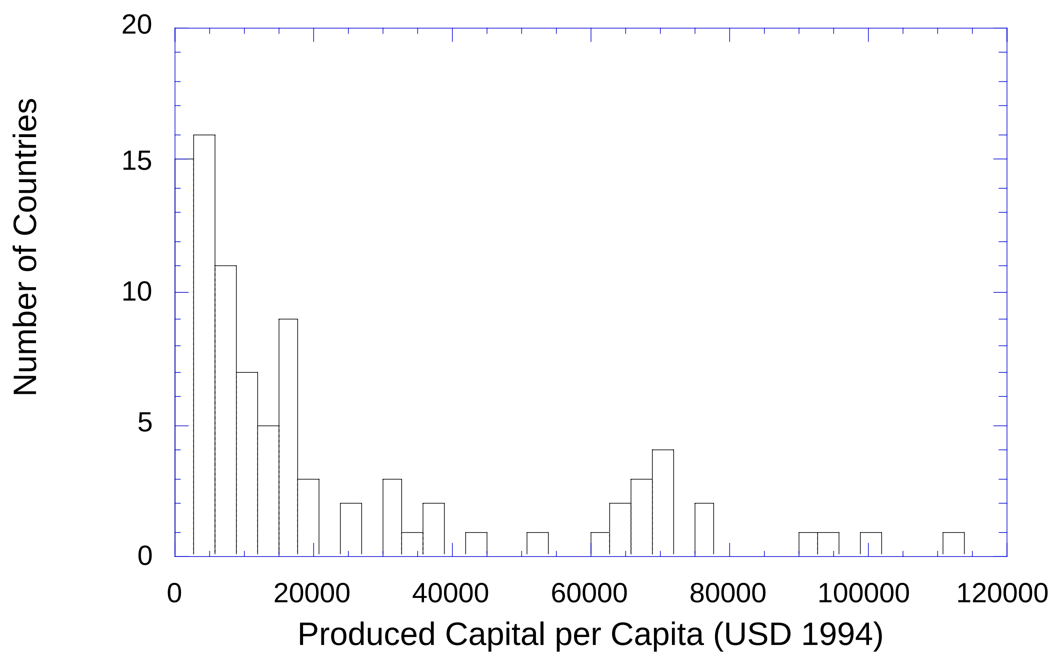

Figure 2.4: Distribution of Produced Capital in the World.
Source: Author calculations.

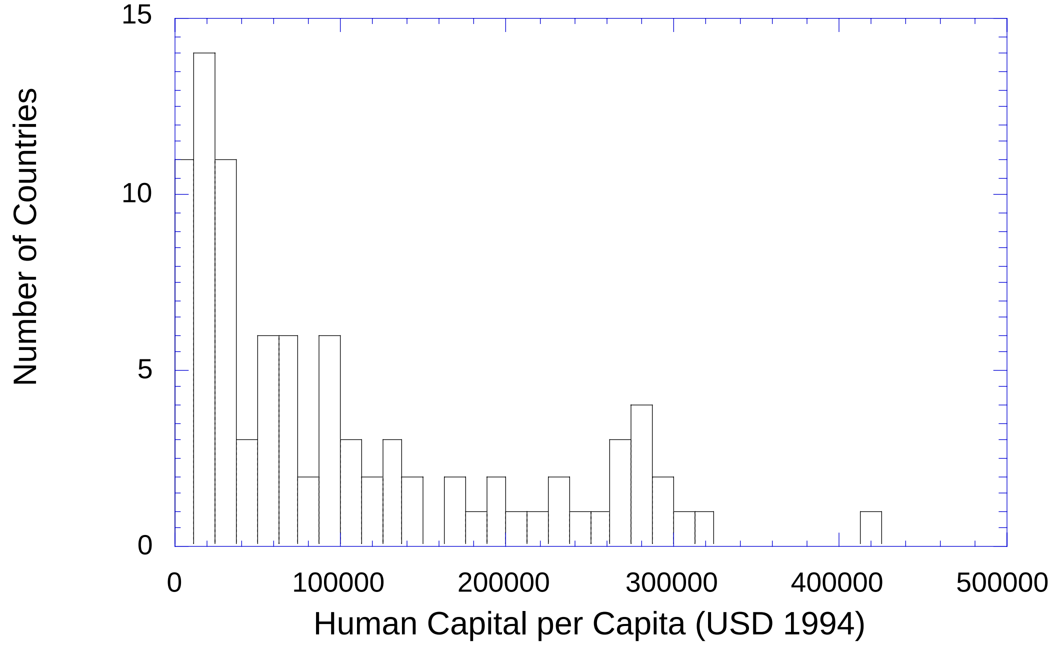

Figure 2.5: Distribution of Human Capital in the World.
Source: Author calculations.

3.2 Measuring Natural Capital

The measurement of the stock of natural capital is probably the main challenge in computing nations' wealth. Natural capital refers to both natural resources and natural services. Natural resources include renewable and non-renewable resources, while natural services refer to those services that are provided "at no cost" by nature. Probably the best example is clean air. In the World Bank study (see Dixon et al., 1998), the stock of natural capital is approximated by a subset of natural resources: agricultural land, pasture lands, forests (timber and non-timber resources), protected areas, metals and minerals, coal, oil, and natural gas.

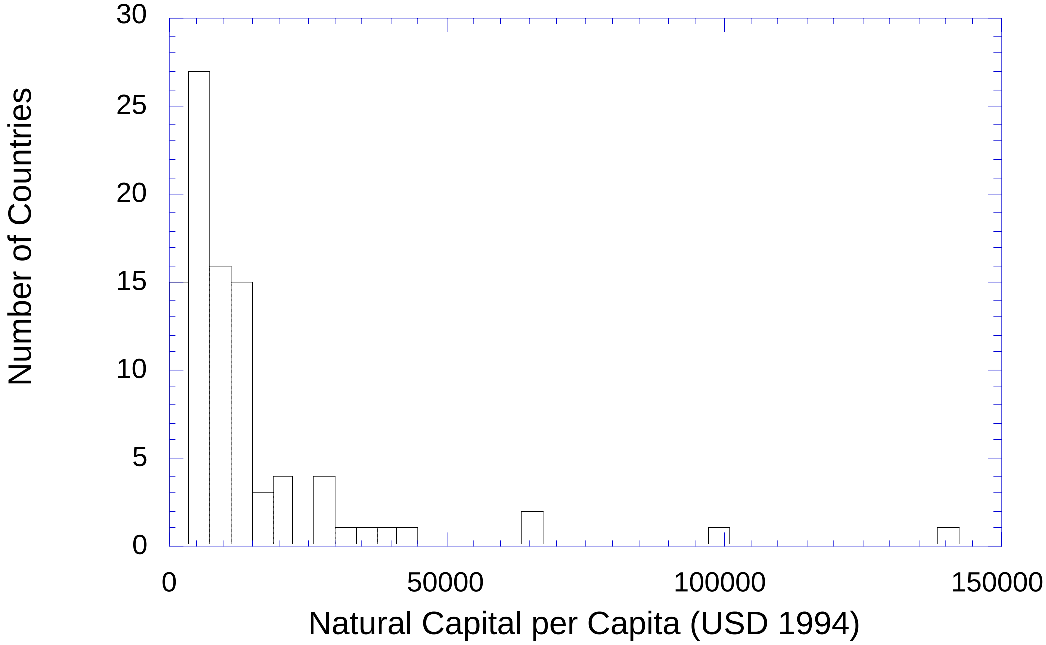

Figure 2.6: Distribution of Natural Capital in the World.
Source: Author calculations.

The availability of natural capital per capita is presented in Figure 2.6. Again, the variance of the indicator is considerable.

In OECD and high income countries, Middle East, and Latin America, the value of natural capital per capita is above USD 6,000. In the last two regions (particularly in the Middle East) this high level of natural capital per capita is mostly explained by availability of oil (copper and zinc are also important in the case of countries such as Chile, Bolivia, and Brazil). In the rest of the world, the value of natural capital per capita is closer to USD 4,000 (see Appendix 8.2).

4. The Dynamics of the Wealth of Nations and Sustainable Growth

4.1 The Need for New National Accounts

From the point of view of sustainable development, the important question is how countries are expanding their wealth to improve the well-being of current and future generations. The dynamics of the wealth of nations depends on investments in the different types of capital and their respective depreciation rates. While standard national accounts take care of the stock of produced capital, no information is provided regarding investments in human capital or desinvestments in natural capital. One of the main methodological contributions of the theory of sustainable development has been to devise methodologies to incorporate these investments to national accounts.

Box 2.1: Green National Accounts.
Source: World Bank (1998).

Hamilton (1994) develops the concept of genuine savings. Genuine savings are defined as net savings (the standard measure) minus the costs of resource depletion and pollution damages (see genuine savings II in Box 2.1). In an extended version, genuine savings also include investments in human capital (see extended savings III in Box 2.1). Thus, genuine savings address a much broader conception of sustainability than net investment, by valuing changes in the stock of natural capital and human capital in addition to produced assets (see Pearce and Atkinson, 1993). This new accounting tool allows the introduction of appropriate adjustments to the standard measure of economic performance, the Gross National Product or the Gross Domestic Product. For example, we can define the Green Net Domestic Product (GNDP) as GDP minus the depreciation of produced capital, minus the depletion of natural resources. Notice that as long as depletion rates and depreciation rates are higher than the growth rate of GDP (in real terms), GNDP will be decreasing. We have seen that depletion rates in most countries of the world are above 5% of GDP, while growth rates are below 4% per year. This suggests that the majority of countries are not growing, or even worse are shrinking. In the next two sections, I will review the dynamics of the three components of genuine savings: investments in produced capital, investments in human capital, and desinvestments in natural capital. The purpose is to get a flavor of how countries have been preparing for the future.

4.2 Dynamics of Investments in Human Capital and Produced Capital

The general argument is that in order to increase consumption per capita in the future, investments in produced capital and human capital are needed today. The dynamics of investments in both of these types of capital during the past thirty years is presented in Figures 2.7 and 2.8.

Investment rates in produced capital are highest among East Asian countries, where they average 25-30% of GDP. In other regions of the world, investments rates are closer to 20% of GDP. A general trend for non-Asian countries is a sharp decline in investment rates since the late 1970s. If we consider that capital depreciation rates are usually close to 10%, current investment rates are barely enabling replacement of the stock of produced capital. We may suggest that declining rates in the stock of produced capital are being substituted for investments in human capital.

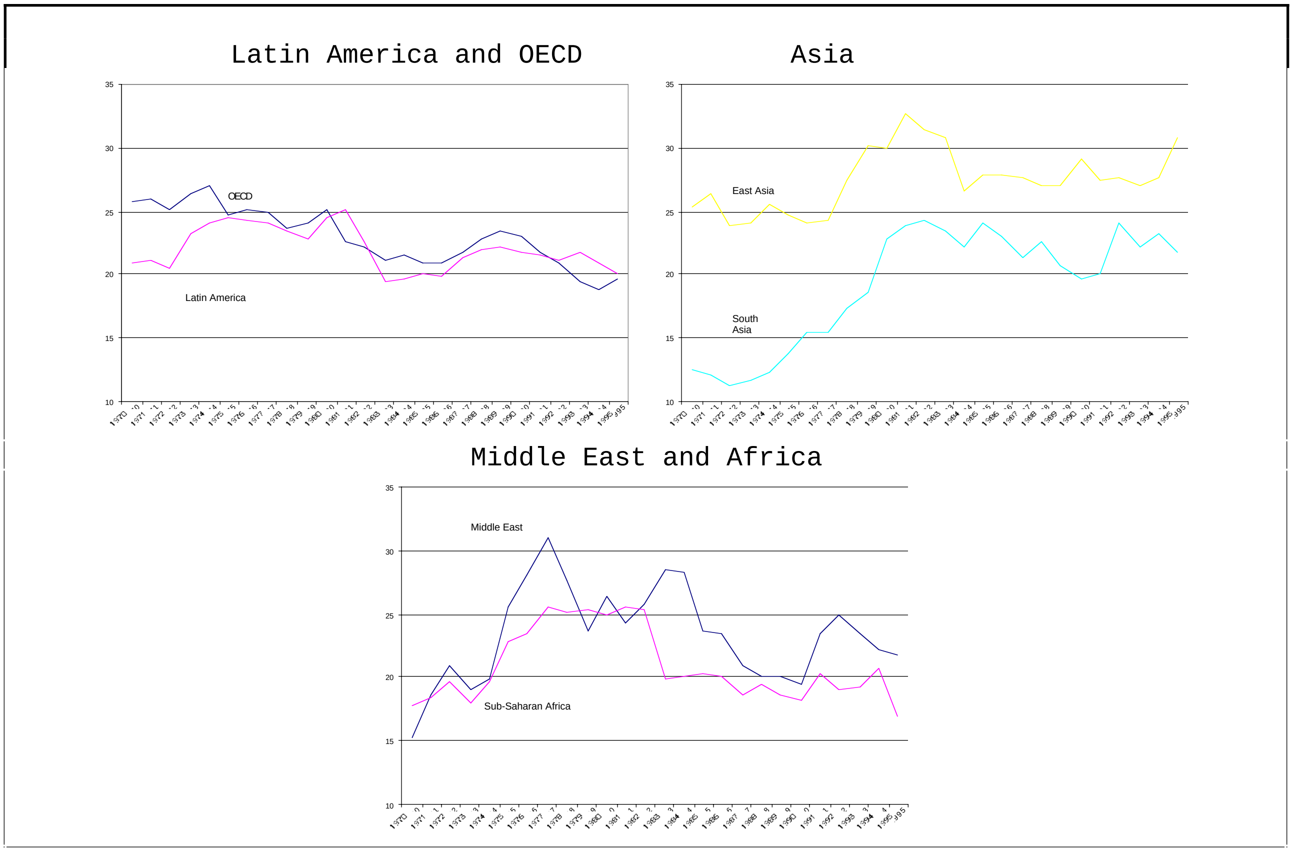

Figure 2.7: Gross Domestic Investment in Produced Capital (% of GDP).
Source: Author calculations based on World Bank data (1997).

