The Roles of the Environment and Natural Resources in Economic Growth Analysis

Michael Toman

May 2003 • Discussion Paper 02–71

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202–328–5000
Fax: 202–939–3460
Internet: http://www.rff.org

The Roles of the Environment and Natural Resources in Economic Growth Analysis

Michael Toman

Abstract

The primary aim of this paper is pedagogical. We first present and discuss a “wiring diagram” framework in order to elucidate the general links between economic growth and "natural capital." After developing the general framework, we develop parallel frameworks applicable to several specific sectors of the economy (agriculture, forestry, and manufacturing). Two appendices provide a mathematical formulation of the economy-wide framework and a brief historical review of the role of natural resources and the environment in economic growth theory.

Key Words: economic growth. natural resources. sustainable development

JEL Classification Numbers: Q00, O1

Contents

The Roles of the Environement and Natural Resources in Economic Growth Analysis

Michael Toman*

1. Introduction

When modern theories of economic growth first began to be developed in the 1950s and 1960s, natural resources and the environment essentially were absent.[1] Economic output flows and rates of output growth were assumed to depend on the applications of services provided by capital and labor. Capital could be augmented by net investment as a result of domestic savings and external capital flows. There were potential "limits to growth" identified in growth theory in that as capital per person grew, the rate of growth in output per person declined until a steady state was achieved. But such limits to growth were not related to natural resources and the environment.

Technology was added to capital and labor as an input to the growth process. Technical progress was almost always assumed to be exogenous and not embodied in specific equipment or skills, though more recent developments in growth theory have relaxed this artificial assumption. Output growth could then be prolonged through (assumed) technical advance. But the role of natural resources and the environment as valuable inputs to the growth process remained outside of growth theory at that time, as did possible constraints from the natural world that could lead to more rapid slowing or even a decline in output per capita over time.

---

* The author greatly appreciates the advice and comments offered by Mike Rock, particularly on research needs, and comments by Russell Misheloff and Kenneth Baum on earlier drafts. He also is very grateful for excellent research assistance from Barbora Jemelkova. Financial support for the writing of the paper was provided by the Agency for International Development through International Resources Group. The views expressed in the paper are the author's alone.

[1] From a historical perspective this absence is somewhat curious, since land had played such a vital role in 19th century classical theories of economic progress. The industrial revolution and the Walrasian neoclassical economics of the late 19th century both initiated a decline in attention to natural capital that has only recently been partly offset with renewed interest in growth and natural capital. Appendix B to this paper summarizes some of these recent developments in growth economics.

Starting in the late 1960's, awareness of the environment and natural resources as a determining factor affecting growth became more widely appreciated. Attention to the interfaces between the natural and economic worlds initially came from natural resource and environmental economists interested in problems of limits to growth. In the late 1970's, development economists began seriously rethinking the neoclassical growth model because of the realization that macroeconomic policy recommendations would be incomplete without reference to environmental policy components. Over time, as a result of efforts by specialists of both types, theories of growth with various kinds of natural resource inputs and environmental implications became fairly well developed.

The analytical paradigm was further altered in the late 1980s to reflect concerns about environmentally sustainable economic growth. Sustainable economic growth policies in this perspective depend on the level, quality, and management of renewable and non-renewable natural resources and on the state of the environment. The state of the environment is dependent, in turn, on the level and growth of pollution, or waste streams, and the natural assimilation of pollution by the environment (as an environmental service) or through clean up expenditures. Pezzey (1989, 1992) presented a simple but well elaborated "wiring diagram" and accompanying mathematical analysis showing various linkages between natural resources flows and environmental services on the one hand, and economic activity and natural resource depletion or degradation on the other.

The primary aim of this paper is pedagogical. We first present and discuss a variant of the Pezzey framework in order to further elucidate the general links between economic growth and "natural capital." Our framework is rooted in a central premise of growth economics, namely that *growth is fundamentally a process of investment in various forms by society,* and the rate and quality of growth depend on the size and composition of such investments. As explained further below, to accomplish its purposes our framework emphasizes some factors at the expense of others; there are uncountably many ways to build a wiring diagram and none are perfect. After developing the general framework, we develop parallel frameworks applicable to several specific sectors of the economy (agriculture, forestry, and manufacturing). Two appendices provide a mathematical formulation of the economy-wide framework and a brief historical review of the role of natural resources and the environment in economic growth theory.

2. A Schematic Representation of the Roles of Natural Resources and the Environment in Economic Growth

Our general schematic framework is laid out in Figure 1 and explained in this section; Appendix A provides a more technical discussion of it. Since our focus is on investments by society, we emphasize the presence of various forms of capital and possibilities for (net) investment in these forms. We recognize of course that the supply and employment of labor also is a critical part of the economic growth process, but to simplify the diagram we do not develop this part of the economic system in much detail. Another simplification of the presentation is that we do not distinguish (as Pezzey did) a stock of technological knowledge separately from the basic capital stock. Investments in knowledge embedded in machines or increased human capacities (human capital) certainly are crucial to economic development. In our framework, knowledge is implicitly embedded in capital, and investment in technical progress is reflected as an increase in the flow of productive services generated by physical capital. Both technological knowledge and human capital stocks could be added explicitly to the wiring diagram, at the cost of considerable complication of the picture.

One other simplification to note at the outset is that the framework in Figure 1 focuses on the links *between* the natural and economic worlds without attempting to elaborate in detail the allocation of resources *within* the economic sphere. In particular, we recognize that produced final output in the economy takes many forms – agriculture, manufacturing, household production, and commercial services for example – and that final output results from the production and application of numerous intermediate goods. In practice growth and development policies must be concerned with these issues of the composition of economic activity – the efficiency of specific sectors, the impacts of trade liberalization, and so forth. Again, the framework can readily be extended to address a richer composition of economic activity, but the substantial complication of the diagram does not add much to the broad understanding of environment-economic linkages at the economy-wide level. Environment-economic linkages for various sectors are elaborated in subsequent parts of the paper.

The large box in the center of Figure 1 represents the production in the economy of both valued goods and services and the inherent co-production of wastes. In this framework, "waste" is not a purely physical concept (based for example on materials balance – what goes in must come out). We conceive of waste as flows that reduce environmental quality as broadly defined below.

As shown in Figure 1, production of goods depends on (a) flows of capital services (and associated labor services), (b) flows of extracted natural materials (biological and geological, renewable and depletable), and (c) environmental services provided by natural systems. The volume of wastes released to the environment depends on the volume of material output and on the flow of services derived from another form of investment by society, that which is applied to manage the byproducts of production generated within the economic system. We use the shorthand "byproducts management capital" to summarize these services. Byproducts management refers both to pollution prevention (reduction in unwanted harmful byproducts relative to desired goods), and to end-of-pipe treatment that reduces the damage caused by physical discharges.

At this level of generality, "environmental services" incorporate a number of productive inputs. Climatic conditions, including temperature and rainfall, are more or less conducive to agricultural and silvicultural production. Water bodies (rivers, lakes, estuaries, wetlands) of certain water quantity, turbidity, flow rate, temperature, and chemical composition provide more or less fruitful habitat for valued aquatic organisms (shrimp, fish, plant life) as well as water resources for human consumption and manufacturing. Biodiversity contributes to ecological stability as well as to tourism, long-term agricultural productivity, and possibly pharmaceuticals. Air quality and broader climatic conditions affect ambient temperatures, health conditions, and variability of weather in ways that affect the productivity of inputs in various household and manufacturing activities. "Environmental quality" then can be understood generally as the capacity of the natural system to provide a sustained flow of these various environmental services.

We make the simplifying assumption in this graphical framework that extracted natural resources and the services of capital are the only produced intermediate inputs. Other intermediate inputs, such as environmental quality, are supplied by nature. In practice, of course, the economy has a number of intermediate goods. The flow of extracted natural resources depends on the effective stocks of those resources, as well as on the flow of capital services (and associated labor services) applied to their development and extraction. This is another point of connection between the economic and ecological domains. "Effective" natural resource stocks also are not a purely physical phenomenon. Society also can invest what for simplicity we call "natural resource management capital" to enhance the natural or economic productivity of those resources. Such investments can range from technical progress that enhances the use of lower-grade ores to improved management of biological resources to enhance their regenerative capacity. In Figure 1, these investments are referred to as “natural resource management.”

Once final outputs are produced, they are allocated between immediate consumption and various forms of investment. As in standard growth analysis, society can sacrifice some current well-being by reducing immediate consumption to gain greater future well-being through augmentation of capital. Here, however, we recognize multiple forms of investment that are possible, each of which can contribute to future well-being. Investment can increase capacity for final goods production; enhance natural resource extraction; reduce wastes (byproducts management) through pollution prevention and end-of-pipe neutralization; enhance the productivity of natural resource stocks (natural resource management); or remediate environmental harms that do occur, thereby upgrading the part of society's wealth reflected in environmental quality.

