Chapter 1

INTRODUCTION TO DYNAMIC AND STOCHASTIC APPROACHES TO THE ENVIRONMENT AND ECONOMIC DEVELOPMENT

We begin by outlining some of the more salient issues in contemporary research at the interface of the environment and economic development. Next, we note that until very recently, environmental issues have largely been absent in the analyses of economic development. Fortunately, despite the past neglect of this field, there is now a burgeoning literature in this important field. Even so, we point out that there is still a dearth of theoretical research that uses dynamic and stochastic approaches to construct and analyze models of research questions at the intersection of the environment and economic development. Therefore, following this introductory chapter, the 12 chapters of this book show how dynamic and stochastic approaches can be used to effectively model and thereby shed valuable light on a whole host of hitherto largely unstudied research questions concerning the environment and economic development.

1. Preliminaries

The totality of all the ecological systems in the world constitutes a very large part of what we might call our *natural capital stock*. Following Dasgupta (1996), we can also think of this natural capital stock as our *environmental resource base*. Life, as we know it on planet earth, depends fundamentally on this environmental resource base. Even so, until very recently, discussions of the salience of this environmental resource base were largely absent in economic analyses in general and in studies of economic development in particular.[1] This unfortunate state of affairs has gradually begun to change and this change has certainly been accelerated by the publication of the so-called *Brundtland Report* in 1987 (see Brundtland, 1987).

This report introduced, *inter alia*, the notion of sustainable development to the world and it is fair to say that this notion has now become a rallying point for researchers in and practitioners of economic development. Researchers now generally agree that whatever else the notion of sustainability may mean, at the very least, this notion involves the conservation of either a part or all of the earth's natural capital stock.[2] Given the general interest in the notion of sustainability, researchers have sharpened the focus of this notion by asking specifically what it would take for the process of economic development to be sustainable.

Along with this interest in the notion of sustainable development, a parallel development that has taken place stems from the increasingly poor state in which we find the world's fisheries, forests, and rangelands. These so-called *renewable resources*[3] have been the object of rigorous analysis by economists at least since Gordon (1954). Further, since the publication of Gordon's (1954) seminal paper, research by the biologist Garrett Hardin (1968), the economist Herman Daly (1968), and the mathematician Colin Clark (1973; 1976) has increasingly led to the view that what economists call renewable resources and what ecologists more generally call ecological systems are really *jointly determined* ecological-economic systems whose evolution over time is dependent on dynamic and stochastic forces that are partly ecological and partly

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[1] See Dasgupta (1996), Dasgupta and Ehrlich (1996), and Dasgupta and Maler (1997) for a more detailed corroboration of this claim.

[2] See Goldin and Winters (1995), Perrings (1996), Farmer and Randall (1997), and Pezzey (1997) for more on the evolution of and the literature concerning the notion of sustainability.

[3] Economists commonly distinguish between resources like fisheries and rangelands that have a natural growth rate and hence are regenerative or renewable and resources like minerals such as coal that do not have a natural growth rate — that is meaningful in the context of typical human lifetimes — and hence are non-renewable or exhaustible.

economic in nature. This view has gained broad acceptance in the last three decades and, as such, it is fair to say that today, natural resource management in general is really all about the optimal management of ecological-economic systems.[4] Further, the field of ecological economics itself is now thriving with the launch of a prominent journal published by Elsevier, *Ecological Economics*, that is dedicated to furthering research in this explicitly interdisciplinary field.

The burgeoning of interest in studying sustainable development and the tremendous growth of the field of ecological economics have together greatly influenced contemporary thinking on research questions concerning the environment and economic development. In particular, economists now no longer treat the environmental resource base of developing nations "as an *indefinitely* large and adaptable capital stock" (Dasgupta, 1996, p. 390; emphasis in original). Similarly, ecologists now understand that it would be a big mistake to "regard the human presence as an inessential component of the ecological landscape" (Dasgupta, 1996, p. 390). Finally, we now have a journal published by Cambridge University Press entitled *Environment and Development Economics* that is devoted to the advancement of research on questions at the interface of the environment and economic development.

Despite the presence of a sizeable and now growing literature on the environment and economic development, it is fair to say that there are *very few* theoretical studies of research questions in this field that explicitly incorporate *dynamic* and *stochastic* approaches into their analyses. This state of affairs is both unfortunate and it provides an incomplete and possibly even erroneous perspective on basic issues concerning the environment and economic development. To see why this might be the case, note that economic development is a *process* and, hence, like all processes, this process is best

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[4] See Walters (1986), Holling (1996), Perrings (1996), Dasgupta and Maler (1997), Batabyal (1999), Batabyal and Beladi (1999), and Batabyal and Yoo (2007) for additional details on this point.

studied from a *dynamic* or intertemporal perspective. Second, if economic development in a nation is to be sustainable then it is incumbent upon this nation to conserve at the very least, as we have already noted, some part of its natural capital stock. Now, such conservation will involve the optimal management of ecological-economic systems[5] that are inherently *dynamic* and *stochastic* in nature.

Given the above state of affairs, the central objective of this book is to demonstrate how dynamic and stochastic approaches can be effectively used to construct and analyze theoretical models that shed valuable light on hitherto largely unstudied research questions at the interface of the environment and economic development. The reader should note well that even though we use the traditional language of economics and refer to renewable natural resources, these resources are dynamic and stochastic ecological-economic systems that are jointly determined. Following this introductory chapter, there are 12 essays (chapters) that are grouped into three parts. Parts II and III are concerned with topics that, broadly speaking, would fall within the ambit of natural resource economics as that term is generally understood in economics. In contrast, Part IV of this book is concerned with questions that traditionally would be the object of inquiry in environmental economics.

More specifically, Chapters 2 through 4 in Part II of this book are concerned with a renewable resource of central importance in developing countries and that resource is swidden agriculture.[6] Chapters 5 through 8 comprise Part III of this book and these chapters focus on renewable resources in general and safe drinking water in particular. Chapter 5 studies the provision of safe drinking water and Chapter 6 focuses on renewable resource management; both analyses are conducted in a closed economy setting. Chapters 7 and 8 also focus on renewable resource management issues but now in an open economy setting. Finally, the five chapters comprising Part IV

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[5] Such systems include renewable resources such as fisheries, forests, and rangelands and exhaustible resources such as minerals.

[6] Swidden agriculture is also referred to as slash and burn agriculture and as shifting cultivation. Therefore, in this book, we shall use these three terms interchangeably.

of this book analyze the many facets of environmental policy in developing countries. We now proceed to highlight the contributions of the individual essays in this book.

2. The Individual Essays

2.1. *Agriculture*

2.1.1. *The Fallow Period in Swidden Agriculture*

Small farmers in most tropical developing countries practice swidden agriculture. Of the five essential stages in a swidden cycle, the fifth and final stage is the most salient. In this stage, a cleared parcel of forest land (CPFL) is left *fallow* after one or two harvests. If the CPFL is left fallow for a sufficiently long period of time, then nutrients will revert back to the soil and this will permit the swidden cycle to be repeated. Despite the salience of swidden agriculture in tropical developing countries, there is controversy about the merits of this kind of agriculture. On one hand, Dove (1983), Southgate (1990), and Pearce and Warford (1993) have noted that slash and burn agriculture is environmentally destructive because the land-clearing activities of shifting cultivators is directly linked to massive and deleterious deforestation. On the other hand, Peters and Neuenschwander (1988) and Dufour (1990) have claimed that under some circumstances, swidden agriculture based on long fallow periods can be an ecologically and an economically sustainable practice in tropical forests.

The viability of swidden agriculture in the long run depends crucially on the *length* of the fallow period; hence, this period must be chosen optimally. However, beyond recognizing this basic point, researchers have not explained *theoretically* how the length of the fallow period ought to be chosen by a small farmer. In addition, researchers have *not* studied the ways in which the choice of the fallow period length affects the ecology and the economics of the underlying CPFL. Given this state of affairs, Chapter 2 has three goals. First, it constructs a three-state, semi-Markov theoretic model of a CPFL that has been readied for swidden agriculture. Second, it shows for a small farmer how the dynamic and the stochastic properties of this CPFL can be used to derive two objectives that are ecologically meaningful. Finally, using these two objectives, Chapter 2 discusses a probabilistic approach to the determination of the optimal length of the fallow period in swidden agriculture.