However, Figure 2.8 does not support that view. Indeed, investments in human capital have also been falling in most regions of the world (they have remained roughly constant among OECD countries and increased in South Asia). Indeed, during the past ten years, investments in human capital have declined from 4.5% of GDP (the level observed among OECD countries) to less than 2.5% on average.

These reductions in human capital investments can be explained in part by reductions in public expenditures required by the stabilization programs implemented during the '80s (see Krugman, 1999). However, it is unclear whether the economic benefits of higher stability can compensate for the negative impacts on long run economic growth of lower levels of human capital. Meeting the challenge of increasing consumption per capita in the developing world will surely require higher than observed levels of investment in human capital, but also higher rates of return in the marginal dollar invested, which implies the need for more efficient health and education systems (see Peabody et al., 1999).

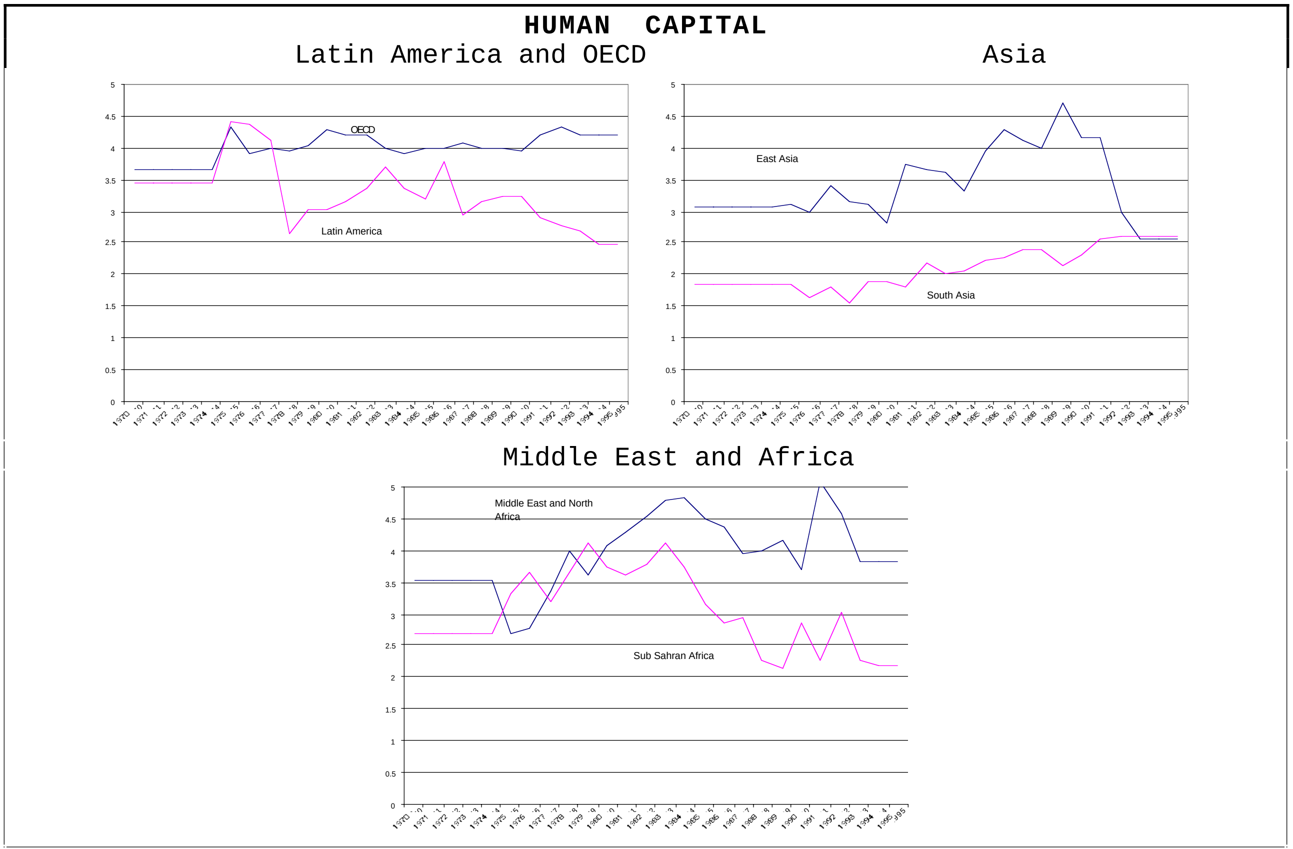

Figure 2.8: Investment in Human Capital (% of GDP).
Source: Author calculations based on World Bank data (1997).

The reader may argue that reductions in investments in human or produced capital are the result of optimal responses to changes in the macroeconomic environment, and that technological progress is compensating for the decline in investments.

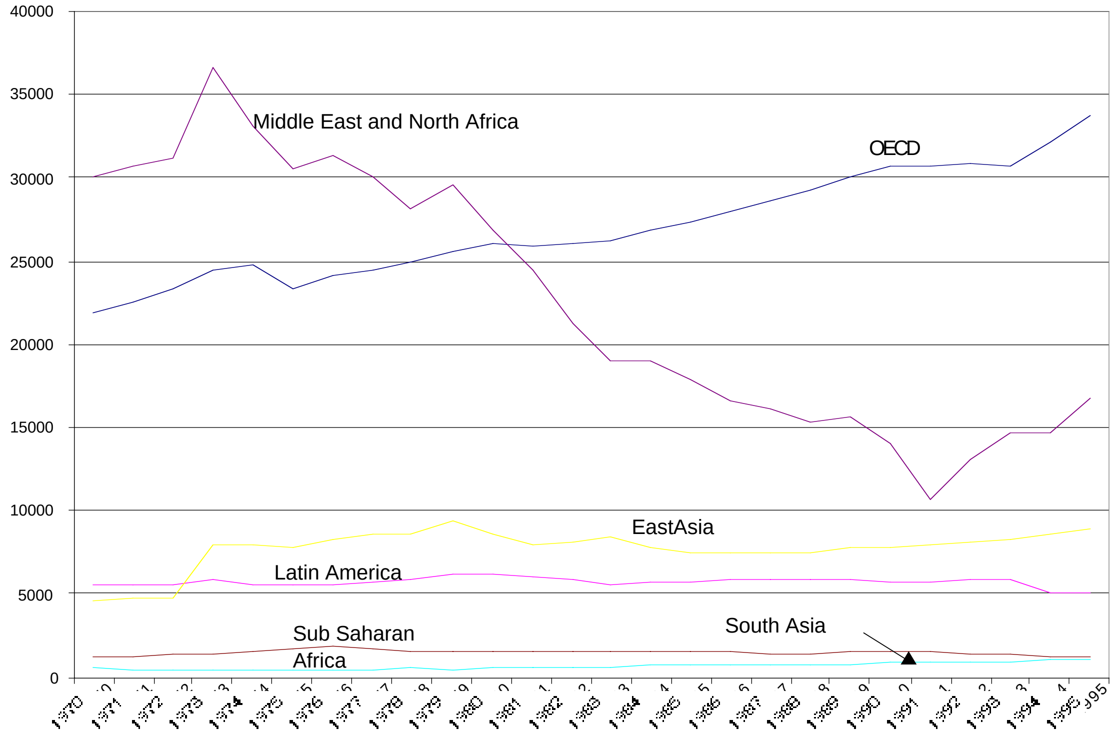

Figure 2.9: Labor Productivity for Different World Regions (USD (1987) per Capita).
Source: Author calculations based on World Bank data (1997).

However, as suggested by Porter and Christensen (1999a), investments in produced and human capital are ultimately the channels through which nations increase their productivity, and in particular labor productivity. Low investment levels imply low productivity growth. This is indeed the picture depicted in Figure 2.9 by the dynamics of the labor/GDP ratio, a proxy for labor productivity, in different regions of the world. The gap between labor productivity in developed countries and labor productivity in the developing world is enormous. While in OECD countries, an average worker produces over USD (1987) 35,000 per year, in Sub-Saharan Africa and South Asia, an average worker produces less than USD (1987) 1,000. During the past two decades, labor productivity has been stagnant in the developing world even in regions that experienced very fast rates of productivity growth in the past, such as Asia that during the '70s. The situation is particularly critical in the Middle East, where high levels of labor productivity during the '70s – resulting from the boom in oil production – have plummeted during the past two decades. These trends contrast with those of OECD countries, where labor productivity has grown steadily.

4.3 Dynamics of Depletion Rates and Pollution Damages

Resource depletion and pollution reduce the stock of natural resources. Resource depletion is measured as the total rents on resource extraction and harvest. Thirteen types of natural resources were considered in the Dixon et al. (1998) study: bauxite, copper, gold, iron, ore, lead, nickel, silver, tin, coal, crude oil, natural gas, and phosphate rock. For each of these resources, rents were estimated as the difference between the value of production at world prices and the total costs of production, including depreciation of fixed assets and return on capital. Strictly speaking, as explained in Dixon et al. (1998), this calculation measures economic profits on extraction rather than scarcity rents, and for technical reasons gives an upward bias to the value of depletion[2]. Also, non-explicit adjustments are made for resource discoveries, since exploration expenditures are treated as investments in standard national accounting conventions (see Hamilton, 1994). Nonetheless, the bias applies to all countries and therefore the calculations are a reasonable approximation for cross-country comparisons.

Forest resources are taken into account in the depletion calculation as the difference between the rental value of round-wood harvest and the corresponding value of natural growth, both in forests and plantations. Only when harvest exceeds growth is there a depletion charge made for any given country.

In the case of pollution damages, there are several methodological issues to consider. For example, damages to produced capital resulting from acid rain should in principle be included in depreciation figures. However, in practice, most statistical systems are not detailed enough to take this into account. The effects of pollution on output (damage to crops or lost production owing to morbidity) are reflected in the standard national accounting system, although not explicitly. Hence, we do not know how much GDP we are losing as a result of pollution. Rigorously, this value should be added to current GDP (presumably implying higher gross domestic savings), and then discounted from the new gross domestic savings to compute genuine savings.

The share of pollution costs that is included explicitly in the calculations of genuine savings, is related to its welfare effects. These are given by the willingness to pay to avoid excess mortality and the pain and suffering from pollution-linked morbidity. The marginal social cost of pollution estimated through this willingness to pay for carbon dioxide is close to USD 20 per metric ton. Hence, the part of pollution damages that contributes to the depreciation of natural capital is approximated by Dixon et al. (1998) on the basis of this figure. Therefore, while depletion rates appear to be over-estimated because of the use of economic profits rather than rents, damages due to pollution are under-estimated, but again provide a reasonable benchmark for cross-country comparison.

For my analysis, I have computed what I call pure depletion rates. These rates are computed by subtracting genuine savings II from net savings, and dividing the result by total GDP. Hence, depletion rates represent the amount of natural resources and natural services consumed (including pollution) per unit of GDP produced.

Figures 2.10, 2.11, 2.12, and 2.13 display the dynamics of depletion rates (expressed as a share of Gross National Product) for 11 regions of the world: Middle East (ME), North Africa (NAF), Sub-Saharan Africa (SSA), South Asia (SAS), East Asia and Pacific (EAP), Central America (CAM), South America (SAM), Caribbean (CAR), North America (NAM), High OECD Countries (HOEC), and Western Europe (WE). We observe that in most regions these depletion rates have had a tendency to drop starting in the first half of the '80s, except for North America that experiences a sharp rise at that time. Even in the Middle East, where depletion rates reached levels of 40% of GNP during the '70s, depletion rates dropped to approximately 15% of GNP in 1986. The only regions where depletion rates have remained roughly constant, at relatively low levels, are Sub-Saharan Africa (SSA) and Central America (CAM). Our econometric analysis in Section 5 will address the question of what are the determinants of the dynamics of depletion rates. For now, it is sufficient to emphasize that while depletion rates have dropped to levels of 1% of GNP in OECD countries, they are still above 5% of GNP in most of the developing world. Furthermore, these estimates should be taken as lower bounds, since as we saw in the previous section, several factors that negatively affect the environment have been excluded from the calculations given data availability.