Wastes that are produced (taking into account byproducts management activities) flow back into the natural environment and reduce environmental quality.[2] Reduced environmental quality negatively affects economic productivity by reducing the flows of various environmental services, as described above, and by reducing the productivity of some natural resources. Reduced environmental quality also has a direct negative effect on household well-being, given a level of material consumption.[3]

The foregoing paragraphs have laid out the various pathways through which natural resources and the environment are related to economic growth and social welfare. Economic output is sustained and enhanced over time through the maintenance and enhancement of various environmental service flows, and through the effective protection and management of natural resource stocks, as well as through the augmentation of natural resource extraction and final production capacity. Stated another way, diminution of the flows of these natural capital

---

[2] In this framework we represent wastes as originating only in the production sector. However, in the economy-wide framework of Figure 1, "production" can be interpreted to include household production activities – provision of food, shelter, warmth, and so forth – that also include waste byproducts. For simplicity we are not including in Figure 1 the flow of byproducts that can originate in natural resource extraction, though it is clear that this is another important source of environmental pressure and the framework can easily be generalized to incorporate this link. The Pezzey diagram represented waste flows as originating exclusively in households as a result of final consumption. Pezzey also divided output into streams of consumption, investments, and environmental clean-up expenditures. In our framework we represent this last claim on output in the accounts as investments in byproducts management and environmental remediation capacity.

[3] The most straightforward way that household well-being is directly affected by environmental quality is health (diversion of productive resources to health remediation being a consequence of the impact). Direct aesthetic impacts also are relevant for household well-being. Other impacts like availability of water or fuel could be seen as part of the production sector broadly defined to include household activities.

services will reduce economic product for a given stock of output producing capital. Such a diminution of production possibilities could only be offset, within certain limits, by increased investment in output producing capital. However, such investments would be subject to diminishing economic returns as well as some inherent natural limits on their efficacy,[4] and in any event they would engender reductions in current consumption that have a social cost. Therefore, *investment in the maintenance of natural capital services is one of the important pathways for achieving sustained growth*, though the nature of the tradeoffs among the various forms of investment in practice is an empirical question.

We can also look at the issue from the perspective of household welfare, the ultimate rationale for sustaining and enhancing growth in any event. We have already noted that household well-being depends on environmental quality as well as material consumption. One way that environmental quality can be enhanced is to simply reduce economic product and the associated environmental degradation from waste flows. Societies can in principle make tradeoffs as to how consumption-rich and environment-poor or consumption-poor and environment-rich they wish to be. Fortunately, there are other margins for tradeoff through investment as well. By foregoing some consumption in the short term society can invest in byproducts management and environmental remediation that not only improve the environment but also enhance economic product in the long term. The same logic applies to investments in natural resource management.

This diagram describes pathways and linkages; it does not describe how an actual economic system performs in terms of overall economic efficiency and investment in natural capital in particular. In any economic system, these outcomes depend on what we can call the effective prices faced by agents in the system. These prices depend on the effective scarcity of the resources in question, which in turn depends on the state of technology (including human capital as well as technical knowledge); knowledge levels and preferences of the population; the size of the natural resource stock; and the *institutions* that mediate the allocation and exchange of the resources in question.

Efficiency problems in the allocation of natural capital resources arise because of externalities that are familiar to natural resource and environmental economists. If a scarce

[4] To cite the simplest example, the laws of physics do not allow the economic system to run on some negligible amount of energy; at some level energy and capital are complements. Therefore, if depletable energy resources are exhausted and renewable energy resources are not developed, output necessarily suffers.

natural resource is nevertheless freely available for the taking (open access), it will be over-exploited and incentives to invest in better protection and management will be lacking. If social mechanisms for internalizing the costs of environmental degradation are lacking, then waste production will be excessive and investments in waste byproducts management and environmental remediation will be deficient.

Development theory has its own list of growth-retarding market and institutional failures to add to the above list. Prominent examples include excessive investment costs because of capital market failures; under-investment in human capital; inadequate infrastructure provision (by public or private actors); and a variety of product market distortions. There are important potential interactions between the two sets of market and institutional failures. In particular, high costs of other investments, limited employment opportunities, and subsidies to certain output sectors all may accelerate natural capital depletion beyond efficient levels. Both sets of market and institutional failures thus admit the possibility of win-win improvements. Corrections of distortions in the allocation of natural capital can stimulate economic progress and enhance human welfare as well as protecting the environment *per se*. Correcting other failures can in a number of cases also lower costly pressure on natural capital.[5]

The next three sections of the paper discuss and illustrate diagrammatically important links between the natural and economic worlds for three sectors of the economy: agriculture, forestry, and manufactures (industry). The first two sectors obviously depend heavily on "natural capital" and also can have substantial environmental implications. For manufactures the dependence on the natural world is somewhat less direct but no less important.

[5] This connection is not automatically so virtuous. Suppose, for example, that a developing country has been *de facto* subsidizing its manufacturing sector through import protection. In this case trade liberalization could increase demands on natural capital through a shift toward agriculture or natural resource extraction and harvesting. Whether this shift creates inefficient pressure on natural capital depends critically on the nature of the natural resource management and protection institutions in place in the country. See Lopez (2000) and Margolis (2002).

3. Sectoral-Level Economy-Environment Linkages: Agriculture

Some key economy-environment links for agriculture are illustrated in Figure 2. The general discussion in the previous section emphasized the importance of natural resources and environmental attributes as inputs to production, and as receiving media for discharges back to the environment such that natural resource depletion and degradation can affect economic activity over time. The characterization of economy-environment links for agriculture illustrated in Figure 2 follows along these lines.

Before discussing the figure, we note that its representation is meant to be illustrative, not comprehensive or definitive. The diagram can be applied in broad terms to both subsistence and commercial agriculture, as well as to high-intensity plantation forestry (more traditional rotation forestry is considered in the next section). Some output processing parts of the agricultural sector are more akin to the economy-environment linkages for manufacturing discussed in Section V.

Figure 2 illustrates three different kinds of linkages. One type (the solid lines) is the flow of physical inputs or other productive services at various points in the process. Another (shown with dashed lines) is the flow of payments to pay for factors of production and undertake various kinds of investments. Finally, the diagram incorporates long-term feedbacks on natural resources and the environment (dotted lines).

The first key set of stylized facts Figure 2 incorporates is that soil fertility, a complex function of the biological and physical conditions of the soil, is an important quasi-renewable input to agriculture along with a number of human-supplied inputs. Soil fertility is naturally renewable to varying degrees, but natural renewal generally is not sufficient for maintaining adequate fertility to economically support agriculture, at least at a commercial or intensive subsistence scale. Various expenditures and investments can supplement the cycle of fertility depletion and natural renewal to maintain the flow of services from the land resource. Also included in this category is investments in improved soil management practices and institutions, including for example the clarification of *de facto* property rights. These are identified in the diagram as "soil rejuvenation inputs" and "improved soil management."

A second key set of stylized facts is that various unwanted and environmentally deleterious wastes are a co-product of agricultural activity along with food, fiber, and animal products. As a concrete example, we focus here on water-borne effluents resulting from various sources including runoff and return irrigation flows (the ideas readily extend to other environmental issues, such as air pollution from windborne soil erosion). The net waste intensity of agricultural output (or, more accurately, the environmental damage intensity of output) can vary with a variety of potentially costly waste reduction and management activities (such as riparian buffers, animal waste management, changes in cultivation technique).

Aside from being a carrier of pollution, water is clearly an important and often scarce input to agriculture. Surface water is ultimately replenishable, but ground water may recharge only slowly or not at all. In either case, expanded water use confronts a rising real opportunity cost of supply. Investments in water conservation capacity represent another channel through which investments in sustainable management of natural resources can support sustainable output.

In the diagram, "environmental technology" is a catch-all for various activities that allow a given flow of agricultural activity to generate more valued outputs and less wastes; for on-site wastes that are created to be treated or otherwise managed to reduce their harm to the environment; and for efforts to improve the efficiency of water use in agricultural activity, thereby reducing pressure on the water resource base. Payments for these environmental management activities and for investments in soil rejuvenation and protection, along with payments for labor, capital, materials and (as applicable) water inputs, can be subtracted from the value of gross output to determine residual income – the return to land and (depending on definitional categories) entrepreneurship. Various payments are in-kind with subsistence growing, and water resources may in practice be used gratis, but the general framework is still applicable.