A key feature of the semi-Markov model of a CPFL in Chapter 2 is that the length of the fallow period is a *random* variable. In addition, this chapter notes that leaving the CPFL fallow for a specific time period does not guarantee that it will revert back to the ecologically healthiest state 1. Rare and unpredictable environmental events and farmer error in setting the length of the fallow period may result in the CPFL recovering only to the intermediate state 2. This chapter uses the various transition probabilities of the CPFL along with the mean times spent by the CPFL in each of the three states to derive two ecologically meaningful objective functions. The small farmer of this second chapter optimizes these two ecological objective functions subject to specific constraints. We now outline the first of these two optimization problems, and then we comment on the ecological and the economic meaning of the solution to this optimization problem.

The first optimization problem faced by our small farmer involves the minimization of an ecological criterion subject to an economic constraint. The ecological criterion is the *resilience*[7] of the CPFL in the intermediate state 2 and the economic constraint says that the profits from swidden agriculture must not fall below a certain minimum threshold. Solving this optimization problem gives us two

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[7] The response of ecological-economic systems to perturbations is frequently measured by the notion of resilience. Generally speaking, ecologists distinguish between two kinds of resilience, namely, resilience in the sense of C.S. Holling and resilience in the sense of S.L. Pimm. Resilience in the sense of Pimm (1984) is concerned with measuring the rapidity with which a stable ecological-economic system returns to its original state following a perturbation. In contrast, resilience in the sense of Holling refers to "the amount of disturbance that can be sustained [by an ecological-economic system] before a change in system control or structure occurs" (Holling *et al.*, 1995, p. 50). Because Chapter 2 is concerned with the sustainability of swidden agriculture, this chapter focuses on Holling and not Pimm resilience.

first-order necessary conditions for an optimum. Solving these two equations simultaneously gives us the optimal length of the fallow period and the shadow value of the profit constraint. One of these two first-order necessary conditions tells us that in choosing the length of the fallow period optimally, the small farmer will balance ecological and economic considerations. Specifically, the optimal length of the fallow period will be chosen so that the marginal impact of the length of the fallow period on the probability of the CPFL being in the intermediate state 2 is set equal to the product of the shadow value of the profit constraint and the marginal profit from choosing the fallow period length optimally.

If the fallow period length is chosen in this way, then we can be reasonably sure that the CPFL will be healthy in the long run. From an ecological perspective, this means that the resilience of the CPFL in the intermediate state 2 will be low. In economic terms, this means that the CPFL will provide our small farmer with a flow of profits or a flow of consumptive and non-consumptive net benefits in the long run. Although the dynamic and stochastic analysis in Chapter 2 sheds considerable light on the nature of the fallow period length choice problem, this chapter does *not* model the fact that swidden cultivators typically have a choice as far as what kind of crop they would like to grow on their CPFL. In addition, this chapter also does not study the land quality accumulation decision problem faced by shifting cultivators. These two questions are addressed in Chapter 3.

2.1.2. *Crop and Land Quality Accumulation Choices*

Chapter 3 has three goals. First, this chapter constructs a dynamic model of land use by swidden cultivators when these cultivators can choose whether to grow a cash crop or a food/subsistence crop. Second, the chapter examines the land quality accumulation decision problem faced by shifting cultivators. This part of the Chapter 3 analysis provides a second way that can be used to compute the length of the fallow period optimally. In this way, the Chapter 3 analysis complements the earlier analysis in Chapter 2. Finally, Chapter 3 investigates the effects that the optimal land quality accumulation decision has for the relative price of the food crop in particular and for slash and burn agriculture in general.

The focus in this chapter is on an economy in which small farmers (or swidden cultivators) each have a parcel of cleared forest land and they can choose to grow either a cash crop or a food/subsistence crop on this land. The cash crop requires labor L and high quality land A_{hq} for production. In contrast, the food or subsistence crop can be grown with labor L and low quality land A_{lq}. Let w, s_{hq}, and s_{lq} denote the factor rewards to labor, to high quality land, and to low quality land, respectively, and let r denote the interest rate. Deleterious and unpredictable environmental events can make the small farmer's land unfit for cultivation of either the cash crop or the food crop. Chapter 3 accounts for this possibility by supposing that with instantaneous probability q, $q \in (0, 1)$, the cleared land of the swidden cultivators will become unfit for cultivation. With this contingency in mind, the discount rate of the swidden cultivator is effectively $r + q$.

The small farmer can convert low quality land into high quality land by keeping his land fallow for an appropriate length of time. Put differently, this farmer can choose to accumulate land quality by keeping his land fallow. The reader should note two things. First, in the framework of Chapter 3, optimally choosing the length of time during which the cleared land is to be kept fallow is equivalent to optimally accumulating land quality. Second, the purpose of investing in land quality now is to obtain higher profit from the sale of the cash crop later.

The swidden cultivator under study in Chapter 3 maximizes the profit from fallowing land. This profit consists of the earnings from cash crop cultivation less the foregone earnings from food crop cultivation. The solution to this profit-maximization problem gives us the optimal length of the fallow period. The analysis in Chapter 3 shows that as the return to fallowing land increases, the optimal length of the fallow period — or the optimal length of time during which land quality is accumulated — increases. Second, as our swidden cultivator's discount rate rises, it is optimal to reduce the length of time during which this cultivator's land is fallow.

Two additional questions of interest in the context of slash and burn agriculture are also analyzed in Chapter 3. The first such question concerns the discounted lifetime earnings that accrue to the swidden cultivator as a result of his or her decision to accumulate land quality optimally. The analysis here shows that the factor reward of optimally fallowed high quality land exceeds the factor reward of low quality land. The second such question concerns the impact of parametric changes on the factor reward to low quality land. Comparative statics exercises that are carried out in Chapter 3 result in three specific conclusions. Specifically, we learn that, *inter alia*, the factor reward to low quality land falls with increases in the interest rate and the probability of an environmentally disastrous event.

Chapter 3 concludes with a very basic result about economies with slash and burn agriculture. Specifically, it is shown that given an interest rate r, the relative price of the food crop is likely to be higher in economies where there is high demand for keeping land fallow[8] because of a high value of the "return to fallowing land" parameter θ, a high value of the shift variable V, or a low value of the probability q of an environmentally disastrous event. Why? This is because a high θ, a high V, or a low q means that the factor reward for low quality land s_{lq} is high. In turn, because the interest rate r is given, a high s_{lq} can be expected to exert an upward pressure on the relative price of the food crop.

Dickinson (1972), Farnsworth and Golley (1973), and Eckholm (1976) have noted that swidden cultivators can increase the number of harvests on a particular CPFL before this CPFL must be fallowed by applying natural and/or chemical fertilizers. However, beyond recognizing this essential point, researchers have not *theoretically* analyzed the fertilizer use decision problem faced by swidden cultivators. In addition, keeping in mind the dynamic and the stochastic

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[8] Indirectly, this indicates high demand for the cash crop.

setting in which swidden cultivators typically operate, researchers also have *not* studied the conditions under which it is optimal to use fertilizers. These two questions are analyzed in Chapter 4.

2.1.3. *Fertilizer Use in Swidden Agriculture*

Chapter 4 focuses on a swidden cultivator with a parcel of land that has just been cleared for the planting of a particular crop. This cultivator would like to repeat as many swidden cycles as possible on the CPFL, but in doing this, (s)he must contend with the deterioration in soil fertility on this CPFL. It is possible to extend the useful life of this CPFL by using fertilizers.[9] However, as noted by Dickinson (1972), Eckholm (1976), and others, fertilizers are *costly*, and because swidden cultivators are typically poor, small-scale farmers, they often will not possess the financial resources to purchase fertilizers. There are two policies available to the swidden cultivator under study. The first policy is a *passive* one in which no fertilizer is used and the cultivator relies solely on natural or environmental factors to delay the deterioration in soil fertility. The second policy is an *active* one in which the cultivator uses fertilizers to decelerate the deterioration in soil fertility.