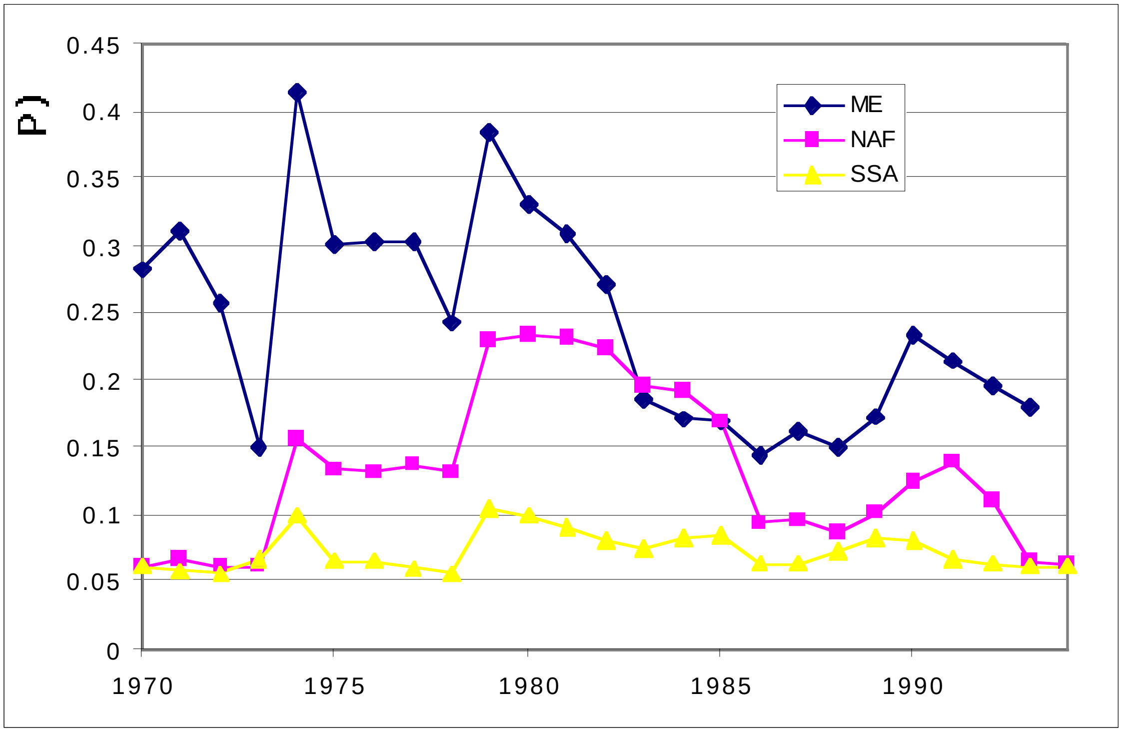

Figure 2.10: Depletion Rates in Africa and the Middle East (% of GNP).
Source: Author calculations.

It is important to notice that for methodological reasons, the depletion rate is not only sensitive to changes in the *quantity* of natural resources consumed and the *quantity* of output produced, but also to changes in prices. More precisely, the depletion rate at a given point in time is computed in real dollars as: $d = \frac{n.p_n}{p} / \frac{NominalGDP}{p} = \frac{n.p_n}{p} / realGDP$, where p_n is the price of the natural resource, and p is the general price index. Now, assume that the real GDP is constant. Then, the growth rate of the depletion rate is approximately given by: $\dot{n} + \dot{p}_n - \dot{p}$ (where the dot over the variable means "growth rate"). If the growth rate of the price of output is not equal to the growth rate of the price of the natural resource, the growth rate of the depletion rate will be distorted. For example, countries that preserve a fixed n/GDP ratio may seem to be reducing their consumption of natural resources per unit of GDP if the price of natural resources p_n is dropping faster than the general price index p. This is a problem that affects our measurement of real GDP as well. Unfortunately, there is little that we can do to avoid this bias, and hope that divergences between p and p_n are not very important.

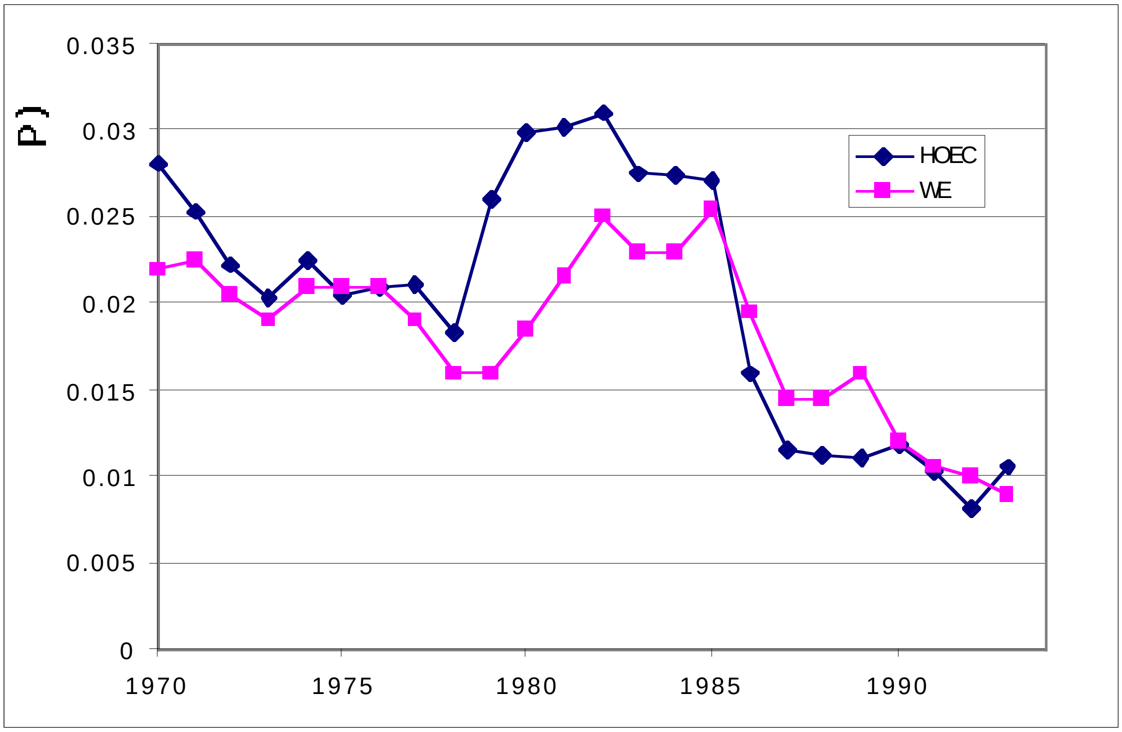

Figure 2.11: Depletion Rates in OECD and Western Europe (% of GNP).
Source: Author calculations.

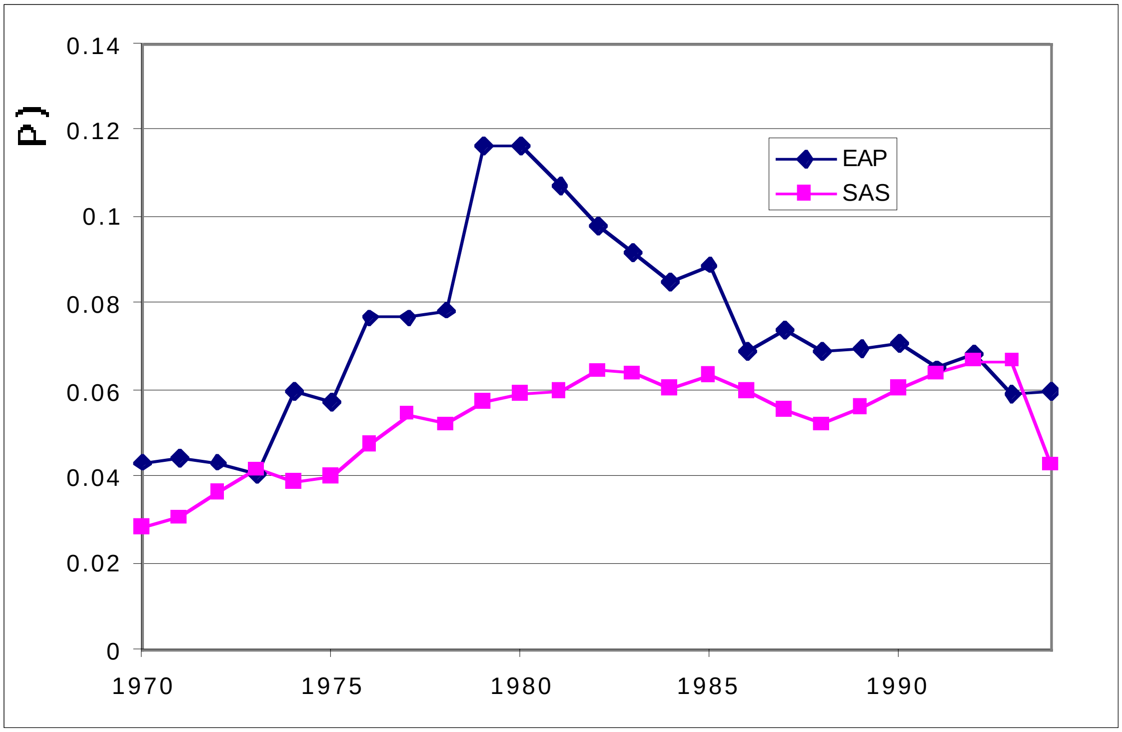

Figure 2.12: Depletion Rates in Asia (% of GNP).
Source: Author calculations.

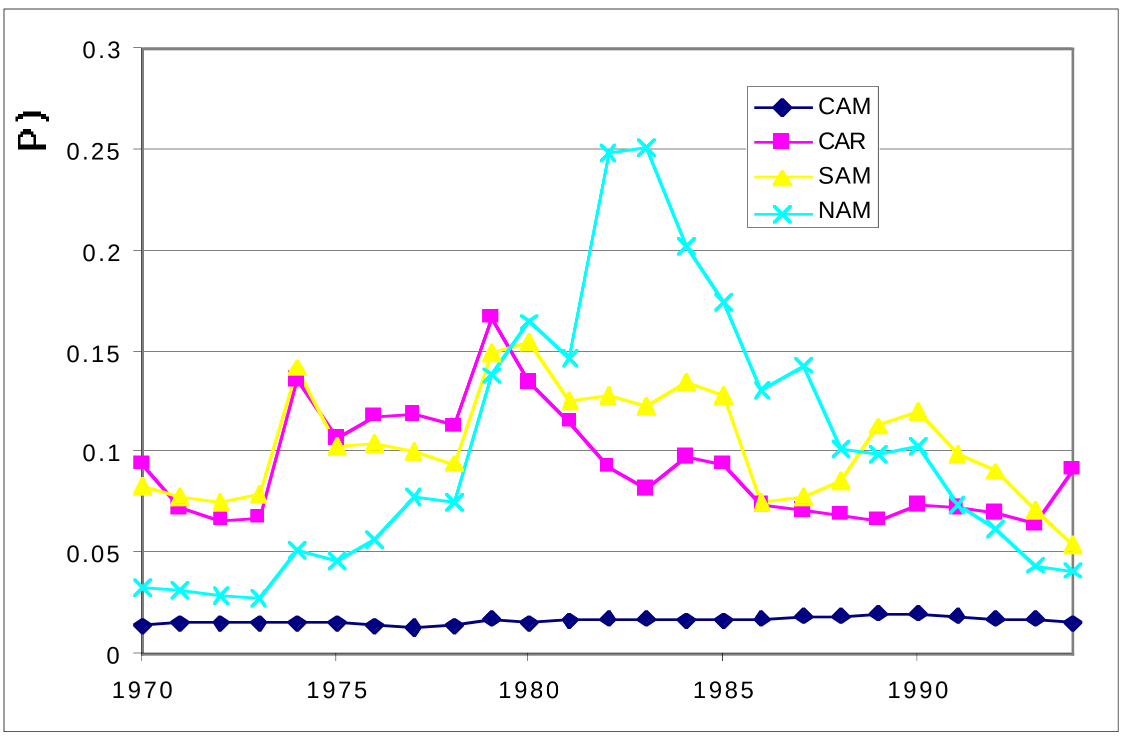

Figure 2.13: Depletion Rates in the Americas (% of GNP).

Source: Author calculations.