It follows from this discussion that *various investments in the maintenance of natural capital services in the form of soil productivity and water availability (quantity and quality) are among the important pathways for achieving sustained growth in the agricultural sector.* We can also apply the general reasoning developed in the previous section to see how policy and institutional failures can reduce the overall economic efficiency of the agricultural sector. On the environmental services side, failure to price water, land services (because of insecure property rights), and environmental loadings according to their true opportunity costs will excessively deplete or degrade natural and environmental resources and in so doing limit opportunities for sustainable economic progress in the agricultural sector. On the agricultural markets side, distortions in the prices of agricultural outputs or material inputs like agro-chemicals will have both direct consequences in reducing economic efficiency and indirect consequences on efficiency and sustainability through effects on the natural system.

4. Sectoral-Level Economy-Environment Linkages: Rotation Forestry and Non-Timber Forest Products and Services

Let us turn next to a stylized representation of the economy-environment interface as it arises in connection with forest resources. Figure 3 illustrates some key interconnections. We have designed Figure 3 to apply principally to a situation in which there is rotational timber harvesting of more or less natural regrowth, with some management inputs. The solid lines in Figure 3 represent the flow of physical inputs or other productive services at various points in the process. The dashed lines represent the flow of payments to pay for factors of production and undertake various kinds of investments.

Our assumption in Figure 3 is that while the scale of timber harvest may vary, rotational harvesting *per se* is maintained at a sustainable level. Accordingly, unlike the agriculture and soil depletion diagram in Figure 2, we do not represent in Figure 3 a long-term ecological feedback from timber harvest to land degradation. Instead, we emphasize in Figure 3 the fact that timber harvesting decisions can have important impacts on the mix of other socially valued outputs of forested areas, and that these impacts are connected to important public policy concerns related to both economic development and environmental protection. The other key area of public policy concern is related to long-term, potentially irreversible loss of forested areas due either to excessive harvesting pressure or deliberate decisions on land conversion. We address this issue in the concluding paragraphs of this section.

One key economy-environment link shown in Figure 3 is the services of the land base and growing conditions for supporting forestry. Unlike in our discussion of agriculture, however, we emphasize in Figure 3 that forested areas produce a number of socially valued goods, some of which are traded in markets and others which are substantially or largely non-market goods. There are both complementarities and tradeoffs in the production of different menus of outputs from the forest that are a key part of the economy-environment linkage. Moreover, these complementarities and tradeoffs are substantially influenced by investments in knowledge and technology.[6]

The box in the center of Figure 3 incorporates a menu of possible outputs from a forested area. Along with timber harvest, the forest may produce a variety of non-timber forest products

[6] This is also true in the other two sectors we are considering and for the economy as a whole, but we choose to illustrate the point here in the forestry discussion.

(animal and plant based) that have direct economic (and often direct market) value. In addition, the forest produces a variety of "ecosystem services" that have different types of direct and indirect economic value but are not likely to be produced and priced efficiently in markets. This is because these services have in varying degrees the aspects of "public goods:" to at least some extent they can be shared by and provide benefits to a number of users without diminishing the value to any of them. Moreover, limiting enjoyment of the benefits to those who pay for them is difficult. To be concrete, in the figure we have identified three ecosystem services frequently identified with forest areas: the sequestration of carbon (a potential long-term benefit in the context of climate change), conservation of biodiversity, and watershed protection (maintenance of ground cover, avoidance of soil erosion).

In the diagram we show the inputs to timber production as being the services of the land base and growing conditions themselves, and the human supplied inputs that receive payments (monetary or in kind) for their services. There are of course labor and possibly other inputs needed to gather non-timber forest products as well, but to avoid clutter in the diagram we do not show these. Greater inputs implies, other things equal, greater timber output. The key question then becomes the consequences for other valued outputs of the forested area from greater timber extraction.

There continues to be scientific uncertainty and policy controversy around this question. Figure 3 shows one plausible set of conditions for these relationships; others are possible. In our representation, the outputs in the left hand column are complements. Increased management of the land for timber harvest also increases the average amount of carbon storage because managed forests often hold more carbon per unit area than natural forests, especially old growth forests, and because the conversion of timber into wood products adds to the reservoir of carbon stored in forms that decompose very slowly.[7] Supplies of some non-timber forest products may also be enhanced by greater rotation timber harvest activity (for example, game animals that benefit from periodic opening of the forest canopy that expands grazing areas).

On the other hand, putting greater amounts of land under rotational harvest management and applying human inputs to those lands more intensively may well reduce those outputs associated more with natural forest conditions. In terms of the diagram, expanded timber output slides the vertical dashed line in the outputs box to the right, reducing outputs in the right hand

[7] We are ignoring here factors such as methane emissions from scrap paper decomposing anaerobically in landfills.

column. Some of the outputs that are reduced when timber harvest increases from a particular forested area could be biodiversity (from disruption of natural habitats), watershed protection (from reduction of forest cover that allows more erosion), and some non-timber forest products (perhaps medicinal plants) that benefit from more natural growing conditions.

Figure 3 emphasizes a pathway for investment in maintaining "natural capital" that is especially important for forested areas, though it is also important for other sectors of the economy as well. Investments in knowledge and technology can reduce the tension between different forest outputs by expanding the size and even the menu of outputs that can be achieved. For example, improved silvicultural techniques (including selective breeding) might increase the supply of timber possible per unit area and reduce the environmental impact per unit of harvest. The result would be less disturbance to forest areas as a result of harvesting and a greater capacity to leave forest lands in a more natural state to produce desired ecological benefits. This is shown in the diagram by knowledge and technology inputs expanding the dimensions of the output box.

Various investments in the maintenance of natural capital services – including improved knowledge and technology – are an important pathway for achieving sustained growth in the overall social value derived from forest areas. In this case especially, the mix of valued outputs can vary and policy decisions must weigh what kinds of output growth to promote as well as how to promote output growth. Again, policy and institutional failures that distort the price of any input or output, including non-market outputs, will reduce overall economic efficiency, constraining growth and causing the mix of outputs to diverge from what society intended. For example, distortions in timber markets, including logging subsidies and open access to forest lands, will stimulate excessive and too rapid harvest which is economically wasteful directly and harms non-market outputs. The problems on the environmental side include potential under-valuation of key ecosystem services whose provision might compete at the margin with timber extraction. Figure 3 illustrates in addition that there may be tradeoffs between different public goods that must be addressed in policy formation. Here, a conflict may arise for example between carbon sequestration, which is enhanced by managing the forest, and biodiversity conservation, which is best served by maintaining the forest in its natural condition.

More extreme versions of the challenges discussed in the previous paragraph can arise when market and policy distortions create incentives for deforestation and land conversion that make sense for the individual actors involved but do not serve a larger social interest. For example, poverty, logging subsidies, open access problems and a lack of adequate financial return for protecting biodiversity all could render rotational timber harvesting less attractive than land conversion. Of course, not all conversion decisions are bad from a societal perspective either – alternative land uses may yield the greatest overall social value. Investments in knowledge and technology that reduce the severity of tradeoffs among forest outputs also can reduce pressure for potentially deleterious land conversion. Equally important, however, are the creation of institutional arrangements that permit socially valued forest uses to generate an adequate economic return for those most immediately involved in such uses (Robinson, Williams and Albers 2002, Ferraro and Simpson 2002).

5. Sectoral-Level Economy-Environment Linkages: Manufacturing

Figure 4 describes in a general way economy-environment relationships relevant to manufacturing. Here the process of production is shown in two stylized steps: the extraction of raw natural resource based materials, using labor and capital as well as the natural resource base, and the combination of these raw materials with the services of additional labor and capital to produce final goods. The natural resource base here can be either geological (minerals) or biological (e.g. fish and crustaceans). This is the first of several important economy-environment links shown in Figure 4.

As in Figure 2, Figure 4 illustrates three different kinds of linkages. One type (the solid lines) is the flow of physical inputs or other productive services at various points in the process. Another (shown with dashed lines) is the flow of payments for factors of production and for various kinds of investments. Finally, the diagram incorporates long-term feedbacks on natural resources and the environment (dotted lines).

Figure 4 shows that extraction of raw materials from the natural resource base causes depletion of these resources. As already explained in connection with the economy wide diagram in Figure 1, the extractive industries can and do make a variety of investments to counter the effects of depletion: the development of new natural resources, and various investments in more productive natural resource management. This is an important part of the overall efficiency of natural resource use in the economic system. But our focus in this section is more on the flow of materials through the industrial sector and their flow back to the environment, so we do not develop the potential for improved natural resource management in Figure 4.