The essential stock variable that is affected by the repeated planting of the crop in question is the stock of soil fertility. Owing to a variety of reasons, the lowering of the stock of soil fertility is generally *probabilistic* and not deterministic. Therefore, the soil fertility stock is assumed to be a stochastic process that can exist in one of many possible states. State 0 is the best possible state of existence for this stock variable. Further, the stock of soil fertility changes state in accordance with a Wiener or Brownian motion process with drift $\delta > 0$.[10] With repeated planting of the crop in question, soil fertility on the CPFL deteriorates, the Brownian motion process changes state, and eventually this process gets to a "breakdown"

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[9] In the rest of this chapter, when we refer to fertilizer use, we are referring to both natural and to chemical fertilizer use.

[10] For more on the Wiener process, see Ross (1996, Chapter 8) and Ross (2003, Chapter 10).

state — denoted by f — in which the land must be fallowed.[11] When this is done, mathematically, the Brownian motion process eventually returns to state 0. The cost of the *passive* or no fertilizer use policy is $c(f)$.

The swidden cultivator's *active* policy involves the use of one or more fertilizers. In particular, if the state of the Brownian motion process is b and the active policy is used, then this policy will be successful in improving soil fertility with probability $p(b)$, and it will be unsuccessful with probability $1 - p(b)$. Further, if the active policy is successful in improving soil fertility, then the Brownian motion process being analyzed returns to state 0. In contrast, if this active policy is unsuccessful in improving soil fertility, then the Brownian motion process goes to state f.[12] The cost of attempting to improve soil fertility actively in state b is $c(b)$.

In this probabilistic setting, Chapter 4 determines whether the active or the passive policy minimizes the long-run average cost per time. The analysis in this chapter shows that the long-run average cost of raising soil fertility with the *active* or fertilizer use policy is given by the ratio of the weighted sum of the two cost expressions $c(b)$ and $c(f)$ to the state b, $0 < b < f$, in which this policy is utilized. Similarly, the long-run average cost of the *passive* policy in which the swidden cultivator relies exclusively on natural or environmental factors to improve soil fertility is given by the ratio of the product of the drift parameter of the Brownian motion process δ and the cost of locating and clearing an alternate parcel of forest land $c(f)$ to the fallow state f. What this Chapter 4 analysis makes abundantly clear is that *given* a specific likelihood function $p(b)$, one can always use calculus to minimize the above-mentioned long-run

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[11] An interesting question that emerges in this context is the determination of the optimal length of time during which the CPFL ought to be fallow. This question is addressed in Batabyal and Beladi (2004) and in Chapter 2.

[12] We understand that the failure of the fertilizer use policy does not necessarily mean that soil fertility has declined to such an extent that our Wiener process must go to state f. Chapter 4 makes this assumption primarily for reasons of mathematical tractability. Having said this, we recognize that it is possible that the Wiener process will go to some intermediate state e, where e is worse than state b but better than state f.

average cost function. Even so, the more significant point is that the *choice* between the active policy and the passive policy is, to a large extent, dependent on the likelihood function $p(b)$. In particular, for some specifications of this likelihood function, it makes more sense for the swidden cultivator to use the active or fertilizer use policy and for alternate specifications of this same likelihood function, it is less costly to adopt the passive or no fertilizer use policy. This completes our brief discussion of the three chapters that analyze swidden agriculture in developing countries. We now proceed to comment on the contributions of the four chapters that study renewable resource use and management in developing countries in both closed and open economy settings. Providing safe drinking water to flood victims in a closed economy setting is the subject of Chapter 5.

2.2. *Renewable Resources*

2.2.1. *Flood Victims and Safe Drinking Water*

National and international development agencies have increasingly begun to embark on a whole host of schemes to provide safe drinking water (SDW) in developing countries.[13] Now, many of the world's developing nations, particularly those in South Asia, are frequently ravaged by floods. Therefore, when a flood occurs, the question of providing SDW to flood victims assumes particular salience. How should a government agency that is interested in distributing SDW to flood victims, go about its task? Further, how might this agency maximize the net social benefit from the provision of SDW? Finally, given that SDW is a particularly scarce commodity in a flood situation, how likely is it that this agency will be unable to meet the stochastic demand for SDW? Although there are a number of empirical and case study based analyses of drinking water problems in developing countries (see Han *et al.*, 1991; Asthana, 1997; Balint, 1999; Reddy, 1999), and even some studies of drinking water

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[13] For more on this, see Munasinghe (1992), Balint (1999), and Kleemeier (2000).

problems in flood situations (see Haque and Zaman, 1993; Emch, 2000), as Chapter 5 points out, there are *no theoretical* studies of the above three questions. Hence, the purpose of Chapter 5 is to show how queuing theory[14] can be used to effectively model and study these three questions concerning the disbursement of SDW in flood-prone developing countries.

Chapter 5 constructs a queuing theoretic model of a place such as West Bengal in India that is frequently ravaged by floods.[15] A government agency is entrusted with the task of providing SDW to flood victims.[16] This agency sets up a relief center and it imports SDW to this center by means of tanker trucks and it "produces" buckets of SDW in accordance with a Poisson process with rate $\lambda > 0$. The analysis in this chapter supposes that once K buckets of water have been produced, the agency under study will have exhausted its available supply of SDW and, hence, it must wait for more water to appear. Flood victims arrive at this relief center in accordance with a Poisson process with rate $\mu > 0$. Each victim is entitled to one bucket of water per day. Upon receipt of this bucket, the victim leaves the relief center. If this victim happens to arrive at the center when K buckets of water have already been disbursed, then (s)he will have to leave the center empty handed. The specific queuing model used to model these events is the $M/M/1$ queue with finite capacity K.[17]

The first task conducted in Chapter 5 is to determine, from the standpoint of the government agency providing SDW to flood victims, the proportion of all flood victims who find the relief center

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[14] See Ross (2003, Chapter 8) for more on queuing theory.

[15] West Bengal is frequently ravaged by floods. As reported in *The Economist* (Anonymous, 2000, September 30, p. 6), in year 2000 alone, upwards of 17 million people were adversely affected by floods in this state and in neighboring Bangladesh.

[16] Government agencies assigned the task of flood control typically perform many duties, only one of which is the provision of SDW. Chapter 5 focuses on SDW because of the fundamental importance of SDW in sustaining human life and because this chapter wishes to shed light on hitherto unanswered research questions in flood management.

[17] For more details on the $M/M/1$ queue with finite capacity, see Batabyal (1996a) and Ross (2003, pp. 480–496).

filled with buckets of SDW. The analysis conducted here shows that this proportion is equal to the stationary probability (P_K) that the relief center has K buckets of SDW. Having computed this probability, the second task that Chapter 5 undertakes is to formulate and solve an optimization problem for the SDW providing government agency. Specifically, this agency chooses the rate μ at which SDW is provided to flood victims to maximize the social net benefit from the provision of SDW. It is shown that optimality requires the government agency to provide SDW so that the marginal social benefit from water provision is equal to the marginal social cost.

The final task that is carried out in Chapter 5 is the computation of the *likelihood* that the government agency under study will be unable to meet the stochastic demand for SDW in a flood situation. The analysis in this part of the chapter shows that the agency in question will be unable to provide SDW to a flood victim only if this victim arrives at the relief center *after* the agency has run out of SDW for that day. Therefore, the likelihood of interest is actually a particular stationary probability and this probability is shown to depend on the parameters of the queue (λ, μ) and on the capacity of the relief center (K) for providing SDW. Further, in the general case, an increase in μ, the rate at which SDW is provided to flood victims, has an ambiguous impact on the proportion of flood victims who come to the agency's relief center and are unable to obtain SDW. This completes our discussion of the Chapter 5 analysis on the provision of SDW to flood victims. We now proceed to discuss renewable resource management in a closed economy setting when there are potential crisis states to contend with.