The effects of poor environmental management are felt dramatically in many developing countries. The amount of agricultural land now being lost outright through soil erosion is estimated at a minimum of 20 million hectares per year (see Myers, 1994). This phenomenon is disastrous, since hundreds of years are required to renew a mere 25 millimeters of soil, or the equivalent of 400 tons of soil per hectare (see Hudson, 1981). It has been estimated that from 1985 to 2000, losses may reach a cumulative total of 540 million hectares (see Sfeir-Younis, 1986). The critical regions are the Andes Mountains, the Yellow River basin in China, and the Indian Deccan.

Another serious problem is deforestation. During the twentieth century, forest surface has been cut in half in developing countries, aggravating problems such as soil depletion, flooding, sedimentation, and threatening the life of countless species of plants and animals (see Pearce and Markandya, 1994). It has been estimated that most of the forested areas of Bangladesh, India, the Philippines, Sri Lanka, and parts of Brazil could be gone by the middle of the next century (see Mahar, 1994). Water is also a source of concern, particularly in cities such as Bombay, Cairo, Lagos, Sao Paulo, and those at the frontier of Mexico and the United States. In the latter, intense economic activity resulting from the "maquiladora" industry and an unprecedented growth of the population have brought several environmental problems (see United States - Mexico Chamber of Commerce, 1996). Emissions of greenhouse gases are also a critical problem in the developing world. Different studies suggest that in 2050, close to 70% of human greenhouse gas emissions will be generated in the developing world, especially in China, India, and Brazil (see Manne and Ritchels, 1998).

The poorest countries, which tend to be heavily dependent on their natural resource base and have relatively high rates of population growth, are the most vulnerable to the effects of environmental degradation. This is due in part to the fact that shortages of capital and trained manpower (resulting in part from low risk adjusted rates of returns to investments) severely limit their ability to switch to other economic activities when their natural resources can no longer sustain them (see Wadford, 1994).

5. Econometric Analysis of Determinants of Depletion Rates

While investments in human and produced capital will be crucial for sustainability, a more detailed empirical analysis of the determinants of their dynamics lies outside the scope of this research. The reader is referred to Little et al. (1993), Bosworth (1993), and Fedderke and Luiz (1999). My focus in the remainder of this chapter will be on the less studied phenomena of the dynamics of depletion rates.

What are the determinants of depletion rates? A first simple story that one could tell is that in a competitive economy, the quantity of natural resources consumed depends on their marginal cost relative to the marginal cost of other inputs. Because marginal costs reflect scarcity, it follows that countries with higher initial endowments of natural resources will tend to have higher depletion rates (i.e., higher consumption of natural resources per unit of output). If we take the case of a fixed stock of natural resources, as this stock is depleted and presumably invested in other forms of capital, the cost of natural resources should increase, and their demand should decrease relative to the demand of other inputs. Hence, over time, we should observe falling depletion rates. If the stock of natural resources is not fixed, due for example to new discoveries, depletion rates may be growing for a while but after some period of time one should expect that the stock of natural capital will stabilize, and that depletion rates will start to fall.

The truth of the matter, however, is that developing economies have not been competitive, at least in early stages of development, and that governments have actively been involved in regulating the economy. Hence, a more realistic story, more in line with the theories of structural change (see Lewis, 1954; Kuznets, 1965; and Chenery and Taylor, 1968) is as follows: given low levels of human and produced capital, countries at low levels of development tend to be intensive in their natural resource base. Domestic output and exports are highly dependent on resources such as land, fisheries, forests, metals, and minerals. During the '70s, developing countries had a tendency to reinforce this model of growth, in hopes of stimulating the development of the industrial sector. Very often, governments provided generous subsidies for natural inputs that accelerated the rise in depletion rates. Also, it was common for governments to be involved in the extraction of these natural resources, using the rent to finance infrastructure projects. For example, during the '70s, in countries such as Mexico, Venezuela and Ecuador, up to 50% of GDP was linked to the oil industry, owned and managed by the public sector. Unfortunately, in many cases, rents from the extraction of natural resources were not invested in projects with the appropriate rate of return. Governments expanded unproductive bureaucracy, or constructed hospitals for electoral purposes without assessing the proper level of future investments required to keep the facilities running.

In a second phase starting roughly after the 1982 Mexico financial crisis, the international community started to embrace market driven reforms. This process has gained momentum particularly during the last decade. Hence, some developing countries have started to eliminate market distortions such as subsidies for natural resources (see Chapter 4). At the same time, for some countries, growth has brought a change in the sectorial composition of the economy, where the share of agriculture and natural resource intensive industries has fallen to give rise to the services and the manufacture sectors that are intensive in knowledge and technology.

This suggests that for the past two decades, changes in depletion rates in the world should reflect changes in the sectorial composition of the economy, but also changes in the legal and institutional framework that regulates the exploitation of natural resources. I will argue that the effectiveness of policies such as those attempting to "get the prices right" will be in part related to countries' capacity to absorb new production technologies. Factors that influence this absorption capacity include the strength of the financial sector and countries' stock of social capital (see Chapter 3 for a discussion of this topic). I will test these ideas in the next section.

5.1 Economic Development and Depletion Rates

I have argued that in the early stages of development countries tend to intensify the use of natural resources, but that after some level of economic development, two phenomena take place: a) the sectorial composition of the economy changes, increasing the shares of modern manufacture and services sectors; and b) institutions and policies change in order to rationalize the use of natural resources. These two phenomena suggest that depletion rates should follow an inverted U-shaped dynamics over a country's development toward a modern economy (Kuznets hypothesis). This is similar to the inverted U-shaped dynamics that one observes in the case of pollution (see John and Peccheniono, 1992; and Seldon and Song, 1995).

In this section, I test this idea empirically. The model that I develop closely follows the model developed by Hettige, Huq, Pargal, and Wheeler (1997). The idea is that the sum of the natural resources and natural services consumed by country i at time t, can be represented by a function of the form:

$$D_{it} = \sum_j s_j(Y) Q \lambda_j(Y) \eta(Y), \tag{2.3}$$

where s_j is the share of an economic sector j (i.e., agriculture, industry, manufacture, and services) in total value added Q, λ_j is the depletion intensity of the sector (the quantity of natural resources required to produce one unit of output in the absence of regulations), and η is the abatement intensity of the economy (the share of the quantity of natural resources per unit of output that the private sector can effectively extract). All are assumed to be functions of the level of economic development that is itself approximated by GDP per capita (Y).

As countries develop and Y increases, we observe a shift in the share of the different sectors within the economy. Usual patterns are that the share of the agricultural sector and the intensive extractive industry diminishes while the shares of the manufacture and services sectors rise (see Gillis et al., 1992). Given that depletion intensities for the services and manufacture sectors are lower than for agriculture and extractive industry, this pattern of growth is accompanied by a reduction in depletion rates. At the same time, the abatement intensity of the economy increases as institutions grow stronger and social organizations interested in preserving the environment develop (see Cameron and Carson, 1999).

To have an empirically estimable relationship, I divide equation (2.3) by Q and thus get an expression for the depletion rate: $d_{it} = \frac{D_{it}}{Q_{it}}$. Given that d_{it} is a share that has to be constrained to lie between 0 and 1[3], for estimation purposes, I use the transformation:

$$\log \frac{d_{it}}{1-d_{it}} = \frac{\log f(y)}{1-\log f(y)} = g(y)\ . \tag{2.4}$$

As in Hettige et al. (1997) I approximate (2.4) by:

$$\log\left(\frac{d_{it}}{1-d_{it}}\right) = \alpha_0 + \alpha_1 \log Y_{it} + \alpha_2 \left(\log Y_{it}\right)^2 + v_i + u_t\ , \tag{2.5}$$

which can be interpreted as a second order expansion of g(.). We verify that $\frac{\partial[d/(1-d)]}{\partial d} = \frac{1}{1-d} - \frac{d}{(1-d)^2} \geq 0$ since d<1. Therefore, when d increases (decreases), 1/(1-d) increases (decreases). The Kuznets hypothesis implies $\alpha_1 > 0 \wedge \alpha_2 < 0$.

I estimate model (2.6) on the basis of a panel data for 104 countries in the world. For each of these countries I observe several economic, social, and environmental indicators, during the period 1970-1994. Table 2.2 summarizes the mean of a selected set of variables. For this part of the analysis, I work exclusively with depletion rates and GDP per capita.

Because model (2.5) is a panel model, it is well known that the Ordinary Least Square method will produce bias estimates, as long as the error terms are correlated. Very often, this is the case with panel models, where for each country, the error terms tend to be correlated over time. At the same time, the variance of the random shocks tends to differ across countries. Two of the most popular alternatives for estimating (2.5) are fixed effects models and random effects models. The choice between the two is given by the variance of v_i. If the variance is zero, one should prefer fixed effects models, but if the variance is different than zero, the random effects model is the preferred choice. It turns out that in the case of our data set, the variance of v_i is significantly different from zero. Hence, there are systematic non-random shocks that affect the intercepts of the equations. Therefore, I have estimated a random effects model by Generalized Least Square methods.

1970										
Var	Central America	Caribe	East Asia Pacific	High Income OCDE	Middle East	North Africa	North America	South America	South Asia	Sub-Saha Afri
depleGDP	.0143333	.0936	.0431111	.0280952	.2833333	.0625	.033	.0822727	.0284	.061
GDP_Cap	-	-	-	-	-	-	-	-	-	-
highX	7.611825	42.26666	10.85663	18.45546	6.249722	4.982099	31.35709	24.0306	2.811683	8.8
agr_GDP	31.48018	11.50902	29.54434	5.802078	12.13279	19.27868	11.64927	16.35246	46.43003	34.7
ind_GDP	24.23433	33.10857	25.99567	42.84767	37.75382	29.31006	29.43633	34.4494	17.65767	22.4
ser_GDP	44.28549	55.38241	44.45999	51.19771	50.11339	51.41125	58.91441	49.19814	35.9123	42.
man_GDP	20.18854	16.9466	16.59309	29.13087	9.926659	13.26349	22.04593	21.10364	11.44181	10.
m3_GDP	19.54733	28.41413	30.99462	58.01651	38.90797	37.84535	15.03131	20.42839	25.03365	18.4
acc_GDP	-	-14.9452	-	.0290264	-10.79747	-5.883508	-	-2.694249	-2.356637	.086
debtX	-	8.291956	17.56966	-	-	27.27548	-	14.10428	20.0127	3.36
urbPop	41.4	38.98333	37.53	70.4	57.88333	40.175	59	58.27273	15.62	18.7
popKm	65.02763	241.6721	767.8388	107.8438	86.62994	26.56937	26.36782	11.4751	209.6001	41.0
x_GDP	23.87539	33.30474	33.25578	28.1723	36.25558	18.95196	6.409186	18.96066	10.03312	26.7
c_GDP	75.9474	72.07592	67.70211	58.04176	53.43263	64.92327	74.78079	69.89485	76.86081	71.3
g_GDP	10.41312	11.80868	12.28651	14.50019	23.00861	17.13248	6.534447	11.27462	11.07208	13.7
fI_GDP	1.135314	6.397242	.5551989	1.161758	.1308843	.6450139	.8429019	-.3517303	.0740427	.186
m_GDP	25.77232	39.99923	39.4743	28.30319	29.58909	23.53204	8.977036	18.5391	13.69475	29.5
Dcpi	3.271495	5.94426	5.988231	5.398737	3.35464	3.880718	5.211781	8.175584	6.909867	3.36
taxGDP	9.331638	-	13.75706	24.11334	-	15.94326	-	11.91722	18.34748	17.2
soe_GDP	-	-	-	-	-	-	-	-	-	-

Table 2.2: Means by Decade and Region.