Both steps (natural resource extraction and final output production) involve creating byproduct wastes. Those wastes that do pass back to the environment have an adverse effect on air and water quality and also may harm the productivity of the natural resource stock (in particular, biological stocks like a fishery). This illustrates a second key economy-environment link. However, the services of what we refer to generally as "environmental technology" can be used to reduce the waste intensity of intermediate or final output and to manage remaining wastes to reduce their environmental harms.

Once again, *various investments in the maintenance of natural capital services can be an important pathway for achieving sustained growth in industrial output*. The investments in this case include the reduction and management of unwanted byproducts in the environment that reduce productivity as well as causing direct harm to people, along with investments in the development and improved management of natural resources. And as already explained, failure to account for these environmental feedbacks in the pricing of goods and services or distortions in input and output markets with potential environmental side effects all reduce overall economic efficiency and thereby unnecessarily constrain growth.

6. Conclusions and Empirical Challenges

This paper has attempted to clarify at an intuitive and conceptual level how economic growth and the environment are interconnected. The framework developed here has emphasized that natural resources and environmental quality can and should be thought of as targets for investment by society in promoting an improved quality of life in developing countries, investments that compete against other valued allocations of social savings. *Economic growth affects the natural environment, but the natural environment also affects growth. This implies that concern for the natural environment needs to be at the core of development policy, not just a stand-alone environmental policy.*

By describing investments in natural capital as competing with other uses of savings, we intend to underscore the inherent tradeoffs societies face in allocating savings. Investments in natural capital should not automatically be favored over other uses of resources, as advocated by some activists. Some degradation (depreciation) of natural capital can be appropriate. By the same token, however, we are arguing against the idea that the environment is somehow a luxury good or for some other reason inherently of secondary importance to those interested in economic growth and the well-being of people.

We have noted that natural capital is inefficiently allocated in practice not just because of market and institutional failures affecting natural resources and the environment, but also because of broader market and institutional failures that simultaneously hamper development and excessively degrade natural capital. In both cases the appropriate policy response must take into account the source and size of the misallocation problem, and the practical constraints of institutional capacity prevailing in the country. Sometimes the best remedy for environmental problems can be found in policies that focus on alleviating institutional barriers to economic growth. But it does not follow automatically that growth policies alone should be pursued to ameliorate environmental problems.

While the conceptual framework we have developed in this paper is well grounded in the economic theory of growth and the environment, the empirical literature on these interconnections is less well developed. Further investigation through work in the field should put a high priority on reducing these empirical gaps.

A fair amount of empirical work has been done on the collateral effects of development policies on the environment, though this work often has involved case studies of specific policies and countries. For example, non-competitive allocation of forest concessions with low rent capture can encourage concessionaires to economically as well as ecologically overexploit forest stocks. Subsidies for agricultural inputs (water, fertilizer, pesticides, insecticides) can encourage excessive and inefficient use of these inputs with increases in water pollution and residues on crops. Import substitution policies tend to lead not only to economic inefficiency in manufacturing; they also can promote excessive development in heavy industries that emit high levels of conventional air and water pollutants; in downstream resource processing that encourages economically excessive exploitation of natural resources; or in agricultural practices that generate excessive land use (soil mining). Policies that foster foreign investment, on the other hand, may sometimes promote some pollution haven effects, but they may also promote cleaner development through access to best technology and corporate practices. While these points have been addressed, there is still plenty of room for more investigation of both the scale of the linkages and the practical options for averting adverse impacts.[8]

Less is known empirically about the effects of environmental quality on economic growth. Some individual studies have described how air and water pollution can reduce agricultural yields and damage materials, as well as forcing industry to invest in costly water clean-up before it uses raw water for industrial purposes. Both water and air pollution seemingly can, through human health effects, reduce labor productivity. And natural resource degradation,

[8] For an older but still useful compendium of analysis related to trade and the environment see Low (1992); see also Margolis (2002).

of the types mentioned in the previous paragraph, limit long-term productivity in the affected sectors. But the empirical literature at the sectoral level for developing countries remains limited, and the macroeconomic consequences of these impacts in terms of growth are even less well understood.

Perhaps the least is known empirically about the effects on growth of investing in natural resource and environmental infrastructure, though this has been an important strand in growth theory recently.[9] A useful broad perspective on the connections between different types of infrastructure and economic progress was provided in the World Bank's 1994 *World Development Report*, which found that whatever the nature of the causality, per capita infrastructure stocks generally correlate highly with per capita GDP levels. However, the reasons for this apparent relationship are not entirely clear, and the specific importance of natural resource and environmental infrastructure is even less well understood.[10] [11] To move ahead in understanding the connections between economic growth and natural capital, deeper probing of both physical and social infrastructure issues ranks as an especially high priority.

---

[9] Infrastructure is a term lacking precise definition, but for present purposes it can be viewed as embracing two major categories of assets. *Physical* infrastructure comprises such basic capital stocks as electric power, communications, transport, water, and health facilities. In a developing country context, these prerequisites to a viable economy are sometimes labeled "social overhead capital." *Institutional* infrastructure comprises a wide range of attributes and conditions that serve as important complements to physical capital in promoting socioeconomic development. Included are financial, legal, and regulatory institutions and policies—e.g., a system of property rights—without which the functioning of a competitive market economy would be severely handicapped. Each category of infrastructure gives rise to, or enables, other sectors to produce a stream of important economic services.

[9] One reason why the relationship can be slippery arises from the difference between indicated *stocks* of infrastructure—paved roads, electric generating capacity, telephone connections, railroad trackage and rolling stock, irrigated land area, access to safe drinking water and sanitation—and the *flow of services* that such facilities provide. The World Bank estimates that across a range of developing countries, 40 percent of installed electric power capacity is in fact unavailable for production (World Bank 1994, page 1). The provision of infrastructure services consistent with users' expectations is related to larger institutional failures to which we already have alluded.

[10] One example of the problem relates to the creation of social infrastructure for environmental protection. Developing countries have pursued a variety of policies with very different implications for both environmental impacts and economic costs (Rock 2002). In Malaysia, the government worked with the private sector to identify low cost, but effective clean-up technologies that enabled oil palm production and exports to grow rapidly while water quality improved. In Singapore, Korea and Taiwan, governments created effective command and control environmental agencies that cracked down on polluters; growth remained high even while ambient environmental quality improved. These examples suggest that the tradeoff between growth and environment need not be that severe, even when policies that are less than ideal from a cost-effectiveness perspective are employed.

Figure 1: Links Connecting Natural and Environmental Resources, Economic Growth, and Social Well-Being: The Importance of Various Investments