2.2.2. *Crisis States and Renewable Resource Management*

Chapter 6 notes that people in developing countries are significantly *dependent* on agriculture and on renewable resources, particularly those renewable resources that are found in their local environment. A renewable resource can reasonably be thought to exist in a finite number of states. Some of these states are desirable and others are undesirable. Also, in both these *sets* of states, some states are better than others. Restricting attention to the undesirable set of states, what is important is that some states are likely to be *irreversible*. In these irreversible or *crisis* states,[18] the resource is so degraded that no matter how hard a manager might try, (s)he will be unable to move the resource to any other state. Given that this is the case, one way to look at the task of renewable resource management is to say that a manager's[19] objective is to *maximize* the amount of time a resource spends in the desirable set of states. One can also say that a resource manager's task is to *minimize* the amount of time the resource spends in the undesirable set of states.

Despite the manager's best efforts, (s)he can never be certain that the managed resource will not hit an irreversible state. Given this state of affairs, how should a developing country resource manager proceed? Chapter 6 studies the properties of the following reasonable approach. First, identify the crisis state. Next, put in place a well-designed plan of action. Even with a well-designed plan of action in place, it is still *possible* that a managed resource will hit a crisis state. Consequently, a key question is this: How long until crisis? In other words, the manager would like to know how long it will take for the resource to hit the crisis state. Further, on what does the answer to this question depend? Finally, is the answer history dependent or independent? In other words, does the answer to the how long until crisis question depend on the state in which the manager's plan of action is put in place? Clearly, answers to these questions are vital for successful renewable resource management in developing countries. Yet, there appear to be no previous studies of these questions. Hence, Chapter 6 provides a theoretical analysis of these hitherto unstudied research questions.

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[18] In the rest of our discussion of the contents of Chapter 6, we shall use the terms "irreversible state" and "crisis state" interchangeably.

[19] The manager need not be a single individual. In many developing countries, communities collectively manage renewable resources. For more on this, see Wade (1988) and Dasgupta (1996).

An arbitrary renewable resource is modeled as a discrete-time Markov chain with a finite number of *rank ordered* states $0, 1, 2, \ldots, S$. State 0 is the least desirable state and state S is the most desirable state. Further, state 0 is the only crisis state and it is assumed that the resource manager inherits the resource under study in state S. The focus of attention in this chapter is on two management regimes, the so-called lax and the so-called strict management regimes.

The lax management regime is lax because even though the manager inherits the resource in the best possible state S, his or her managerial actions are largely unsuccessful in keeping the resource away from the undesirable states in general and the crisis state in particular. Therefore, given that the resource is in state S, it is just as likely that the resource will next be in state 0 as it is that it will next be in state $S - 3$. Analysis shows that for the lax management regime, when the number of states of the resource approaches infinity, the expected amount of time until the laxly managed resource hits the crisis state is given by the logarithm of the state in which the manager inherits the resource.

The strict management regime is strict in two senses. First, given that the resource is now in state S, the likelihood of hitting the crisis state next is *not* identical to the likelihood of hitting some other (non-crisis) state. Second, the probability of hitting the crisis state next depends on where the resource is initially. In particular, the closer the initial state is to state S, the less likely it is that the resource will hit the crisis state. Analysis shows that as the number of states approaches infinity, the expected amount of time until the strictly managed resource hits the crisis state is given by twice the logarithm of the state in which the manager inherits the resource less the constant 3. Comparing this result with the corresponding result for the lax management regime, it is clear that it generally takes *longer* for the resource to hit the crisis state with the strict management regime. Specifically, Chapter 6 shows that when $S = 1{,}000{,}000$, it takes approximately 14 (25) time periods to hit the crisis state with the lax (strict) management regime.

The analysis of the lax and the strict management regimes in Chapter 6 show that the answer to the how long until crisis question depends on the state in which our resource manager inherits the resource under study. Hence, the initial condition *matters.* More generally, the more desirable the state in which the manager inherits the resource, the longer it will take for the resource to hit the crisis state. Chapter 6 looks at renewable resource management in developing countries that are closed economies. In an open economy setting, a number of hitherto irrelevant issues become germane. Chapters 7 and 8 conduct differential game theoretic analyses of some of these issues and it is to these analyses that we now turn.

2.2.3. *Trade in Renewable Resources with Competitive Sellers*

Renewable resources such as fish, timber, ivory, and rhino horns have been traded between countries for quite some time. However, as noted by Clark (1973), Jablonski (1991), and Pimm *et al.* (1995), a great deal of concern has now been expressed about the declining stock levels of most renewable resources. Therefore, the general and hitherto unstudied question that is addressed in Chapter 7 concerns the effect of the stock dependence or the independence of harvesting costs on the efficacy of trade policy. The Stackelberg differential game theoretic analysis conducted in this chapter shows that the *form* of the harvesting cost function has significant implications for the efficacy of trade policy in promoting the conservation of renewable resources.

This chapter first focuses on the efficacy of open loop unit and *ad valorem* tariffs when the harvest cost function is stock *independent.* It is noted that although open loop tariffs are generally dynamically inconsistent (Karp and Newbery, 1993), for this "stock independent" case, the open loop tariffs *are* dynamically consistent. To grasp this point, consider the case in which these tariffs are dynamically inconsistent. In this latter case, at some time $t > 0$ the buyer would want, if he could, to deviate from the tariff trajectory he announced at the beginning of the game and announce a different tariff trajectory. Being forward looking, the representative *competitive* seller in this chapter will anticipate the buyer's desire to change the tariff trajectory he announced initially and hence this tariff will fail to achieve its intended objectives.

The goal of the importing nation is to obliquely encourage the conservation of the renewable resource. Because the tariffs studied in the first part of this chapter are dynamically consistent, they will indirectly achieve their intended conservation goals. Even so, tariffs are not the ideal policy instruments with which to encourage resource conservation. This is because tariffs target imports and they do not do anything directly to encourage conservation of the renewable resource in the exporting nations.

The second half of Chapter 7 analyzes the efficacy of open loop unit and *ad valorem* tariffs when the harvest cost function is stock *dependent*. In this case, it is shown that the optimal open loop unit and *ad valorem* tariffs are dynamically *inconsistent*. Further, the analysis undertaken in this second half demonstrates that attempts to promote renewable resource conservation by means of trade policies are problematic in more ways than one. To see this, note that the analysis in Karp and Newbery (1993) and in Batabyal (1998a) tells us that even when the open loop unit and *ad valorem* tariffs are dynamically inconsistent — and this happens when the harvest cost function is stock dependent — the buyer in the importing nation will prefer to use these inconsistent trade policies rather than follow a dynamically consistent course of action. However, inconsistent policies are not credible and hence the tariff trajectory announced by the buyer at the beginning of the game will not be believed by the sellers and therefore inconsistent policies will typically fail to achieve their resource conservation objectives.

In contrast, when the harvest cost function is stock independent, the optimal open loop tariffs are dynamically consistent and hence believable by the sellers of the resource. Hence, in this case, the buyer's trade policies (tariffs) will indirectly attain their conservation objectives. Although tariffs are an imperfect way of promoting conservation, the analysis in this chapter shows that they may not work as desired. This is because the credibility of the optimal tariffs depends on the form of the harvest cost function and this form is *not* controllable by the buyer. This crucial point has *not* been recognized previously in the literature on international trade in renewable resources.

The stock dependent cost function is more appropriate for endangered renewable resources. Such resources are endangered in part because adequate *domestic* measures have not been taken in the pertinent countries to prevent overexploitation. It is for these endangered resources — where the apposite domestic conservation measures have not been taken — that imperfect supra-national measures such as trade policies are most needed. Unfortunately, the analysis in Chapter 7 tells us that trade policies are likely to be ineffective (because they are not credible) precisely when they are most needed (when the harvest cost function is stock dependent). Does the basic negative message of Chapter 7 change when a monopsonistic buyer in the importing nation engages in resource trade with a monopolistic — and not competitive — seller in the exporting nation in a Stackelberg differential game? This question is analyzed in Chapter 8.