Source: Author calculations.

depleGDP = Depletion rate
GDP_Cap = GDP per capita (USD (1987))
highX = Share of High tech exports in total exports
agr_GDP = Share of agriculture in GDP
ind_GDP = Share of industry in GDP
ser_GDP = Share of services in GDP
man_GDP = Share of manufacture in GDP
m3_GDP = Extended money supply(M3)/GDP ratio
acc_GDP = Current account balance as a percent of GDP
debtX = External debt payments as a share of exports
urbPop = Urban population
popKm = Population per Km
x_GDP = Exports as a share of GDP
c_GDP = Consumption as a share of GDP
g_GDP = Government expenditures as a share of GDP
fI_GDP = Investments as a share of GDP
m_GDP = Imports as a share of GDP
Dcpi = Inflation as a share of GDP
taxGDP = Tax revenues
soe_GDP = Value-added of State-owned enterprises in GDP

1980										
Var	Central America	Caribe	East Asia Pacific	High Income OCDE	Middle East	North Africa	North America	South America	South Asia	S A
depleGDP	.0163433	.0974571	.077773	13055.02	.2383	.1441316	.1155789	.1088086	.0522737	.
GDP_Cap	2862.773	3753.013	4484.304	21.71669	7022.746	2807.314	5983.793	4291.811	852.2281	1
highX	11.99212	32.0369	21.38122	4.648171	12.02953	14.37581	33.24248	15.49342	2.2696	9
agr_GDP	25.86937	10.79158	23.85983	34.37008	11.08347	16.92315	9.199292	14.88063	41.06439	3
ind_GDP	25.26834	32.07969	32.33224	60.78123	39.39201	34.48655	31.15928	36.32426	20.44791	2
ser_GDP	48.86229	57.12874	43.80794	22.81547	49.52451	48.5903	59.64143	48.79511	38.4877	4
man_GDP	19.0735	13.30447	20.604	62.70392	9.818759	14.19952	22.27157	21.84038	12.8841	1
m3_GDP	31.33079	36.40754	38.57805	-1.474901	54.27276	53.82762	22.58302	27.52486	30.32501	2
acc_GDP	-3.581813	-5.090728	-3.545765	-	.8099487	-6.481571	-1.291856	-2.930776	-3.56822	-
debtX	19.44643	13.39192	23.6221	73.31754	10.8107	25.73847	44.36989	33.85977	16.29821	1
urbPop	42.81184	43.09825	42.55263	113.7112	65.14825	45.12895	66.13158	63.7823	18.08211	
popKm	82.48693	261.8875	955.4622	32.67582	131.0657	33.72106	34.97672	14.35851	268.4661	
x_GDP	30.35291	37.7117	47.63113	58.89373	41.00919	25.42299	12.13959	20.72507	12.36023	2
c_GDP	72.77703	69.41155	59.64402	17.09703	54.53556	61.3407	68.77735	66.58852	79.87265	7
g_GDP	13.10006	14.39561	12.47991	.8941052	24.78455	16.73422	8.668796	11.9573	9.309295	1
fI_GDP	1.142298	1.89086	2.025499	33.01184	.2121173	1.032549	.8885797	.3526503	.1529952	.
m_GDP	35.70243	44.44082	48.93097	8.423531	45.58088	32.46068	11.32361	21.08239	19.4645	3
Dcpi	13.42601	12.30752	9.495933	28.14739	23.50742	9.705055	43.79636	171.5604	10.67961	1
taxGDP	13.63809	20.25536	14.62501	6.739024	17.66714	22.47711	12.5743	15.10861	10.90857	1
soe_GDP	4.016465	9.566667	9.368046	-	-	24.58	6.700043	9.634425	7.776729	1

Table 2.2: Means by Decade and Region.

Source: Author calculations.

1990										
Var	Central America	Caribe	East Asia Pacific	High Income OCDE	Middle East	North Africa	North America	South America	South Asia	Sub-Afri
depleGDP	.0177778	.0735	.0648696	.0102143	.1926957	.10125	.0646	.0877593	.0607917	.06
GDP_Cap	3202.34	3770.666	6903.709	15366.06	6728.906	2956.078	6071.585	4813.98	1062.682	154
highX	14.89918	34.13533	36.176	27.6995	24.87483	14.34838	32.91305	15.62286	3.220862	12.
agr_GDP	19.11975	13.81513	18.56905	2.881679	11.31828	15.50479	5.944369	11.80107	31.61164	31.
ind_GDP	24.56893	29.13567	34.70153	30.23087	33.80712	34.8663	25.50377	33.58305	23.37138	24.
ser_GDP	56.31132	57.0492	46.72942	66.54488	54.62371	49.62891	68.55186	54.61588	45.01698	43.
man_GDP	19.0195	12.39168	22.24459	19.72345	14.83107	17.46084	18.55017	21.00384	13.78844	12.
m3_GDP	36.08584	46.23607	72.73254	72.95894	69.20162	59.29867	27.27379	34.58739	38.57414	23.
acc_GDP	-3.858115	-2.56674	.0309521	.2313765	-4.373978	-1.490436	-4.038618	-1.54460	-4.602852	-5
debtX	13.5907	14.66789	18.07157	-	12.53344	30.80901	29.35585	27.02612	18.34096	22
urbPop	44.62286	49.33571	49.91057	75.56531	73.35476	52.26786	73.04286	70.85662	21.69029	31
popKm	106.3815	294.074	1187.75	120.0989	200.04	45.10919	46.29924	18.47568	353.7163	69.
x_GDP	32.79629	37.68639	59.60122	35.31201	48.6974	29.6206	19.33896	19.75638	17.80542	28
c_GDP	74.47928	70.54143	54.74153	59.62152	55.18317	64.69198	74.39067	70.53189	74.59415	76.
g_GDP	11.67564	12.33594	11.30787	18.34061	23.07539	14.96605	4.758887	10.14153	11.33994	14.
fI_GDP	1.897618	3.358471	3.764922	1.497761	.2995172	1.154868	1.860615	.7514475	.4596842	.69
m_GDP	40.28088	42.84583	58.84719	33.10279	53.42022	33.67512	21.11549	19.73384	24.61471	36.
Dcpi	13.56126	15.48461	8.92402	3.277935	10.11016	12.50802	21.55956	277.9429	9.718115	17
taxGDP	14.94051	18.99224	14.56085	31.38419	17.0138	22.90612	13.38157	15.40457	12.24104	16
soe_GDP	6.1719	17.06667	3.300331	6.166667	-	25.86667	4.880857	8.060964	7.068017	12.

Table 2.2: Means by Decade and Region.

Source: Author calculations.

Description	Coef.	Std. Err.	P>|z|	Number of obs	R-sq within
Simple version (no time effects) χ = 0.0000				1397	0.1313
log(Y)	4.16736	0.7481575	0.000		
log(Y)^2	-0.3149549	0.0459373	0.000		
_cons	-16.26304	3.031062	0.000		
Extended version (time effects) χ = 0.0000				1397	0.3747
log(Y)	2.924027	1.117548	0.009		
log(Y)^2	-0.163493	0.0704243	0.020		
log(Y)*t	-0.2093404	0.0426656	0.000		
log(Y)^2 * t	0.0105802	0.0026572	0.000		
t	0.9370649	0.1691579	0.000		
_cons	-15.36133	4.396594	0.000		

Table 2.3: Regression of Kuznets Hypothesis.
Source: Author calculations.

The results of the estimation are presented in the first panel of Table 2.3. We observe that the parameters for $\log(Y)$ and $(\log Y)^2$ are not only individually highly significant, but jointly significant as well (the χ statistic is zero). Hence, the data seems to support the idea that, at low levels of economic development, depletion rates increase, and that they diminish as further economic growth takes place. To better illustrate this idea, I graph the depletion rate as a function of GDP per capita in Figure 2.14. The adequate transformation of (2.5) is:

$$d_{it} = \frac{e^{\alpha_0 + \alpha_i Y_{it} + \alpha_2 Y_{it}^2}}{1 - e^{\alpha_0 + \alpha_i Y_{it} + \alpha_2 Y_{it}^2}} \tag{2.6}$$

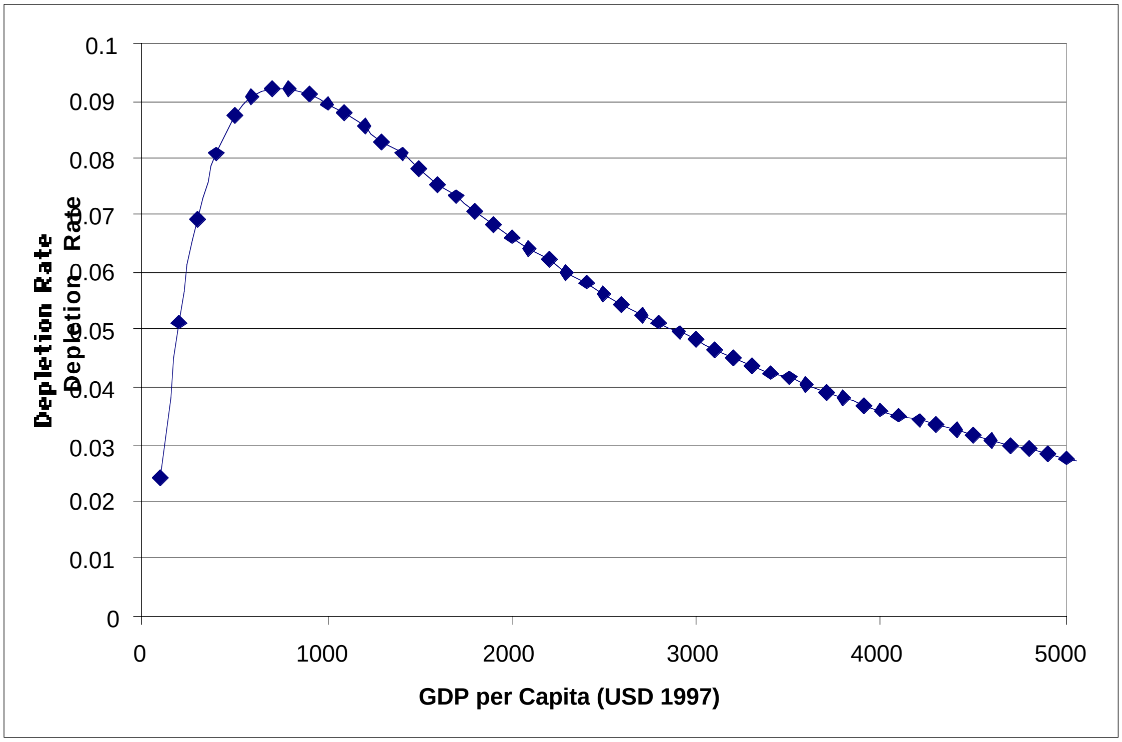

Figure 2.14: Depletion Rates as a Function of GDP per Capita (% of GDP).
Source: Author calculations.

The figure suggests that depletion rates tend to rise for levels of income below USD (1987) 1,000 per capita, and tend to decrease for higher levels of income per capita.

This simple model can be modified slightly to allow for the possibility of technological progress, or "accumulation of knowledge". The idea is that independently of the level of income, time should bring lower depletion rates that result, presumably, from the adoption of more environmentally friendly technologies, or simply better policies to manage the stock of natural resources. To model this phenomena it is enough to add an additional variable, a normalized time index (starting at 1 and increasing by one each year), to model (2.5). However, it is also reasonable to expect that technological progress will have different effects depending on the level of income. In other words, if less developed countries use different technologies, then the effect of technological progress on the depletion rate should be different for lower levels of Y. This suggests that one should also include interactions between time and the level of GDP per capital. Therefore, we rewrite (2.5) as:

$$\log\left(\frac{d_{it}}{1-d_{it}}\right)=\alpha_0+\alpha_1 Y_{it}+\alpha_2 Y_{it}^2+\alpha_3 Y_{it}t+\alpha_4 Y_{it}^2 t+\alpha_5 t+\nu_i+u_{it}\,, \qquad (2.7)$$

where t is the normalized time index[4].

The results of the estimates of model (2.7) are presented in the second panel of Table 2.3. Statistically, this model appears to be more robust (the R^2 is three times higher). Again, we verify that $\alpha_1 > 2$ and $\alpha_2 < 0$. To better understand the dynamics of this model, I have also plotted the depletion rate for different values of the time index (see Figure 2.15). The figure displays with dark lines (one full line, and one dotted line), the trajectory of two imaginary countries that start with equal levels of income per capita (USD (1987) 700) and depletion rates (7% of GDP).

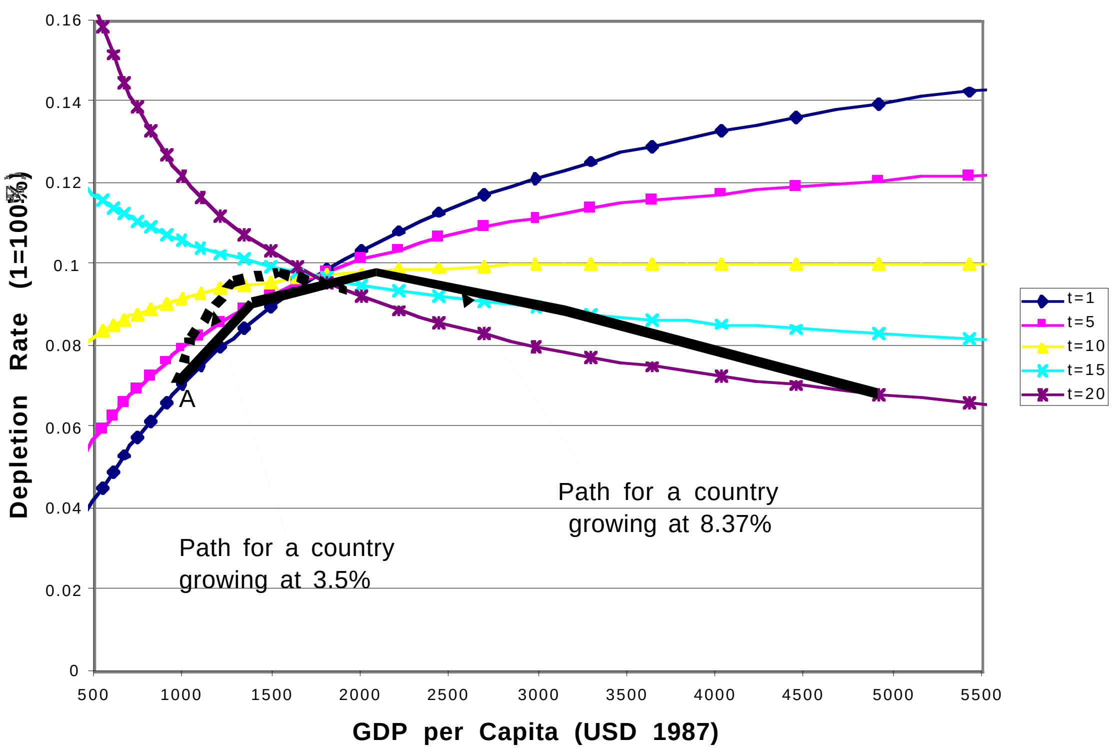

Figure 2.15: Depletion Rate as a Function of GDP per Capita (Time Effects Model).
Source: Author calculations.