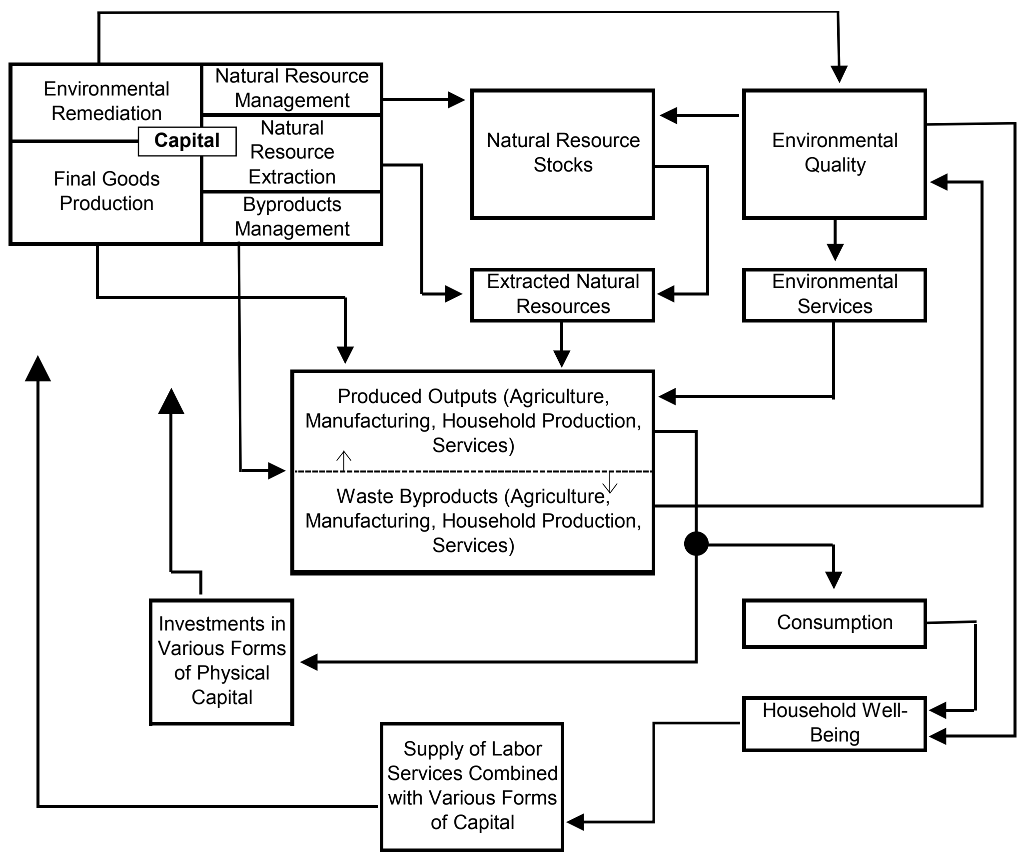


Figure 2: Economy-Environment Interactions Illustrated: Agriculture

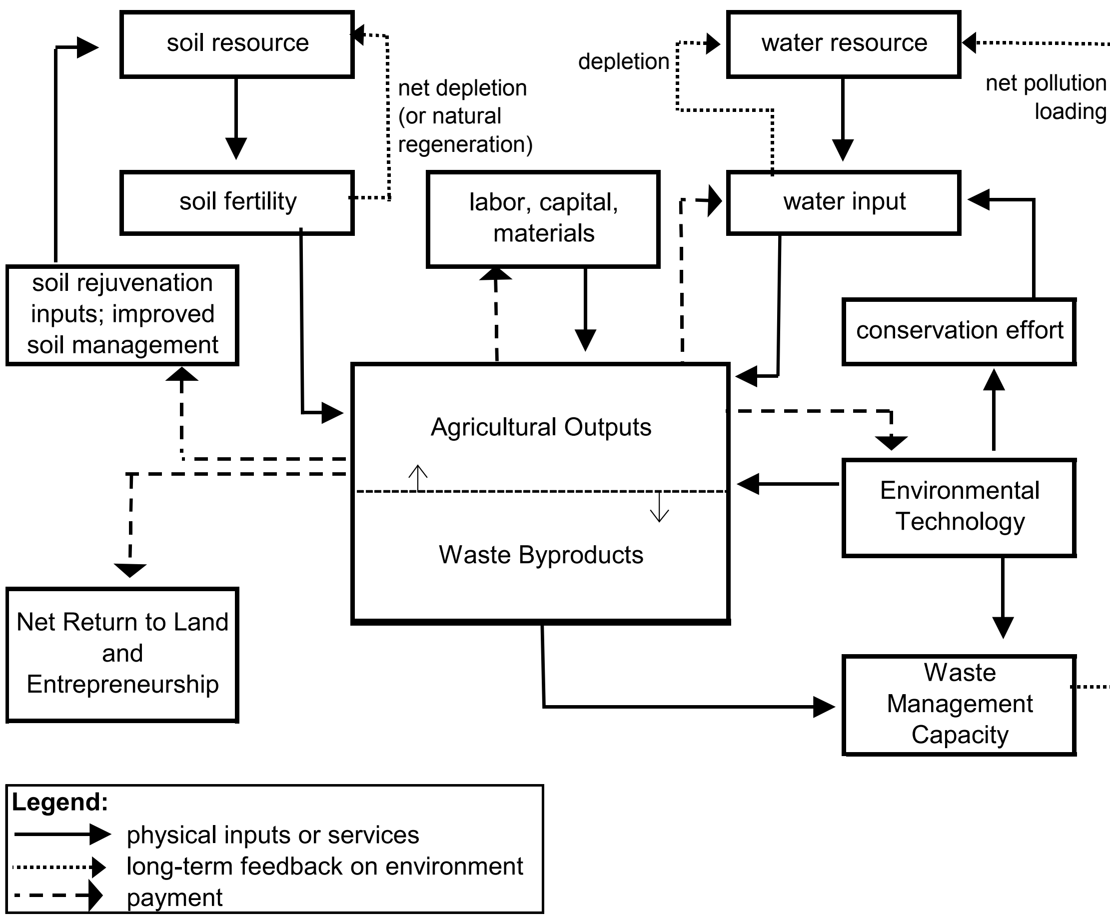


Figure 3: Economy-Environment Interactions Illustrated: Commercial (Rotation Harvest) Forestry and Other Forest Related Values

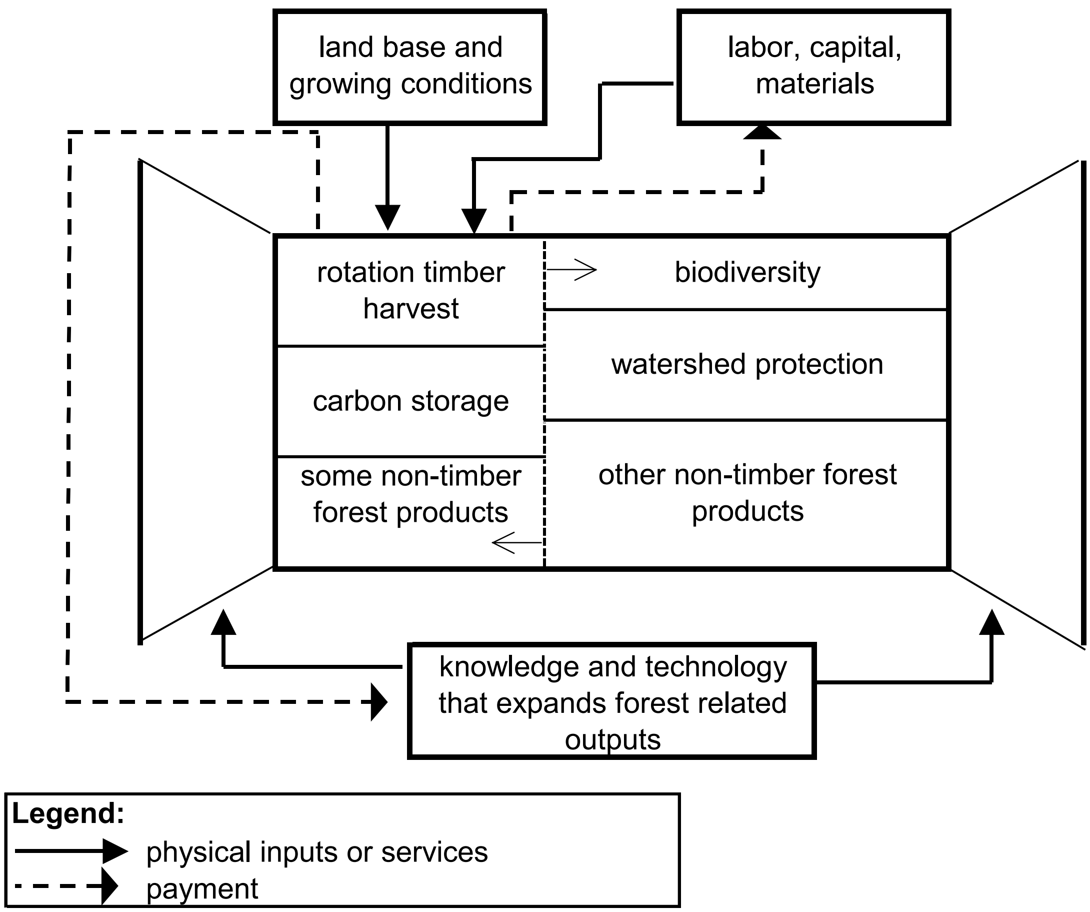
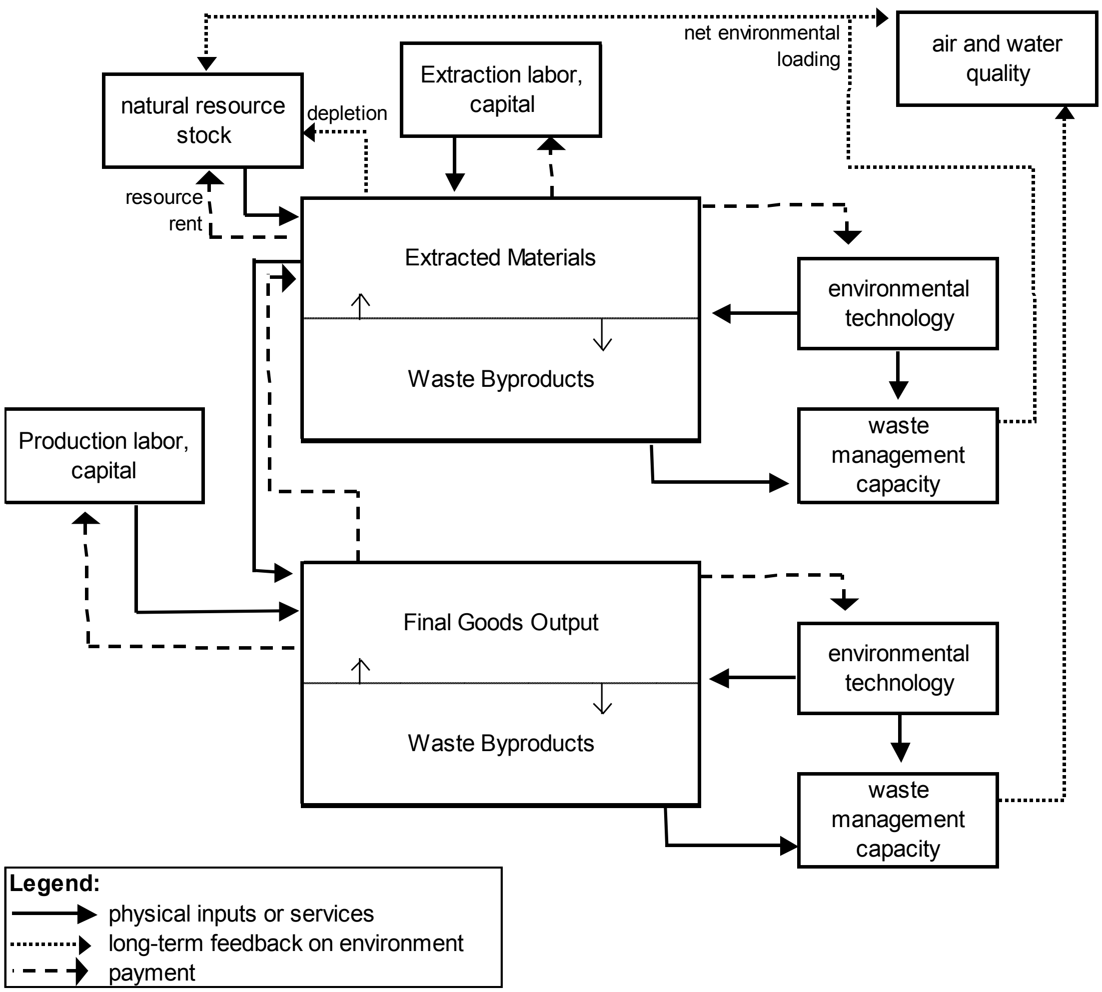