2.2.4. *Trade in Renewable Resources with a Monopolistic Seller*

There are two key *differences* between exhaustible and renewable resources. First, exhaustible resources do not regenerate but renewable resources do. Second, in contrast with exhaustible resources, renewable resources are often an argument in the utility functions of citizens in resource importing nations. Now, the problem of time inconsistency arises when agents with market power make promises that they would subsequently like to break. This problem — see Karp and Newbery (1993) and Groot *et al.* (2003) — has now been fairly well studied in the exhaustible resources literature. As noted in Karp and Newbery (1993, pp. 882–883), a key insight of this literature is that when (i) the future affects the present, (ii) at least one economic actor has market power and is able to influence the future, and (iii) the actor with market power cannot credibly commit herself to future actions, the problem of time inconsistency is salient. These three features are also present in the models analyzed in Chapter 8. In addition, Karp and Newbery (1993, p. 892) note that the problem of time inconsistency is caused by *stock dependent* costs. Therefore, a key question studied in Chapter 8 is whether stock dependent costs alone account for the time inconsistency of optimal policies or whether other factors can also cause time inconsistency.

The analysis in Chapter 8 concentrates on a single buyer who purchases the resource from a *single* seller in a Stackelberg differential game in which the buyer leads. Initially, the focus in this chapter is on the impact of optimal open loop unit and *ad valorem* tariffs when the harvesting cost function is stock independent. In this situation, Chapter 8 obtains three specific results that are contrary to the findings in Chapter 7. First, when the single buyer of a renewable resource faces a monopolistic seller, the buyer's payoff depends on which tariff she uses. Second, the two optimal open loop unit and *ad valorem* tariffs are *not* equivalent. Third, when the buyer uses both tariffs together, she is able to force the monopolistic seller to behave competitively. This means that the harvest rate of the resource is the same whether a competitive seller faces an optimal tariff of either kind or a monopolistic seller faces optimal unit and *ad valorem* tariffs.

As in Chapter 7, because the tariffs studied in the case of the stock independent harvest cost function are time consistent, they will obliquely achieve their intended conservation aims. Even so, Chapter 8 points out that if an importing nation's goal is to encourage conservation of the renewable resource in the exporting country, then tariffs are not the ideal policy tool because tariffs do not do anything directly to promote conservation of the resource in the exporting nation. Therefore, from a resource conservation standpoint, tariffs are blunt policy instruments.

The final contribution of the first part of Chapter 8 is to note that the result that with a stock independent harvest cost function, the optimal tariffs are time consistent, is *not* general. Even with a stock independent harvest cost function, when either the biological growth function of the resource under study is logistic or when the buyer's utility depends on consumption and on the resource stock, the optimal tariffs are time *inconsistent*.

The second part of Chapter 8 examines the efficacy of open loop unit and *ad valorem* tariffs when the harvest cost function is stock dependent. In this case, the optimal unit and *ad valorem* tariffs are time *inconsistent*. Further, the above discussed three specific results obtained in the first part of Chapter 8 hold once again with a stock dependent cost function. In addition, this second part of Chapter 8 corroborates a key Chapter 7 message concerning the problematic nature of efforts to further resource conservation with tariffs. Specifically, we are reminded that when the harvest cost function is stock independent, the optimal tariffs are time consistent and hence believable by the seller. Therefore, in this case, the buyer's tariffs will indirectly attain their resource conservation aims.

Ideally, tariffs ought not to be used to promote renewable resource conservation. This is because tariffs get at the conservation issue indirectly. However, if the seller is unwilling or unable to take measures in his own nation to further resource conservation, then tariffs are one imperfect instrument with which the seller can be encouraged to take the relevant conservation measures. Even so, tariffs may not function as desired. This is because the believability of the optimal tariffs depends on the form of the harvest cost function and this form is *not* controllable by the buyer. One would think that for threatened resources, where the proper domestic conservation measures have not been taken, imperfect supra-national measures such as trade policies might be useful. In this regard, the message from this and the preceding chapter is identical in one fundamental way. Both chapters tell us that tariffs are likely to be unbelievable and hence futile for threatened renewable resource trade where the harvest cost function is generally stock dependent. This brings us to the third and the last part of this book and this part concerns environmental policy in developing countries.

2.3. *Environmental Policy*

2.3.1. *Environmental Policy with Economic Dualism*

Much concern has now been expressed about a developing country (DC) government's ability to commit to environmental policy for any reasonable time period. Indeed, some observers have noted that in the face of pressing employment creation needs, DC governments may initiate the process of establishing pollution control policies but their will to continue with such policies is likely to be limited. This employment/environment question in DCs has received very little attention in the extant literature.[20] Hence, Chapter 9 has two aims. First, it analyzes an employment driven dynamic model of environmental policy in a stylized DC. Second, the chapter shows how the DC government's optimal course of action is closely related to its ability to commit to its announced environmental policy.

This chapter uses the specific factors model to study a small, two-sector, trading DC. The two DC sectors consist of a modern, high-wage, environmentally intensive sector in which production causes pollution. The second sector is the traditional, low-wage, environmentally benign sector in which there is no pollution. Workers migrate from the traditional to the modern sector to obtain higher wages. Although workers, as consumers, are adversely affected by pollution, they do not factor this into their migration decisions. Thus, in the absence of governmental policy, migration takes place too quickly and, hence, there is excessive pollution in the nation under study. In this situation, the first-best policy is to tax pollution directly. However, in many DCs the government does not possess the wherewithal to tax pollution directly. Therefore, this chapter assumes that the DC government operates in a second-best environment in which it controls pollution with a production tax.

Chapter 9 studies the DC government's optimal dynamic environmental policy under three assumptions about its ability to commit to a specific course of action. In the first case, the government

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[20] See Lekakis (1991) and Mehmet (1995) for a more detailed corroboration of this claim.

commits to a tax trajectory for an infinite period of time. In the second case, the DC government commits to a tax trajectory for a finite period of time. Unfortunately, in both these cases, the optimal tax policy is dynamically inconsistent.[21] Therefore, forward looking workers will not believe that the government will carry through with its initially announced policy, and hence, this policy will fail to accomplish its aims. In the third case, the government commits to a tax trajectory for an infinitesimal period of time. In the limiting case in which the period of commitment shrinks to zero, the government's tax policy is time consistent.

Section 3 of Chapter 9 depicts the DC government's optimal dynamic environmental policy when it displays infinite commitment. In certain specific scenarios, the DC government moves toward an equilibrium by starting with a large pollution tax. It then gradually lowers this tax to the steady state level. Specifically, the government's open loop tax policy calls for an activist course of action. In other words, in the model of this chapter, it is typically suboptimal to set a zero tax at any point in the program. This notwithstanding, the government's open loop tax policy is time inconsistent. This means that unless there is some mechanism by which the DC government can be bound to its initially announced tax trajectory, this government will fail to achieve its initially announced employment and environmental objectives.[22]

Section 4 of Chapter 9 studies the case in which the DC government commits to its announced environmental policy for a finite time period. In the resulting Markov perfect equilibrium, under certain conditions, an optimal program once again calls for an activist pollution control policy. Further, while the infinite commitment case called for starting with a high tax and then lowering this tax to its steady state value, the limited commitment case calls for

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[21] The reader will recall that dynamic inconsistency was also the focus of much of the analysis in Chapters 7 and 8.

[22] The extent to which the government will fail to achieve its objectives depends on the nature and the direction of deviation from the initially announced tax policy.

equalizing the tax at the beginning and at the end of the program. While this limited commitment scenario is plausible, this equilibrium too is time inconsistent. Hence, pollution and employment in sector 2 will not be reduced, and migration from the traditional to the modern sector will not be slowed.

Given this state of affairs, Section 5 of Chapter 9 examines the case in which the DC government commits to a specific tax policy for an infinitesimal period. In this setting, the chapter focuses on the limiting Markov perfect equilibrium in which the government's period of commitment shrinks to zero.[23] Analysis shows that even when the DC government displays no commitment to its tax policy, the welfare loss from being unable to commit is never as great as the welfare gain from reducing pollution. Consequently, the optimal pollution tax is positive. Put differently, the passive aspect (do nothing) of governmental policy is dominated by the activist aspect (control pollution). This is why the limiting pollution tax is positive.