The first country grows at 3.5% per year, and within a period of 20 years reaches a per capita income of close to USD (1987) 2,000. During the first fifteen years its depletion rate increases up to 10% of GDP and then declines slowly to 9%. The other country, by growing faster, at 8.3%, is able to reach a level of income per capita of USD (1987) 5,000. Its depletion rate originally increases to 10% but then falls below 8% of GDP. We observe that in this second model, the increase in the depletion rate for low levels of development is sharper than in the previous model. The decline, on the other hand, is slower. Also, the inflection point varies depending on the growth rate.

Both models, however, confirm the hypothesis that depletion rates increase at lower levels of economic development, and tend to decrease at higher levels of development. The cut-off takes place at levels of income close to USD (1987) 1,000. Both models, unfortunately, hide the real sources of change in depletion rates. Hence, in the next section, I study models that take a closer look at the structural determinants of depletion rates.

5.2 Structural Change, Social Capital, and Depletion Rates

We have shown that depletion rates are intimately related to the level of economic development. The questions that remain to be answered are: a) what are the factors that change when economic development takes place, and that affect depletion rates; and b) are there factors that, while not correlated with the level of economic development, are important determinants of depletion rates. Factors that undoubtedly change as economic development takes place are the sectorial composition of the economy, and the legal and institutional frameworks that regulate the use of natural resources and environmental services. However, other factors such as the absorption capacity of new technologies or the type of international financial commitments that a given country has to meet, are not necessarily directly linked to the level of economic development, and yet may also influence depletion rates.

In this section, I use the panel data set to explain international variations in depletions rates. A first question that I address is what is the role of each economic sector in explaining international differences in depletion rates. The second question is related to policy changes. I have suggested that during the past two decades, countries have had a tendency to move to economies based on market signals that may have eliminated distortions in the market for natural resources. Unfortunately, we do not have specific measures for these changes. Also, we do not observe indicators, such as country level prices for natural resources that could be used as proxies for the level of regulation. Nonetheless, it is reasonable to expect that the ability of countries to implement sound environmental policies will be related to the form and strength of their institutions (see North, 1990). For example, we may expect that in countries with consolidated democratic systems where individuals enjoy broad political and civic rights, social organizations that lobby for environmental protection are more likely to emerge. Therefore, we can use indicators for the level of political and civil rights as proxies for the likelihood that a given country will implement sound environmental policies.

A third idea that I address is related to the role of the structural dimension of social capital, that is the degree of network connectivity that exists within a given country. Indeed, the ability of developing countries to reduce depletion rates depends in part on their ability to choose production technologies with lower environmental damages. For example, policies that eliminate price distortions in the market for natural resources will be more effective (e.g., will have less negative impact on economic growth) when alternative production technologies - less intensive in natural resources and environmental services - are available as substitutes for old technologies. By affecting information flows and the extent to which cooperative behavior emerges, business and social networks play an important role in determining the absorption capacity for new technologies in the economy (see Chapter 4). Hence, we may expect that other things being equal, more interconnected societies will tend to have lower depletion rates. The strength of the financial sector is also an important enabler for the diffusion of new technologies. A well functioning and competitive financial sector is likely to reduce credit constraints, and supply the financial resources required to finance investments in new technologies.

A fourth idea, that has received little or no attention, is the role of external financial constraints. During the '70s, developing countries increased their public and private foreign debt dramatically. Different factors explain this phenomena, such as the over supply of oil-related dollars in the international financial system (see Little et al., 1993; and Krugman, 1999 for other arguments). Regardless of whether creditors were being rational when they lent the money, the fact is that as in the case of natural resources, too often the new financial resources coming from abroad were not invested in projects with adequate rates of return. In many cases, governments use these resources to provide subsidized credits to private companies that deposited back their loans in foreign banks where they received market interest rates. The debt crisis initiated with the Mexican moratorium in 1982 reflected developing countries' incapacity to generate the resources necessary to comply with creditors' obligations. Since then, many developing countries have been trying to equilibrate their external accounts through policies aiming to stimulate the development of the exports sector. Very often, these strategies have resulted in an over-exploitation of the natural resource base (see for example the case of the mining sector in Mexico in Robalino and Treverton, 1997). This being the case, one may expect that other things being equal, countries with a higher burden of payments to service foreign debt will also tend to have higher depletion rates.

In summary, I hypothesize that there are seven factors that explain international variations in depletion rates: 1) the sectorial composition of the economy; 2) the external financial pressure facing the country; 3) the degree of development of the financial sector; 4) the level of development of the country; 5) international technological progress; 6) the degree of institutional strength; and 7) network structures. Given little theoretical guidance in terms of the type of model specification that one should use, I have opted for estimating reduced form models. Therefore, I express the depletion rate of a country i at time t by:

$$\log\left(\frac{d_{it}}{1-d_{it}}\right)= \beta_0 + \beta_j \sum_{j=1}^{3} s_{jt} + \beta_4 FDX_{it} + \beta_5 M3_{it} + \beta_6 y_{it} + \beta_7 x_{it} + \beta_8 t + \mathbf{I}_{it}\gamma + \mathbf{NW}_{it}\iota + \varphi_k \sum_k reg_k \quad (2.8)$$

where s_j represents the share of economic sector $j\in$ {1=industry, 2=manufacture, and 3=services} (agriculture appears as the reference sector); FDX is the share of foreign debt payments in total exports revenues (our indicator of international financial pressures), M3 represents money and quasi-money as a share of GDP (our proxy for the "size" of the financial system), y is the GDP per capita, t is a time index (our proxy for international technological progress), **I** is a vector with proxies for institutional strength, NW is a vector with proxies for networks' structures; and **reg** are regions dummy variables used to estimate (2.8) as a fixed effects models.

I have estimated several models like (2.8) that differ in the types of institutional indicators and proxies for networks structures considered, as well as the inclusion or exclusion of GDP per capita. In the case of institutional indicators, I have worked with two proxies: the index of civil liberties (*civLib*) and the index of political rights (*polRight*). These are subjective indicators that measure attributes such as the meaningfulness of elections, firmness of election laws and campaign opportunities, voting power, political competition, or freedom from external or military control. The validity of these indicators is analyzed in depth in Fedderke and Klitgaard (1998), and Klitgaard and Fedderke (1995). I have also used two proxies for networks' structures: Kedzie's indicator (1997) of social connectivity (*conect*) and Fedderke and Klitgaard (1998) indicators of Ethno-Linguistic Fractionalization (*avelf*) (see Fedderke and Klitgaard, 1998, for an interpretation of these indicators). The former is constructed on the basis of indicators such as information regarding the number of phone lines per capita, and internet nodes per capita. The latter is the average of three indicators of Ethno-Linguistic Fractionalization (Muller, Roberts, and Gunnemark 1 and 2) described in Easterly and Levine (1997). These indicators measure the probability that two individuals picked at random belong to different ethnic groups.

In Table 2.4, I report the results of four models that are able to explain up to 50% of the international variance of depletion rates. One can confidently (i.e., independently of model specifications) derive three clear messages from these results. First, the sectorial composition of the economy is, as expected, an important explanatory factor of depletion rates. A one percentage point increase in the share of the industrial sector (e.g., from 30% to 31%) with an equal reduction in the agriculture sector, appears to increase the depletion rate by 1.8 percentage points (e.g., from 10% to 11.8%). On the other hand, the manufacture and services sectors reduce depletion rates, although their effects are less important (a 1% expansion of these sectors relative to the agricultural sector reduces depletion rates between 0.1 and 0.8 percentage points). Hence, observed increases in depletion rates in early stages of development are mostly explained by increases in the share of the industrial sector.

Second, the burden of foreign debt appears to be positively related to depletion rates. Hence, a 10 percentage points increase in the share of foreign debt reimbursements in total exports, is associated with an increase in depletion rates of 1.2 percentage points (i.e., from 10% to 11.2%). There are two interpretations of this result. The first is that originally, more loans where given to countries with high depletion rates. In other words the debt burden is an endogenous variable that depends on the depletion rate. A counter argument is that current levels of foreign debt are already the products of renegotiations that are more or less independent of depletion rates (e.g., Plan Brady). Also, if the foreign debt depends on depletion rates, our indicator of the debt burden should be correlated with past depletion rates and not with current depletion rates. Therefore, a second interpretation of the econometric result is simply that as the burden of foreign debt increases, countries may feel more pressure to deplete their natural resources in order to comply with foreign creditors. An implication is that in the case of highly indebted countries, stabilization of depletion rates may require external debt renegotiation.

The third message is that time and the level of economic development remain important drivers of reductions in depletion rates. These two variables are very likely to account for increases in the levels of education of the population and technological progress, but also for changes in dominant ideologies (e.g., the movement to free market reforms observed during the '80s and '90s).

Model	1			2			3			
Prob > F	0			0			0			
Adj R-squared	**0.5682**			**0.5738**			**0.5881**			**0.**
oddD	**Coef.**	**Std. Err.**	**P>|t|**	**Coef.**	**Std. Err.**	**P>|t|**	**Coef.**	**Std. Err.**	**P>|t|**	**Coe**
x_GDP	0.0007857	0.002995	0.793	-0.0078264	0.0038227	0.041	-0.0044613	0.0038165	0.243	-0
ind_GDP	0.1208571	0.0043467	0	0.1271688	0.0064511	0	0.1253318	0.0064662	0	0.
ser_GDP	-0.0171082	0.004473	0	-0.0178253	0.0057012	0.002	-0.0211211	0.0057093	0	-0
man_GDP	-0.0896858	0.0064987	0	-0.0970719	0.0080381	0	-0.0854648	0.0089145	0	-
debtX	0.0146562	0.002415	0	0.0114817	0.0028325	0	0.0085075	0.0028549	0.003	0.
t	-0.0133241	0.0055846	0.017	-0.0186217	0.0086656	0.032	-0.0201098	0.0085309	0.019	-0
avelf	-0.977997	0.1613533	0	-0.785394	0.1835652	0	-0.7320819	0.1874333	0	-2
m3_GDP	-0.0016609	0.0028657	0.562	0.0081765	0.0034555	0.018	0.0092862	0.0034849	0.008	0.
GDP_Cap				-0.0001176	0.0000391	0.003	-0.0000876	0.0000417	0.036	-0
civLib							-0.5121193	0.1042416	0	-0
polRight				-0.0788116	0.0333522	0.018	0.2866035	0.0852589	0.001	
conect				-0.0385687	0.023301	0.098	-0.0817727	0.0243374	0.001	-0
cam	-0.1227767	0.1753826	0.484	0.0056682	0.2167611	0.979	0.0782991	0.2453548	0.75	-
car	(dropped)			(dropped)			(dropped)			(drc
eap	1.11504	0.1632198	0	0.6920703	0.2045465	0.001	0.791264	0.2470214	0.001	1.
me	0.0978587	0.3761324	0.795	-0.734191	0.4498538	0.103	-0.4531443	0.446114	0.31	-0
naf	0.5217179	0.1604092	0.001	-0.0695301	0.2143826	0.746	0.26458	0.2389552	0.269	0.
nam	1.821486	0.2745594	0	2.075112	0.2882591	0	2.394343	0.3385507	0	2.
sas	1.374878	0.1509666	0	0.6910717	0.1865319	0	1.048106	0.2174532	0	0.
ssa	0.5390574	0.1342037	0	0.2760482	0.1747721	0.115	0.5983329	0.2271102	0.009	0.
we	-0.2075907	0.2385706	0.384	-0.4791043	0.2732899	0.08	0.2544021	0.3211936	0.429	0.
sam							0.3101168	0.2091904	0.139	0.
avelf2										2.
conect2										0
_cons	-4.643449	0.2655014	0	-3.604942	0.4168425	0	-3.246368	0.4340269	0	-3

Table 2.4: Structural Determinants of Depletion Rates.
Source: Author calculations.