Figure 4: Economy-Environment Interactions Illustrated: Raw Materials and Final Goods Production



APPENDIX A: A MORE FORMAL PRESENTATION OF THE FRAMEWORK IN FIGURE 1

Here we provide a brief mathematical presentation of the environment-growth framework laid out in Figure 1. To define notation, let:

K_Y = capital used for producing final output
K_W = capital used for waste byproducts management
K_R = capital used for natural resource extraction
K_{RM} = capital used for natural resource management
K_{EM} = capital used for environmental management

S_R = stock of natural resources
S_E = stock of "environmental quality"

Y = flow of final output
R = flow of extracted natural resources into production
E = flow of "environmental services" into production
C = final consumption
I_j = investment in capital stock of type j ($j = Y, W, R, RM, EM$)
W = net flow of "waste" back into the natural system
U = utility of a typical economic agent or household

δ = rate of capital depreciation (assumed equal for all types)
ρ = rate of discount of utility over time

These variables are related by the following functional relationships and an accounting identity:

$$Y = F(K_Y, R, E)$$
$$W = G(K_W, Y)$$
$$R = H(K_R, S_R)$$
$$E = E(S_E)$$
$$\dot{S}_R = -R + f(S_R, K_{RM})$$
$$\dot{S}_E = -W + g(S_E, K_{EM})$$
$$\dot{K}_j = -\delta K_j + I_j \; (j = Y, W, R, RM, EM)$$
$$C + \sum_j I_j = Y$$
$$U = U(C, S_E)$$

Using subscripts to functions to denote partial derivatives, we have that $G_K < 0$: an increase in waste byproducts management capacity reduces waste flow back into the environment for a given level of output. We also have the possibility that f_S and g_S can assume either sign: as in standard economic models of a fishery, for example, the rate of regeneration can increase with the stock and then decline. We further discuss restrictions on the signs of these derivatives below. Otherwise all first partial derivatives are greater than zero: more inputs imply more desired outputs (including natural capital regeneration); households benefit from more consumption and more environmental quality; more output implies more waste for given amounts of byproducts management capacity; and environmental services are positively related to environmental quality.

The standard approach in optimal growth theory based on this set-up is to maximize the present value of utility,

$$\int_0^\infty e^{-\rho t} U(C, S_E)\,dt$$

subject to the various restrictions specified above. Using standard optimal control theory methods, we can characterize an optimal path for the natural-and-economic systems by first forming a constrained Hamiltonian function,[12]

$$\begin{aligned} L = {} & U(C,S_E) + \sum_j \lambda_j[-\delta K_j + I_j] + \mu_R[-H(K_R,S_R) + f(S_R,K_{RM})] + \\ & \mu_E[-G(K_W, F(K_Y, H(K_R,S_R), E(S_E))) + g(S_E,K_{EM})] + \\ & \xi[F(K_Y, H(K_R,S_R), E(S_E)) - C - \sum_j I_j] \end{aligned}$$

[12] Note: The Hamiltonian is written here in current value form rather than in present value form. This is taken into account in the specification of the equations of motion for the shadow prices (co-states) below.

Here the λ_j represent the shadow value of additional investment in the various capital stocks, and μ_R, μ_E represent the shadow values of additional natural resource and environmental quality stocks respectively. As we will see below, ξ, the multiplier for the national income accounting constraint, reflects the marginal utility of additional consumption.

Using standard techniques from the theory of optimal control, we can derive the following differential equations for the shadow prices of the physical and natural capital stocks:

$$\dot{\lambda}_Y = (\rho+\delta)\lambda_Y - (\xi - \mu_E G_Y)F_K$$
$$\dot{\lambda}_W = (\rho+\delta)\lambda_W + \mu_E G_K$$
$$\dot{\lambda}_R = (\rho+\delta)\lambda_R + H_K[\mu_R - (\xi - \mu_E G_Y)F_R]$$
$$\dot{\lambda}_{RM} = (\rho+\delta)\lambda_{RM} - \mu_R f_K$$
$$\dot{\lambda}_{EM} = (\rho+\delta)\lambda_{EM} - \mu_E g_K$$
$$\dot{\mu}_R = (\rho - f_S + H_S)\mu_R - (\xi - \mu_E G_Y)F_R H_S$$
$$\dot{\mu}_E = [\rho - g_S + G_Y F_E E'(S_E)]\mu_E - U_S - \xi F_E E'(S_E)$$

It is possible to provide interpretations of these equations; but a more intuitive interpretation can be obtained from the steady state conditions to which we turn below.

The optimal decisions with respect to consumption and investment can be derived by differentiating the expression *L* above. Note that this expression is linear in the investment variables (the I_j), so that in general the solution is indeterminate. However, if we restrict attention to a balanced growth path, in which investments in all forms of capital are greater than zero, then the optimization yields the following simple expressions:

$$U_C = \xi = \lambda_j \; (j = Y, W, R, RM, EM)$$

Since ξ is the shadow price of the national income constraint, the first equality simply says that the shadow value to society of additional national income should reflect the marginal utility of additional consumption. This is a standard condition in all optimal growth models. The remaining conditions simply say that that the shadow value of increasing a capital stock should reflect the opportunity cost of doing so, which again is the marginal utility of current consumption.

To find the steady state growth path, we would need to set $\dot{\lambda}_j = \dot{\mu}_R = \dot{\mu}_E = 0 \text{ (all } j)$ in the expressions above.[13] Carrying out this algebra yields

$$\lambda_Y = (U_C - \mu_E G_Y) F_K / (\rho + \delta)$$
$$\lambda_W = -\mu_E G_K / (\rho + \delta)$$
$$\lambda_R = H_K [-\mu_R + (U_C - \mu_E G_Y) F_R] / (\rho + \delta)$$
$$\lambda_{RM} = \mu_R f_K / (\rho + \delta)$$
$$\lambda_{EM} = \mu_E g_K / (\rho + \delta)$$
$$\mu_R = (U_C - \mu_E G_Y) F_R H_S / (\rho - f_S + H_S)$$
$$\mu_E = U_S + U_C F_E E'(S_E) / [\rho - g_S + G_Y F_E E'(S_E)]$$

All of the λ_j expressions can be interpreted as present values of constant net income streams discounted at the effective discount rate ($\rho+\delta$), reflecting both the social rate of time preference and the rate of capital depreciation. The λ_Y expression says that the marginal value of additional production capital reflects the present value of the marginal utility of the additional consumption opportunity created, less the social marginal cost of the resulting environmental degradation resulting from increased net waste flow back into the environment. The λ_W expression says that the marginal value of additional byproducts management capital is the present value of marginal environmental damage avoided (recall that $G_K < 0$).