It is possible to rank the three policies studied in this chapter in terms of the government's preference and the policy's ability to achieve its goals. From the standpoint of the DC government's payoff, the most desirable policy is the open loop policy. This policy permits infinite commitment. The second-best policy is the Markov perfect tax policy with a finite period of commitment. The least desirable policy is the limiting Markov perfect tax policy. In contrast, the ranking in terms of goal attainment is exactly the opposite. The limiting Markov perfect tax policy is credible. Hence, this policy will be able to reduce pollution. The other two policies are *not* credible. Therefore, they will fail to achieve the government's environmental goals. This discussion highlights the DC government's dilemma. The policy which results in the highest payoff to the government is the one that is least desirable from the standpoint of goal attainment and social welfare.

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[23] For an alternate approach to the construction of dynamically consistent policies, see Batabyal (1996b; 1996c).

2.3.2. *Environmental Policy in the Presence of an Export Subsidy*

A number of DCs have protected their export sectors with subsidies to exporters. Therefore, Chapter 10 studies the conduct of dynamic environmental policy in a DC in which the export and the environmentally benign sector is protected with an export subsidy. The specific question that is analyzed in Chapter 10 is the following. What are the properties of optimal environmental policy when a DC government controls pollution by taxing the production of the good manufactured by the polluting and also the import-competing sector, and when this government is unable to commit to the tax policy it announced at the beginning of its tenure in office? It is shown that, in general, the export subsidy has only a slight impact on the DC government's ability to conduct environmental policy effectively.

Chapter 10 uses a specific factors model of the sort used in Chapter 9 to analyze a *small* DC.[24] One sector of this DC is the traditional, low-wage, and non-polluting sector. This traditional sector is also the export sector, and the DC government *protects* this sector by granting a *subsidy* to exporters. For political reasons, this subsidy cannot be repealed. The second sector is the modern, high-wage sector in which production causes pollution. This pollution is *not* transboundary in nature.[25] The modern sector is also the import-competing sector of the DC.[26]

Initially, the DC economy is in disequilibrium. A movement toward equilibrium involves slowing the rate at which workers migrate from the traditional to the modern sector. Chapter 10 studies the DC government's optimal intertemporal environmental policy under three assumptions about its ability to commit to a

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[24] The focus of Chapter 10 on a small DC means that this DC's own policies do not affect world prices. As such, in the rest of our discussion of Chapter 10, we shall not talk about the terms of trade effects of the DC government's environmental policies. The principal focus of Chapter 10 is on the time consistency/inconsistency of alternate pollution control policies. For more on the terms of trade effects of environmental policies, see Batabyal (1993; 1994a; 1994b).

[25] For more on the control of one kind of transboundary pollution, see Batabyal (1996d; 1998b) and Xu and Batabyal (2001a; 2001b).

[26] The reader may wish to think of the traditional sector as the agricultural sector, and the modern — possibly the infant industry — sector as the steel sector.

particular policy. In the first (second) case, the government commits to its announced tax policy for an infinite (finite) period of time. In both these cases, the government's optimal tax policy is time inconsistent and, hence, implausible. Therefore, a third case is also studied in which the government commits to its tax policy for an infinitesimal period of time. In this case, in the limit, as this period of commitment approaches zero, the government's tax policy is time consistent.

When the DC government displays infinite commitment, the optimal course of action calls for this government to begin with a zero tax. It then raises this tax over the length of the program, and then lowers the tax so that in the stationary state, the pollution tax is, in fact, a subsidy. As explained in this chapter, a tax at time $t = 0$ involves costs but it has no positive policy effect. This is why the optimal initial tax is zero. Further, on account of the positive export subsidy, the steady state level of labor in the two sectors is suboptimal. Hence, to encourage some migration from the traditional to the modern sector in the stationary state, the government grants a subsidy to the producers of the polluting good.

The open loop tax policy with infinite commitment is time inconsistent. Therefore, Chapter 10 next studies a Markov perfect equilibrium in which the DC government displays finite commitment to its announced environmental policy. A salient finding in this case is that the export subsidy now has no effect on the DC government's optimal environmental policy. This suggests that distortions that are *not* in the polluting sector are far less likely to have a detrimental impact on the DC government's ability to conduct environmental policy effectively. As in the infinite commitment case, the DC government's optimal tax policy is not always activist; specifically, when the modern sector's revenue function is separable in its arguments, whether commitment is infinite or finite has *no* bearing on this government's optimal course of action.

The Markov perfect equilibrium in the finite commitment case is time inconsistent. Analysis shows that when the DC government displays infinitesimal commitment to its announced policy, the limiting Markov perfect pollution tax is zero and this tax is independent of the existing export subsidy. This finding has two implications. First, the welfare loss from being unable to commit to environmental policy swamps the welfare gain from reducing pollution. Second, when the DC government revises the pollution tax continually, this government's environmental policy *is* time consistent and hence credible.

The ranking of the three policies studied in this chapter in terms of the government's preference and the policy's ability to achieve its goals is similar to the ranking in Chapter 9. Therefore, despite the presence of a distortion in the traditional sector, the DC government is, once again, in a situation comparable to that in Chapter 9. Specifically, the policy that results in the highest reward for the government is the one that is least likely to lead to the satisfaction of this government's policy goals. It is in this sense that the fear of observers who have worried that in the face of urgent employment creation needs, DC governments are unlikely to be serious about environmental protection, is justified.

2.3.3. *Environmental Policy in the Presence of an Import Tariff*

Chapter 11 continues with and generalizes the previous analysis of dynamic environmental policy in DCs in Chapter 9. In particular, Chapter 11 makes no assumptions about the form of the underlying revenue functions, and it studies the conduct of environmental policy by a small-trading DC in which a tariff protects the import-competing and the polluting sector. The specific question that is addressed in this chapter is the following. What are the properties of optimal dynamic environmental policy when a DC government controls pollution by taxing the production of the good manufactured by the protected sector, and when this government is not necessarily able to commit to the pollution tax policy it announced at the beginning of its tenure in office?

The Chapter 11 model is very similar to the models used in Chapters 9 and 10. Specifically, this chapter uses a dynamic version of the Ricardo–Viner model[27] to study a small-trading and dualistic DC. The polluting sector of the DC is also the import-competing sector and the government uses a positive tariff to protect this sector. One possible interpretation of this sector is that it is the DC's "infant industry."[28] The second sector is the traditional, low-wage, environmentally benign export sector. The political clout of the import-competing sector is such that the government is unable to remove the existing tariff.

The DC economy is initially in disequilibrium because there are distortions (pollution and the tariff) in the DC economy. A move toward equilibrium requires that the production of the polluting good decline over time. Workers have rational expectations. Chapter 11 analyzes the DC government's optimal dynamic environmental policy under three assumptions about its ability to commit to a particular policy. In the first (second) case, the government commits to a tax trajectory for an infinite (finite) period of time. In both these cases, the government's optimal tax policy is time inconsistent and, hence, not credible. Therefore, a third case is also analyzed in which the government commits to its tax policy for an infinitesimal period of time. In the limiting case in which the period of commitment approaches zero, the government's tax policy is time consistent.

When the DC government displays infinite commitment, in an optimal program, the government's pollution tax depends on the existing tariff. First, at the beginning and at the end of the program, the magnitude of the optimal pollution tax is equal to the magnitude of the existing tariff and both are positive. Second, the optimal pollution tax at an *interior* point in the program is generally larger

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[27] This is a standard model in trade theory. In this model, there are two sectors with a factor of production specific to each of these two sectors and a mobile factor of production (typically labor) that can move between these two sectors. For more on this model, see Krugman and Obstfeld (2000, Chapter 3).