Geographic location also explains differences in depletion rates. Sub-Saharan Africa, South America, Mexico, South Asia, and East Asia and Pacific tend to have higher depletion rates than high-income OECD countries. Since the model controls for the share of the different economic sectors, proxies for initial endowments, one possible interpretation for these results is differences in climate and culture.

Regarding the role of the financial sector (proxied by the extended measure of money supply, M3) the results are inconclusive. This indicator was supposed to be a proxy for a country's new technologies absorption capacity. When GDP per capita is not introduced in the model, this variable appears to contribute to a reduction in depletion rates. However, when we include GDP per capita, M3 appears to increase depletion rates. One is then tempted to conclude that, other things being equal, dynamic financial sectors tend to evolve in countries with higher depletion rates. One can in part explain the phenomena by noticing that countries with emerging financial markets tend to be countries that are attractive to foreign investors. Probably one of the reasons why these countries are interesting is lax environmental policies that facilitate the exploitation of natural resources (see the case of Mexico in Robalino and Treverton, 1997).

In the case of the institutional indicators, the results also need to be interpreted with caution. Both the civil rights indicator and the political rights indicators have a negative sign when used independently. Hence, an increase in any of these indicators tends to be associated with lower depletion rates. However, when both indicators are used together, increases in civil rights reduce depletion rates while increases in political rights increase depletion rates. This change in sign could simply indicate correlation between the two institutional indicators. However, this correlation is less than 0.3. An alternative explanation is that the civil rights indicator becomes a proxy for the ability of economically weak social groups to lobby for environmental protection. Thus, Governments may be less likely to fail to implement policies that guarantee an adequate management of natural resources, in order to satisfy the interest of particular commercial power centers. For example, in Ecuador, the Shuaras Indians in the Amazon region were able to stop the concession of a new oil field to the multinational Texaco. They have also put pressure on Texaco to reimburse environmental damages associated with the exploitation of oil fields in the region. On the other hand, the political rights index is measuring the degree of political competition. The results suggest that as competition increases, it becomes more difficult to coordinate the implementation of environmental policies that tend to reduce depletion rates.

In Table 2.4, the first three model specifications provide mixed evidence regarding the role of networks connectivity. As expected, the indicator *conect* has a negative sign, suggesting that in more interconnected societies coordination can facilitate not only the implementation of environmental policies but also the adoption of low environmental damaging technologies. The Ethno-Linguistic Fractionalization (ELF) index, however, tells an unexpected story: that as fractionalization increases, depletion rates *decrease*. One possible interpretation is that fractionalization is acting against the diffusion of technologies that have high environmental impacts. For example, fractionalization may impede the development of the industrial sector. A more interesting story, however, is that both connectivity and fractionalization are non-linearly related to the depletion rates. The fourth model specification in Table 2.4 provides strong support for this view. Indeed, both squared terms are positive and significant, while the non-squared terms are negative. For example, at low levels of Ethno-Linguistic Fractionalization, increases in the index reduce depletion rates. Given that 30% of our sample falls in the first and fifth quintile of the ELF distribution, one can interpret this result by saying that some degree of diversity is "socially optimal" (see Page, 1999). However, after some threshold, higher fractionalization is accompanied with higher depletion rates, meaning that coordination for technology adoption or policy implementation becomes more difficult. A similar story would hold with the connectivity indicator. At low levels of connectivity, higher connectivity reduces depletion rates. However, at high levels of connectivity, further increases may increase depletion rates, due to inertia or also coordination failures. To illustrate these results, I have plotted in Figure 2.16 the marginal effect of changes in the Ethno-Linguistic Fractionalization index and the connectivity index.

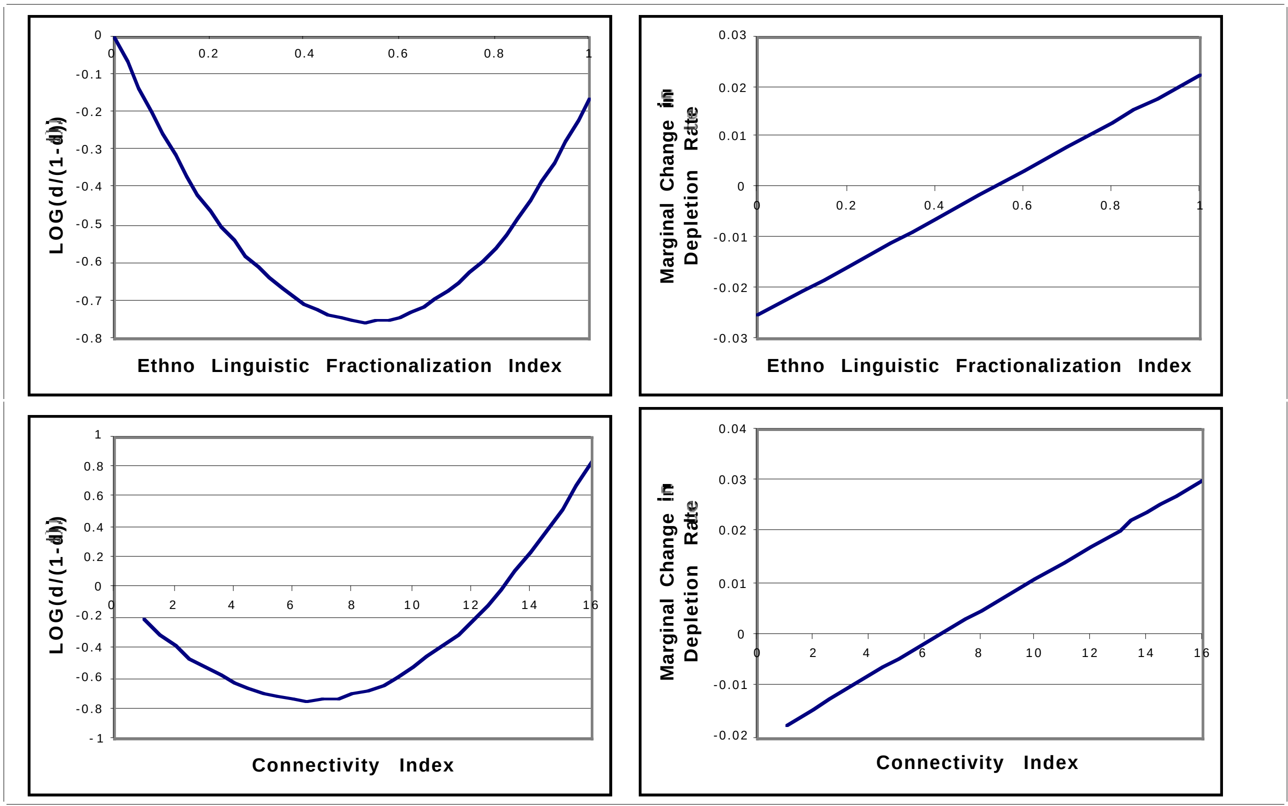

Figure 2.16: Network Structures and Depletion Rates.
Source: Author calculations.

The figures have been drawn *within* the range of variation of these indexes in the estimation sample. Hence, the ELF index ranges between 0 and 1, while the connectivity index ranges between 1 and 16. I assume that the reference depletion rate is set at 0.10 (10% of GDP). We observe that an increase of the ELF index from 0.2 to 0.3 decreases depletion rates by 1.5 percentage points (i.e., from 10% to 8.5%). However, an increase of ELF from 0.8 to 0.9 increases depletion rates from 10% to 11.5%. Similarly, in the case of the connectivity index, an increase from 2 to 3 reduces depletion rates from 10% to 9%. An increase in this index from 14 to 15 increases depletion rates from 10% to 12%.

5.3 Do Depletion Rates Converge?

Besides being indicators of sustainability, depletion rates are indicators of the degree of nations' dependence on their natural resource base. The question that I want to address is whether we are witnessing the creation of a multi-polar world where some countries specialize in the production of natural inputs (these economies will be relatively intensive in natural resources); while others specialize in the production of outputs. High depletion rates do not necessarily imply unsustainability. Indeed, countries with a large natural resource base may enjoy the possibility of high extraction rates. Nonetheless, in the long run, this type of specialization may tend to be associated with lower labor productivity, and hence lower income per capita (see Sachs and Warner, 1996).

There is no strong theoretical reason to believe that countries should converge to similar depletion rates. As shown in the previous section, differences in depletion rates are in part explained by structural differences. If countries converge to some steady state, the depletion rate should differ in relation to these structural factors.

The question of convergence in depletion rates is similar to the question of convergence in income per capita. Several empirical and theoretical studies have addressed the issue (see Durlauf, 1996; Sala-i-Martin, 1996; Bernard and Jones, 1996; Quah, 1996; and Galor, 1996) of whether income per capita tends to equalize. The majority of studies analyze convergence in one of two forms: countries converging to the same steady state; or countries converging to different steady states, depending on initial conditions and policies. Using different samples, studies have provided evidence for one or the other of the forms of convergence (see Barro, 1997 for a review). However, in recent years, seminal work by Quah (1992) demonstrated that the econometric methods used to test the convergence hypothesis were in most cases inappropriate. Indeed, the standard method was to compute an average growth rate for a given period of time, and then regress this rate on the initial level of income per capita and other controls (mostly proxies for initial conditions). A negative coefficient on the initial level of income per capita implies that, controlling for initial conditions, growth rates are higher for low income countries and these will therefore tend to catch up with high income countries. Notice that this result does not necessarily imply that they will converge to the same level of income per capita of developed countries. Indeed, because the initial conditions differ, the steady states differ. However, given these initial conditions, each steady state is unique. Quah's argument to demonstrate the inappropriateness of the method is the following. Imagine that the convergence hypothesis is true. Then with a sufficiently long time series, the sample average growth rates for different economies all converge in probability to the same underlying number (this is simply the law of large numbers for the growth rate: it applies regardless of whether incomes are individually difference stationary or trend stationary). On the other hand, initial conditions have some distribution and are independent of the length of the sample period. Thus, any correlation estimator between average growth rates and initial conditions will converge to zero with probability one. This will happen precisely when the convergence hypothesis is true. But, if one applies the methods, this zero correlation will be evidence against the convergence hypothesis: therein lies a contradiction.

Quah suggests a novel alternative (see Quah, 1992). He sets the null hypothesis by stating: "the income disparity across any two economies is a zero drift integrated process". Then, there is convergence if this hypothesis can be rejected in favor of stationarity. When the income of two countries are integrated, the income disparity is stationary if and only if the bivariate income process has a co-integrating vector (1,-1). Thus, if we are only interested in two economies, standard methods to test for co-integration could be used. It is clear however, that co-integration between two countries is irrelevant for the convergence hypothesis. Unfortunately, once the sample of countries increases, the problem becomes intractable with standard time series methods, since one would be forced to take into account a large number of cross-country income covariances. The method used by Quah incorporates concepts from statistical mechanics into classical econometrics. I will describe the method in relation to my application.

I am interested in testing whether depletion rates across countries tend to converge. These depletion rates are observed for a set of N countries and T time periods. Thus by fixing some country z as a benchmark, I can define relative depletion rates by:

$$\tilde{d}_{it} = d_{it} - d_{zt} \; , \qquad (2.9)$$

Instead of treating $\tilde{d}_{it}$ as a panel, following Quah, I treat it as a *random field*. This random field is more precisely a collection of random variables in a two dimensional lattice Z ={(i,t)|i,t are integers}. Before any type of statistical analysis can be done, it is necessary to model the possible dependence and heterogeneity across vertices in the lattice (i.e., observations). The assumption that observations are independent and identically distributed is a benchmark in econometrics. However, this assumption is clearly inappropriate in this case. Indeed, we know that countries "move together" and that they are heterogeneous. The alternative is to define a probability space over the lattice that provides the probability distribution of each subset of vertices as a function of the states of other vertices. Given that this method is relatively new in econometrics, its detailed discussion has been reserved to Appendix 8.3. Here, it is sufficient to state the following theorem due to Quah (1992):

Suppose that $\{\tilde{d}_{it}\}$ is generated by:

a) $\tilde{d}_{it} = \beta_0 \tilde{d}_{it-1} + \mu_{it}, \; i = 1,...,N; t \geq 1;$

b) $\beta_0 = 1$

c) $\tilde{d}_{i0}, u_{it}$ satisfy "basic assumptions" (see Appendix 8.3),

then the vector: $\beta_N = \dfrac{\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{d}_{it}\tilde{d}_{it-1}}{\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{d}^2_{it-1}}$ verifies:

$\beta_N \xrightarrow{\Pr} 1 \;\; as \;\; N \to \infty$. Furthermore, its distribution is normal[5]. Intuitively, what the estimator is doing is taking a country as a reference, and estimating the standard time series model or all the other countries. So, given a reference country, the indicator computes whether on average other countries converge to the reference country. If all countries on average converge to all countries, independently of which country is chosen as the reference, the β_N will be less than 1. Hence, if we take the average of all β_N across all reference countries, we should get a number less than one. However, if there are countries from which on average other countries diverge, the average of the β_N 's may be greater than one.