[13] To complete the solution we also need to have the stocks themselves not changing.

The λ_R expression says that the marginal value of additional natural resource extraction capital is a balance between two forces. On the one hand, increased extraction capacity implies increased national output and consumption; this is valued at the net marginal utility of consumption taking into account environmental damage. On the other hand, increased extraction capacity implies a reduced natural resource stock, which means lower productivity of extraction activity in the future (since $H_S > 0$). The term $-\mu_R$ in the expression for λ_R captures this element.

The λ_{RM} expression says that the marginal value of additional natural resource management capital is equal to the present value of the social income stream that results when natural resource management capital enhances regeneration and natural productivity of natural resource stocks (recall that $f_K > 0$, and μ_R is the marginal social value of enhanced natural resource stocks). The same interpretation applies to the expression for λ_{EM}, the marginal value of environmental remediation capital.

The μ_R expression says that the marginal value of increased natural resource stocks ultimately can be traced back to the value of such stock augmentation in enhancing the productivity of natural resource extraction, and the net marginal utility of the resulting increased consumption opportunities. In this expression, the "effective discount rate" in the denominator is a bit more complex than in the expressions for the shadow values of physical stocks. Here the effective discount rate depends on the difference between the social time preference rate and the "own rate of interest" on natural resource stocks in terms of enhanced regeneration capacity, f_S, plus the "dividend rate" H_S reflecting how natural resource stocks enhance extraction productivity. This formulation is a standard feature of, for example, optimal fishery models, and it carries over to the more general setting here. As in fishery models, it is possible that f_S exceeds zero initially (large stocks enhance growth) but that f_S is less than zero as stocks grow (because ecosystems get congested). For our purposes, it is necessary only that $(\rho - f_S + H_S) > 0$, which would be true in particular if $(\rho - f_S) > 0$ (the rate of social discount exceeds the natural rate of interest along the optimal path).

Finally, the μ_E expression has a similar interpretation to the μ_R expression. The numerator reflects the rate at which increased environmental quality (a larger "environmental capital stock") increases social welfare: This is the sum of the direct effect of environmental quality on household utility, and the effect of increased environmental services on economic productivity. Thus, even if direct household benefits from the environment were small (and there is no reason to believe this is the case), the environment would be valued as a productive input that contributes to household well-being. The denominator in the μ_E expression, similar to the μ_R expression, reflects the difference between the social discount rate and the natural rate of return on environmental stocks, plus the rate at which environmental stocks can moderate the adverse effects of waste accumulation.

The foregoing discussion of shadow prices focuses on an intertemporally efficient program of consumption and investments. We can use the same framework to highlight what goes wrong when market and institutional failures cause divergence from an efficient path. Consider first the case in which environmental values are not fully internalized in market prices. In effect, then, μ_E is being undervalued. Looking at the other shadow price expressions, we see that undervaluation of the environment leads to:

- excessive investment in productive plant (K_Y) and therefore too much final output
- under-investment in byproducts management capacity (K_W)
- under-investment in environmental remediation capacity (K_{EM})
- indirectly, too much natural resource extraction
- excessive environmental degradation that reduces long-term productivity and consumption possibilities, as well as having direct adverse effects on household well-being

Now consider the consequences of distortions in natural resource markets, like open access or extraction subsidies, that cause μ_R to be at lower than efficient levels in the market. The resulting underpricing of extracted natural resources will lead to:

- excessive investment in extraction capital (K_R) relative to other productive options
- under-investment in natural resource management capacity (K_{RM})
- indirectly, excess final output and natural resource-reliant investment,[14] calling into question the economic as well environmental sustainability of the economy generally
- to the extent that natural resource-intensive sectors also generate more waste byproducts, there will also be more environmental pressure and/or a need to divert more capital toward byproducts management

[14] In our simple analytical framework we have not explicitly represented different production technologies for final output that are more or less resource-reliant; but if natural resources are under-valued this will also pull investment capital in the economy more generally toward more resource-intensive uses.

Similar reasoning can be applied to analyze market and institutional failures more traditionally associated with development economics. For example, if any of several distortions increase the opportunity cost of capital investment in downstream sectors (or lower the productivity of such investment, e.g., because of limits on imports of high-tech capital goods), then economic activity will be excessively pushed into primary natural resource extraction and away from natural resource and environmental management as well as final goods production. This will cause economic losses even if natural resource and environmental management institutions are ideal; if they are less than ideal, as is the case in practice, then the distortions in investment allocation will have further adverse effects on investment in natural capital.

APPENDIX B: A BRIEF REVIEW OF THE ROLE OF ENVIRONMENT AND NATURAL RESOURCES IN ECONOMIC GROWTH THEORY

A complete history of the role of environmental and natural resources in economic growth analysis would go back at least to the 19th century writings of Malthus, Mill, and Jevons. Our less ambitious task here is to provide a brief summary of key developments in the literature over roughly the past 30 years. We divide the material to be discussed into four parts, which are considered in roughly chronological order. These parts are: growth and natural resource depletion; growth and pollution/natural resource degradation; endogenous growth, innovation and the environment; and trade, development, and the environment. In discussing these various parts of the literature we provide selective citations of key studies. Surveys by Beltratti (1997), Smulders (1999), and Margolis (2002) provide a more complete review of the literature.

Growth and Natural Resource Depletion

This topic, which has figured prominently in various debates over "limits to growth," attracted much attention in the wake of the oil market shocks of the early 1970s and remained prominent in the literature for at least a decade thereafter. Perhaps the most important articles in this strand of literature were by Dasgupta and Heal (1974), Solow (1974), Stiglitz (1974), and Hartwick (1977). In these studies , economic output depends on an "essential" depletable natural resource as well as investment in conventional capital. The key insights derived from these studies can be summarized as follows:

- Given the assumptions of the models, scarcity of the natural resource implies an inherent limit to growth, unless some kind of resource-augmenting technical progress can work to alleviate the scarcity constraint so as to allow growth to occur unimpeded. Merely investing in more capital is not enough.
- Investment in more capital may be a way to maintain output over time. But if capital cannot be readily enough substituted for the natural resource, growing natural resource scarcity will eventually lead to inexorably worsening economic conditions.

- If substitution to maintain output is technically feasible, society may still not be able to sustain output unless the societal rate of savings is raised. The "scarcity rents" associated with the depletable natural resource can be reinvested to augment the capital stock, but this rate of savings likely will be inconsistent with individuals' preferences for higher near-term consumption.

The models used to generate these results are quite stylized and incomplete, excluding in particular both renewable substitutes for depletable natural resources and endogenous investment in new technologies and skills. Therefore the results obtained from the models cannot be taken too seriously. However, the models remain useful for highlighting the importance of essential natural capital and the implications of limited substitution possibilities between natural and other capital. For example, the ability to endlessly substitute capital for energy inputs is physically impossible given the laws of physics; yet many of the models purporting to show a "way out" of natural resource scarcity require such substitution. The scarcity models also can shed light on the consequences of depletion of nonrenewable and difficult-to-replace ecological resources, like biodiversity and (at some stage) the carbon-holding capacity of the atmosphere.

Growth and Pollution/Natural Resource Degradation

This literature began to develop in the early 1970s and grew rapidly through the mid-1980s, with contributions continuing to the present. One strand of this literature describes how pollution byproducts of economic activity can accumulate in the natural environment and cause social losses, either directly affecting households (worsened health, loss of amenities) or indirectly affecting them through reduced production possibilities.[15] Another strand focuses on the role of renewable natural resources in economic output and the adverse effects of renewable natural resource depletion. From a formal analytical perspective the two strands are strongly related. Both involve different kinds of stock effects on output and well-being; both involve similar natural stock dynamics (pollution accumulation and decay, renewable natural resource extraction and regeneration); and both allow for the possibility of various kinds of threshold effects (species extinction, discontinuous damages from pollution accumulation).

[15] Most of the earlier contributions focused on the direct adverse effects as modeled by including a pollution stock in the utility function. More recently the production-side effects have been emphasized in studies of harms from greenhouse gas accumulation (see for example Nordhaus 1993).