[28] An "infant industry" is a nascent indigenous industry. Initially, such industries frequently have high costs, and, hence, they find it difficult to compete with other, more established, foreign industries. In turn, this difficulty is often the justification for the protection of "infant industries." For more on these issues, see Krugman and Obstfeld (2000, pp. 255–257).

than the existing positive tariff. Therefore, in an optimal program, the government begins with a positive pollution tax that is equal to the tariff, then raises this tax, and finally lowers this tax so that in the steady state the pollution tax and the tariff are once again equal and positive.

There are two distortions in the DC economy — the import tariff and pollution — and the government has available to it a single policy instrument, namely, the pollution tax. For there to be an improvement in welfare, the number of policy instruments generally ought to equal the number of distortions. This means that the government will *not* be able to use environmental policy to raise welfare unambiguously.

The optimal open loop tax policy with infinite commitment, although activist in nature, is time inconsistent. Hence, Chapter 11 next analyzes a Markov perfect equilibrium in which the DC government displays finite commitment to its proclaimed environmental policy. Analysis shows that a diminution in the length of commitment results in no qualitative change in the government's optimal tax policy. Hence, in general, the discussion in the previous two paragraphs applies to this limited commitment scenario as well. However, there is one difference. In the infinite commitment case, in the steady state there is a single distortion in the economy (the tariff) and the pollution tax raises welfare. However, in the finite commitment case, the government operates in a second-best environment at all points in time.

The Markov perfect equilibrium in the finite commitment case is also time inconsistent. Analysis shows that when the DC government displays infinitesimal commitment to its proclaimed policy, the limiting Markov perfect pollution tax which calls for continuous policy revision is positive, equal to the tariff, and time consistent. This tells us that even when the DC government's period of commitment is infinitesimal, unlike the result in Chapter 10, it is now *not* optimal for the government to set a zero pollution tax. In other words, the activist course of action dominates the "do nothing" or passive course of action.

Three noteworthy outcomes follow from the analysis in Chapter 11. First, this chapter's model is richer than the model in Chapter 9, and it includes the Chapter 9 model as a special case. Second, this Chapter 11 model is able to shed light on the following salient question: What effect does an existing distortion (the import tariff) have on the DC government's optimal dynamic environmental policy? This question cannot be answered using the Chapter 9 model. Third, this chapter's model also answers the following question: What are the properties of optimal dynamic environmental policy in a second-best environment?[29] This question too cannot be answered with the model in Chapter 9.

2.3.4. *Deficits Versus Surpluses and Discretion in Environmental Policy*

In contemporary times, the connections between the environment and economic development have come to dominate academic and public debate in most parts of the world. The analyses in Chapters 9 through 11 tell us that under certain circumstances, employment creation and environmental protection are competing goals. What this means is that although DCs may begin the process of implementing environmental policies, over time, their *commitment* to such policies is likely to wane. The purpose of Chapter 12 is to study two additional aspects of this basic proposition.

In this regard, the nature of dynamic environmental policy in DCs in the presence of a (possibly) binding *financial* or *budget* constraint has been little studied in the extant literature.[30] Therefore, the first part of Chapter 12 examines the following question. When faced with a self-financing or budget constraint, is it optimal for an environmental authority (EA) to alter the trajectory of pollution taxes

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[29] By second-best environment we mean a situation in which (i) the number of distortions exceeds the number of corrective policy instruments available to the DC government, and (ii) the DC government is unable to tax pollution directly. In Chapter 11, there are two distortions (import tariff and pollution) and one policy instrument (pollution tax).

[30] For more on the practical effects of budget constraints on the activities of EAs in China and India, see Sinkule and Ortalano (1995, p. 29) and Dwivedi (1997, pp. 124–125).

over time? Or, depending on the actual expenses incurred, does it make more sense for this EA to run deficits/surpluses? Chapters 9 through 11 have demonstrated that a DC government's announced environmental policy is frequently *dynamically inconsistent*. As such, one can ask what nexus there exists between an EA's preferences and credible environmental policy. Specifically, the question analyzed in the second part of Chapter 12 is this. Should an EA make its preferences about the relative benefits of environmental protection versus production of the polluting good public, or should it keep its preferences private?

The analysis in the first part of Chapter 12 focuses on a small, open, infinite horizon DC whose economy is dualistic. One sector is the traditional sector in which there is no pollution. Attention is concentrated primarily on the second and modern sector in which production causes pollution. The EA maximizes the representative consumer's lifetime utility. There are two constraints on the EA's optimization problem. The first is the polluting sector's budget constraint. The second constraint arises from the EA's optimization problem. Specifically, because the subjective time preference factor equals the market discount factor, an Euler equation describing the representative consumer's consumption in any two time periods must be accounted for.[31]

Solving the EA's optimization problem yields four specific results. First, the marginal utility of consumption equals the shadow value of the polluting sector's resources. Second, there is a wedge between the shadow value of the EA's resources and the private value of consumption. Further, this wedge equals the marginal deadweight loss of the pollution tax measured in terms of the representative consumer's utility. Third, like the representative consumer, the EA also finds it optimal to smooth pollution taxes over time. Finally, and most notably, when faced with a self-financing constraint, the EA ought to set a *constant* pollution tax over time. When its expenditures are unusually high, it will be optimal for the EA to run a

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[31] For more on this, see Obstfeld and Rogoff (1996, p. 3).

deficit. Similarly, when its expenditures are unusually low, the EA should run a surplus.

The analysis in the second part of Chapter 12 examines the nexus between the EA's preferences and credible environmental policy. Initially, attention is focused on the so-called discretionary case. In this case, the EA and the polluting sector play a one-shot game among themselves. In the equilibrium of this one-shot game, the optimal level of pollution equals the EA's type. Further, the equilibrium expected level of pollution equals the expected value of the random variable denoting the EA's type. Finally, this chapter computes the expected loss to the EA in the equilibrium of this discretionary one-shot game. These obtained results are then compared with the corresponding results when the EA displays commitment to its environmental policy.

This comparative exercise demonstrates that environmental policy with commitment results in *lower* social losses than does environmental policy with discretion. In other words, society is better off when the EA is committed to environmental policy. A salient implication of the analysis in this part of Chapter 12 is that the EA will actually prefer a system that mandates secrecy about its true preferences regarding the relative benefits of environmental protection versus production of the polluting good. Practically speaking, this means that it is better to have an EA that displays *commitment* to its environmental policy so that the polluting "industries know what to expect [and] how far to go with respect to changing their production processes ..." (Dwivedi, 1997, p. 216).

2.3.5. *Personal Versus Public Welfare in Environmental Policymaking*

The analysis in Chapter 12 shows that when faced with a self-financing constraint, it is optimal for the EA to run a deficit/surplus. Second, social losses are lower when this EA keeps its preferences private. Given these findings, Chapter 13 analyzes the nature of the collaboration between an EA and the polluting sector in a DC when the relative weight that this EA places on *public* versus its *own* welfare is unknown. In particular, this chapter first documents the relevance of this issue by discussing actual instances of environmental policymaking in China and India. Next, within the context of the above-stated general issue, this chapter sheds light on three specific questions for any arbitrary time period t.

The first question concerns the determination of the expected and the actual levels of pollution in the DC's polluting sector. The particular object of interest here is an analysis of the equilibrium of the one-shot game between the EA and the polluting sector. To this end, Chapter 13 introduces the *random* variable $\lambda > 0$ which captures the weight that the EA places on public welfare versus its own welfare. To keep the mathematical analysis tractable, it is assumed that the expectation in period $t-1$ of the value of λ in period t is unity. An examination of the EA's optimization problem shows that when there is uncertainty about an EA's intentions as far as public versus private welfare is concerned, the expected amount of pollution is the *same* as when λ is known to equal unity. However, the *ex post* uncertainty about the type of EA that the polluting sector is confronted with creates *additional variability* in the actual amount of pollution that arises in the polluting sector of the DC under study.

The second question relates to the computation of the average social loss arising in part from the uncertainty about the relative weight that the EA places on public versus its own welfare. The analysis conducted in the second part of Chapter 13 gives rise to three noteworthy results. First, we learn that as the parameter χ, which measures the cost of pollution relative to that of suboptimal output increases, the expected loss to society decreases. Second, as the uncertainty associated with the output supply shock (σ_z^2) goes up, the average loss to society also goes up. Finally, when the uncertainty associated with the EA's weight over public versus its own welfare (σ_λ^2) increases, once again, the expected loss to society also increases. This last result tells us that as far as environmental policymaking is concerned, DCs need to ensure, to the extent possible, that individuals who are placed in positions of authority are public spirited in the discharge of their official duties.