The previous theorem basically states that under our set of assumptions, β_N can be treated as a random variable with known distribution. The hypothesis that I want to test is whether β_N is statistically different from one. Because the estimator is normally distributed, the standard t-test can be applied (this is in contrast to the standard time series estimator of the first order integrated process, where adjustments to the probability distribution are required; see Dickey and Fuller, 1981; and Phillips, 1987).

There is no standard statistical package that can be used to estimate β_N. However, the implementation of the estimator is straightforward. My results are better illustrated by Figure 2.17.

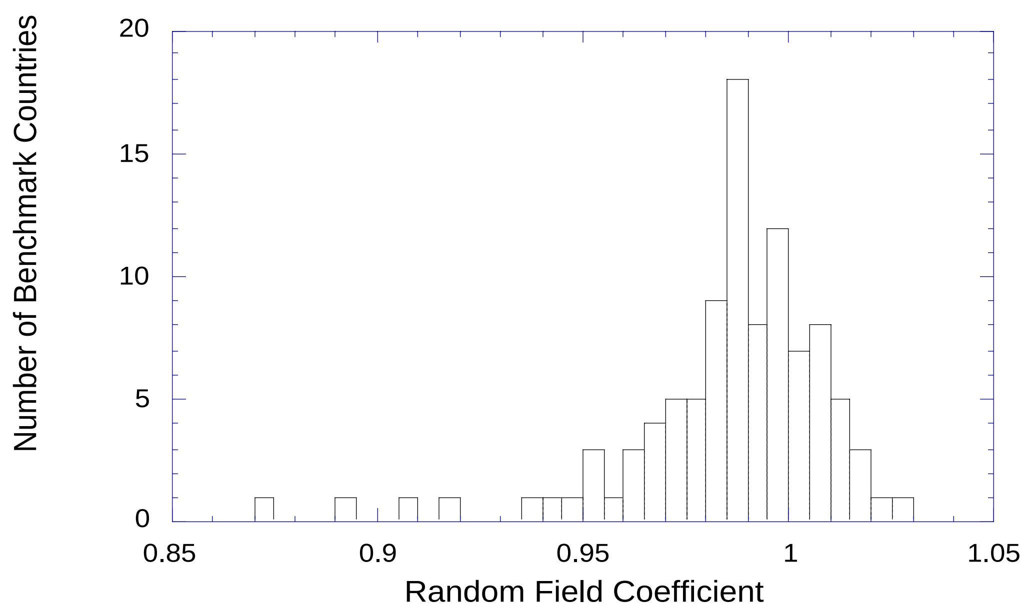

Figure 2.17: Distribution of the Convergence Parameter.

Source: Author calculations.

The figure provides the distribution of β_N, where each realization corresponds to the selection of a benchmark country. The conclusion is straightforward: the estimated coefficient is not likely to be significantly different from one. Indeed the t value for the test H0: $\beta_N - 1 = 0$, is 0.575. Hence, I cannot reject the null hypothesis and have to conclude that depletion rates across countries tend to diverge. Notice that I have not made any assumptions regarding structural homogeneity or heterogeneity across countries. Countries may be diverging simply because they are structurally different. Alternatively, divergence may be the result of the vagaries of history. Which is the actual reason does not matter here. Our only goal is to provide robust empirical evidence of whether countries converge or not.

However, the previous result needs to be interpreted with caution. Indeed, in the analysis of Sub-section 5.1, I showed that at initial levels of development, countries tend to increase depletion rates. Hence if we compare a low income and a high income country, it is likely that their depletion rates will be diverging, yet it does not mean that they will not start to converge after the first country has reached some level of development.

To correct for this bias, I have repeated the analysis by income groups, using high income countries as reference. The results are presented in Figure 2.18. While low income countries include countries with income per capita lower than USD 1,000, the other categories have countries with more than USD 1,000 per capita. Our analysis in Sub-section 5.1 suggests that these countries should have started to reduce depletion rates. Yet, we observe that within the low-middle income group, we are likely to observe countries such as Iran with depletion rates that diverge from the group. The same is true for some countries within the middle-high income group, such as Bahrain.

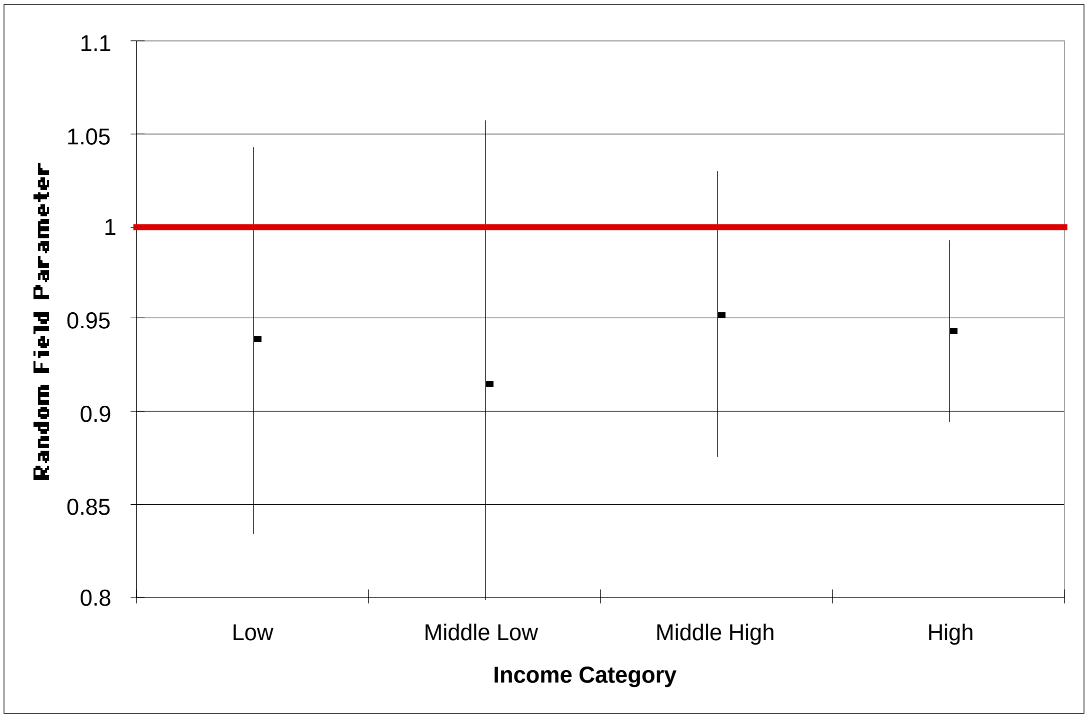

Figure 2.18: 95% Confidence Interval for Convergence Coefficient by Income Group.
Source: Author calculations.

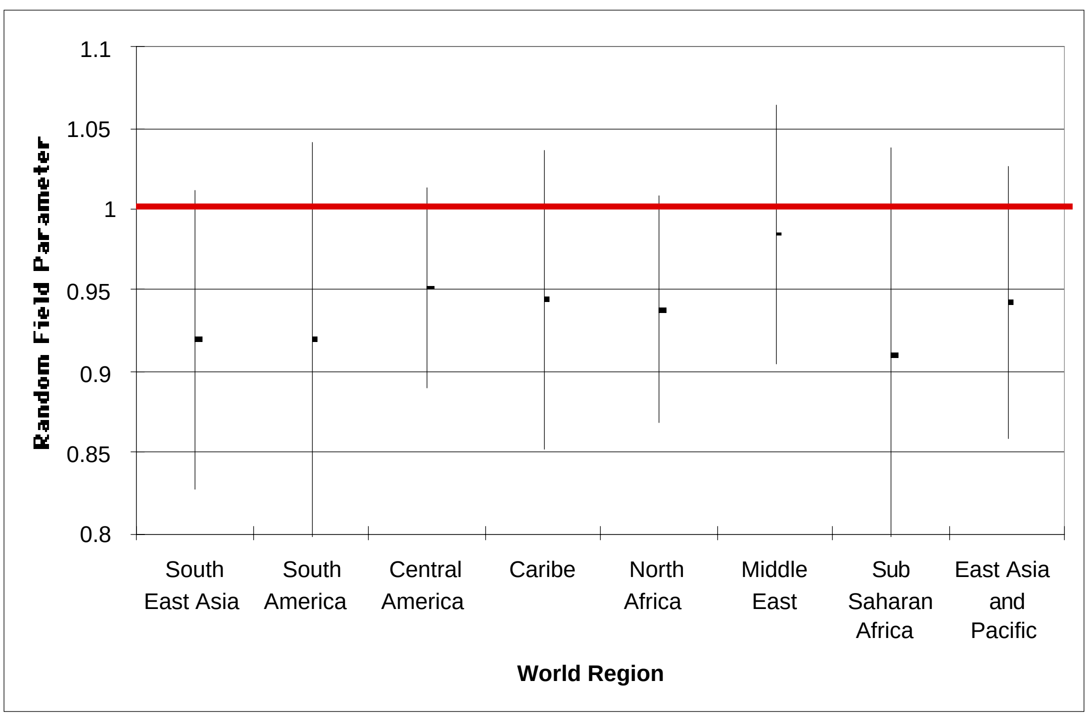

Figure 2.19: 95% Confidence Interval for Convergence Coefficient by Region.
Source: Author calculations.

In Figure 2.19, I have repeated the analysis for different regions of the world, taking in all cases OECD countries as the reference. The message is that some regions of the world are more likely to converge to OECD levels than others. South East Asia and North Africa fall into this category. However, for South America, Caribbean, Middle East, and South Africa, countries are more likely to diverge.

These results present some empirical evidence to suggest the idea of the formation of a multipolar world with countries with high depletion rates that specialize in the production of natural inputs for the production process, and countries with low depletion rates that specialize in processing these natural inputs. High depletion rates do not necessarily imply that a country is outside a sustainable path. Indeed, the optimal growth path may imply high depletion rates, as long as the rent from exploitation of the natural resources is invested efficiently. However, in the long run, sustainability may require stabilization of the stock of natural resources (the stock of non-renewable resources cannot last forever). This inevitably implies reducing depletion rates. For those countries that have higher depletion rates this stabilization process may turn out be more difficult. Thus, these countries should receive most of the attention of international organizations.

6. Conclusion

This chapter focussed on the definition and measurement of sustainable growth, as well as an empirical analysis of the determinants of the dynamics of depletion rates. In the first part of the chapter, I suggested that key indicators (i.e., flags) of sustainability are the stock of natural, produced, and human capital and their respective net investment rates. Thus, a sustainable growth path can be assessed in terms of extended genuine savings, defined as the traditional savings minus the depreciation of produced capital and the stock of natural resources, plus investments in education and health. Sustainability in the long run will depend on developing countries' ability to increase investments in human and produced capital, and stabilize their stock of natural resources.

In a second part of the chapter, I studied the determinants of depletion rates. The data provide evidence that in the first stages of economic development, countries tend to increase depletion rates but that as economic growth takes place, these depletion rates tend to diminish. The transition point appears to be close to USD (1987) 1,000 per capita. The data also suggests that institutions and social network structures are important determinants of the dynamics of depletion rates. In particular, depletion rates tend to be higher in countries with low political and civil rights, and in countries with low or very high levels of social capital. I also provided some evidence that the external financial constraint imposes pressures on developing countries to increase their depletion rates. Finally, the data supports the idea of a multi-polar world where some countries remain highly dependent on their natural resources base.

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[1] Lately, it has been suggested that another form of capital, social capital, should also be incorporated in nations' wealth. I have postponed the discussion of this issue to Chapter 5.

[2] The true social cost of a unit of natural resource is its marginal production cost. If this cost can be represented by a function mc(q) where q is the level of output, then the total social cost of production is given by: $\int_0^q mc(q)dq$.

Yet, in the World Bank calculations, this cost is implicitly given by: mc(q).q + Fixed Costs. Hence, profits over estimate producer surplus.

[3] The reader can argue that if d is high and environmental damages are high, then D>Q and d>1. However, these damages are not likely to be registered in Q (GDP from the standard national accounts). As a matter of fact, in our panel data set we always have 0<d<1.

[4] Other specification could have been used. For example, time effects that vary discontinuously with the level of GDP per capita (e.g., low, middle, high). However, defining these thresholds is rather an arbitrary operation. Thus, I have chosen to work with continuous time effects.

[5] The estimator of the random field coefficient is different from the standard time series estimator given by

$$\hat{\beta} = \frac{\sum_t \tilde{d}_t \tilde{d}_{t-1}}{\sum_t \tilde{d}_{t-1}^2} .$$