A typical theoretical finding in this part of the literature, as discussed in Appendix A, is the optimality of some long-term steady state in which pollution growth balances natural decay, or natural resource extraction balances regeneration. However, it is also possible for the optimal outcome to be a corner solution in which the renewable natural resource is exhausted or pollution is allowed to accumulate without bound. Such outcomes are more to be expected when the discount rate is high or possibilities for economic progress through more environmentally "benign" means are limited (that is, societies with limited quantities of other capital).

A steady state can be supported by a theoretically optimal set of shadow prices, and in principle policy can focus on market, policy and institutional reforms that move actual prices toward the theoretical ideal. Note that the options for policy intervention are richer in this setting than with simple depletion models, incorporating natural resource management and defensive expenditures to enhance natural resource regeneration or environmental improvement as well as efforts simply to conserve natural capital. But natural resources and environmental quality are still a limit to growth in these models. Especially when the effects of natural resource or environmental degradation are experienced through reduced economic productivity, such policies can be considered a subset of development policies. In practice, the focus until recently in this part of the literature has been more on natural resource and environmental policies than on broader development policies (for example, how improving opportunities for human capital formation may help economic growth and natural resource protection).

Endogenous Growth, Innovation and the Environment

This part of the literature began to emerge in the mid-1990s (though endogenous growth models without an environmental component began to be developed in the 1980s). The general idea in all endogenous growth models, including those with an environmental component, is that the marginal product of human-supplied capital broadly defined does not decline toward zero even as the volume of capital grows. "Human-supplied capital" incorporates not just equipment, but also knowledge and skills. The ability to augment human as well as machine capital is one of the pathways emphasized in the theoretical assumption that marginal product of investment can remain above some positive threshold level. Other pathways include the effects of learning by doing and economies of scale from investment in various kinds of infrastructure.

Key findings from this part of the literature include the following:

- With the assumed ability to sustain the marginal product of human-supplied capital over time, sustained (not just transitional) income growth is possible without complete environmental degradation or natural resource depletion being inevitable. The models thus seem to suggest a way around limits to growth: in addition to sound natural resource and environmental practice, invest adequately in built and human capital.
- While income growth is possible in these models, it is not inevitable. A society with strong preferences for environmental amenities could shift increasing quantities of investment toward natural capital protection as income rises. A society with a high rate of discount could still choose extensive natural resource depletion.
- Environmental and natural resource policies that ameliorate supply-side depletion effects can have sustained long-term productivity enhancement effects. This seems to point toward an appealing win-win opportunity. But natural resource and environmental protection also has short term costs, including crowding out of other investment – some of which could have been in innovation to enhance human capital. Thus, crowding out can have long-term as well as short-term costs. It is an empirical question which effect is more important in practice.

While the endogenous growth literature seems to offer a way around limits to growth, it is important to be cognizant of the assumptions underlying these models. They depend in particular on the ability of capital growth broadly defined to generate sustained income growth, even while flows of natural and environmental resource services remain bounded. This seems more plausible than the simple capital-resource substitution story in the natural resource depletion models of the 1970s, but it is still not entirely self-evident. For example, can increased flows of knowledge and skills from innovation provide for rising output, for example by providing ever-easier and cheaper access to solar energy and dilute-concentration minerals? Moreover, even if capital investment broadly defined can sustain growth, the ability to do so likely depends on sustaining (preventing unlimited deterioration) of some natural capital. Investment in maintenance of services from natural capital as well as other forms of investment is required.

Trade, Development, and the Environment

Stylized, relatively aggregated growth models based on at least an implicit assumption of well-functioning markets will not capture several important aspects of growth and the environment relevant to developing countries. Another strand of literature addressing trade, institutional problems, and distributional concerns has developed rapidly through the 1990s and continues to grow.

Natural resources and the environment figure prominently, either directly or indirectly, in the exports as well as overall output of many developing countries (mineral extraction, use of soil and water for agricultural exports, local environmental effects of commodity output for trade). It is thus important to ask if developing countries necessarily benefit over the longer term from natural resource-intensive export orientations.

Recent theoretical examinations of this issue indicate that (a) such an orientation can worsen natural resource and environmental conditions; and (b) it is even possible for overall well-being to decline in such an approach to trade and development. However, (a) is not inherently inconsistent with efficient and sustainable development over time. Some degree of tradeoff between natural and environmental resources and income generation is both unavoidable and desirable. It is an inefficiently large degree of natural and environmental resource degradation that is of concern. Moreover, the theoretical conditions under which increased and natural resource-intensive trade could reduce overall well-being appear to be somewhat limited and do not provide a blanket argument against trade liberalization and natural resource-dependent exports as a strategy for longer-term growth.

The tradeoffs governing (a) and (b) depend strongly on the nature of domestic institutions for environmental and natural resource management. The weaker these institutions, the more likely that adverse spillover effects from use of natural and environmental resources will dissipate the apparent income gains. The management institutions themselves are endogenous – more wealth and a rising *relative* value of natural resource stocks will encourage improved public and private management efforts (as well as more rent seeking). Nevertheless, side effects could be significant, underscoring the need for trade liberalization and export promotion policies to be accompanied with improved natural resource and environmental management policies to help ensure overall benefits are realized.

Finally, models that look at the economy as a whole through the lens of the "representative agent" give somewhat short shrift to some important distributional issues. If natural resource rents from exploiting natural capital for export go mainly to benefit an already-educated and affluent elite, the benefits for development may also be limited. This is especially the case if, as is the case in many countries, a significant impediment to development is a shortage of human capital and distortions in financial markets that make it difficult for poorer households to upgrade skills. Under these conditions, increased taxation of natural or environmental resource use to fund human capital formation may ultimately support development, even if it renders natural resource-intensive exports less competitive internationally. In this situation, the basic theorem of Hartwick (1977) concerning reinvestment of natural resource rents needs extending to address how the funds are used.

References

Beltratti, Andrea. 1997. Growth with Natural and Environmental Resources, in Carlo Carraro and Diminico Siniscalco, eds., *New Directions in the Economic Theory of the Environment*. Cambridge, Cambridge University Press.

Dasgupta, Partha S. and Geoffrey M. Heal. 1974. The Optimal Depletion of Exhaustible Resources. *Review of Economic Studies, Symposium on the Economics of Exhaustible Resources*.

Ferraro, Paul J. and R. David Simpson. 2002. The Cost-Effectiveness of Conservation Payments, *Land Economics* 78(3): 339-353.

Hartwick, John M. 1977. Intergenerational Equity and the Investing of Rents from Exhaustible Resources. *American Economic Review* 67(5): 972-974.

Lopez, Ramon. 2000. Trade Reform and Environmental Externalities in General Equilibrium: Analysis for an Archetype Poor Tropical Country. *Environment and Development Economics* 5(4): 377-404.

Low, Patrick (ed.). 1992. *International Trade and the Environment.* Washington, DC: World Bank.

Margolis, Michael. 2002. The Impact of Trade on the Environment. Resources for the Future Issues Brief 02-28 (August). Accessed at http://www.rff.org/Johannesburg/Issuebriefs/joburg20.pdf.

Nordhaus, William D. 1993. Rolling the “DICE”: An Optimal Transition Path for Controlling Greenhouse Gases. *Resource and Energy Economics* 15(1): 27–50.

Pezzey, John. 1989. Economic Analysis of Sustainable Growth and Sustainable Development. Washington D.C.: World Bank. Environment Department Working Paper No. 15. Published as *Sustainable Development Concepts: An Economic Analysis*, World Bank Environment Paper No. 2, 1992.

Robinson, Elizabeth J.Z., Jeffrey C. Williams, and Heidi J. Albers. 2002. The Impact of Markets and Policy on Spatial Patterns of Non-Timber Forest Product Extraction. *Land Economics* 78(2): 260-271.

Rock, Michael T. 2002. *Pollution Control in East Asia: Lessons from Newly Industrializing Countries.* Washington, DC: Resources for the Future.

Smulders, Sjak. 1999. Endogenous Growth Theory and the Environment, in van den Bergh, Jeroen C. J. M., ed., *Handbook of Environmental and Resource Economics*. Cheltenham, U.K.: Elgar.

Solow, Robert M. 1974. Intergenerational Equity and Exhaustible Resources. *Review of Economic Studies, Symposium on the Economics of Exhaustible Resources*.

Stiglitz, Joseph E. 1974. Growth with Exhaustible Natural Resources: Efficient and Optimal Growth Paths. *Review of Economic Studies, Symposium on the Economics of Exhaustible Resources*.

World Bank. 1994. *World Development Report 1994: Infrastructure for Development*. New York: Oxford University Press