The third and final question involves solving for the optimal value of the parameter, which measures the relative weight the EA places on public versus its own welfare. The analysis in this part of Chapter 13 begins by considering the case in which λ is predictable, and, hence, there is no uncertainty about the relative weight the EA places on public versus its own welfare. In this case of certainty about the EA's type, the relative weight parameter δ is chosen so that it is equal to the positive wedge between the targeted output level of the polluting good and the actual output level of this same good. However, when $\sigma_\lambda^2 \neq 0$ and, hence, λ is unpredictable, the above-discussed choice of δ is not optimal and we have to contend with the fact that there is a tradeoff between reducing *average* pollution by choosing a positive δ and raising the *variance* of pollution because the EA's preferences are stochastic.

3. Conclusions

There is no gainsaying the fact that there is now a sizeable and growing literature on the environment and economic development. Even so, there are very few theoretical studies of research questions in this field that explicitly integrate *dynamic* and *stochastic* approaches into their analyses. As noted in Section 1 of this introductory chapter, this state of affairs is both regrettable and it provides an incomplete and perhaps even inaccurate perspective on fundamental issues concerning the environment and economic development.

Given this objectionable state of affairs, our objective in this book is to demonstrate how dynamic and stochastic approaches can be effectively used to construct and analyze theoretical models that shed valuable light on hitherto largely unstudied questions at the interface of the environment and economic development. To this end, in this introductory chapter, we have highlighted the ways in which the analyses in the 12 individual chapters collectively help accomplish this book's stated objective. The use of dynamic and stochastic approaches to study research questions at the interface of the environment and economic development is still very much in its infancy. Therefore, in the coming years, one may look forward to many interesting developments in theoretical research in this burgeoning new field of inquiry.

References

Anonymous (2000). Politics this Week. *The Economist*, September 30:6.

Asthana, A.N. (1997). Where the Water is Free but the Buckets are Empty: Demand Analysis of Drinking Water in Rural India. *Open Economies Review*, 8:137–149.

Balint, P.J. (1999). Drinking Water and Sanitation in the Developing World: The Miskito Coast of Nicaragua and Honduras as a Case Study. *Journal of Public and International Affairs* 10:99–117.

Batabyal, A.A. (1993). Should Large Developing Countries Pursue Environmental Policy Unilaterally? *Indian Economic Review* 28:191–202.

Batabyal, A.A. (1994a). An Open Economy Model of the Effects of Unilateral Environmental Policy by a Large Developing Country. *Ecological Economics* 10:221–232.

Batabyal, A.A. (1994b). On the Possibility of Attaining Environmental and Trade Objectives Simultaneously. *Environmental and Resource Economics* 4:545–553.

Batabyal, A.A. (1996a). The Queuing Theoretic Approach to Groundwater Management. *Ecological Modelling* 85:219–227.

Batabyal, A.A. (1996b). Consistency and Optimality in a Dynamic Game of Pollution Control I: Competition. *Environmental and Resource Economics* 8:205–220.

Batabyal, A.A. (1996c). Consistency and Optimality in a Dynamic Game of Pollution Control II: Monopoly. *Environmental and Resource Economics* 8:315–330.

Batabyal, A.A. (1996d). Game Models of Environmental Policy in an Open Economy. *Annals of Regional Science* 30:185–200.

Batabyal, A.A. (1998a). Environmental Policy in Developing Countries: A Dynamic Analysis. *Review of Development Economics* 2:293–304.

Batabyal, A.A. (1998b). Games Governments Play: An Analysis of National Environmental Policy in an Open Economy. *Annals of Regional Science* 32:237–251.

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Batabyal, A.A. (1999). Contemporary Research in Ecological Economics: Five Outstanding Issues. *International Journal of Ecology and Environmental Sciences* 25:143–154.

Batabyal, A.A. and Beladi, H. (1999). The Stability of Stochastic Systems: The Case of Persistence and Resilience. *Mathematical and Computer Modelling* 30:27–34.

Batabyal, A.A. and Beladi, H. (2004). Swidden Agriculture in Developing Countries. *Review of Development Economics* 8:255–265.

Batabyal, A.A. and Yoo, S.J. (2007). A Probabilistic Approach to Optimal Orchard Management. *Ecological Economics* 60:483–486.

Brundtland, G.H. (1987). *Our Common Future.* The UN World Commission on Environment and Development. Oxford, UK: Oxford University Press.

Clark, C.W. (1973). The Economics of Overexploitation. *Science* 181:630–634.

Clark, C.W. (1976). *Mathematical Bioeconomics.* New York: Wiley.

Daly, H.E. (1968). On Economics as a Life Science. *Journal of Political Economy* 76:392–406.

Dasgupta, P. (1996). The Economics of the Environment. *Environment and Development Economics* 1:387–428.

Dasgupta, P. and Ehrlich, P.H. (1996). Nature's Housekeeping and Human Housekeeping. *Discussion Paper*, Beijer International Institute of Ecological Economics, Stockhohm, Sweden.

Dasgupta, P. and Maler, K.G. (1997). *The Environment and Emerging Development Issues*, Vol. 1. Oxford, UK: Clarendon Press.

Dickinson, J.C. (1972). Alternatives to Monoculture in the Humid Tropics of Latin America. *Professional Geographer* 24:217–222.

Dove, M.R. (1983). Theories of Swidden Agriculture and the Political Economy of Ignorance. *Agroforestry Systems* 1:85–99.

Dufour, D.L. (1990). Use of Tropical Rainforests by Native Amazonians. *BioScience* 40:652–659.

Dwivedi, O.P. (1997). *India's Environmental Policies, Programmes, and Stewardship.* New York: St. Martin's Press.

Eckholm, E.P. (1976). *Losing Ground.* New York: W.W. Norton.

Emch, M. (2000). Relationships Between Flood Control, Kala-azar, and Diarrheal Disease in Bangladesh. *Environment and Planning A* 32:1051–1063.

Farmer, M.C. and Randall, A. (1997). Policies for Sustainability: Lessons from an Overlapping Generations Model. *Land Economics* 73:608–622.

Farnsworth, E.G. and Golley, F.B. (eds.) (1973). *Fragile Ecosystems.* New York: Springer-Verlag.

Goldin, I. and Winters, L.A. (eds.) (1995). *The Economics of Sustainable Development.* Cambridge, UK: Cambridge University Press.

Gordon, H.S. (1954). The Economic Theory of the Common Property Resource: The Fishery. *Journal of Political Economy* 62:124–142.

Groot, F., Withagen, C. and de Zeeuw, A. (2003). Strong Time-Consistency in the Cartel-versus-Fringe Model. *Journal of Economic Dynamics and Control* 28:287–306.

Han, G., Jiang, F. and Yan, J. (1991). 2000AD: Water Environment Problems of China. *International Journal of Social Economics* 18:174–179.

Haque, C.E. and Zaman, M.Q. (1993). Human Responses to Riverine Hazards in Bangladesh: A Proposal for Sustainable Floodplain Development. *World Development* 21:93–107.

Hardin, G. (1968). The Tragedy of the Commons. *Science* 162:1243–1248.

Holling, C.S., Schindler, D.W., Walker, B.W. and Roughgarden, J. (1995). Biodiversity in the Functioning of Ecosystems: An Ecological Synthesis. *In* C. Perrings, K.G. Maler, C. Folke, C.S. Holling and B.O. Jansson (eds.), *Biodiversity Loss.* Cambridge, UK: Cambridge University Press.

Holling, C.S. (1996). Engineering Resilience Versus Ecological Resilience. *In* P.C. Schulze (ed.), *Engineering Within Ecological Constraints.* Washington, DC: National Academy Press.

Jablonski, D. (1991). Extinctions: A Paleontological Perspective. *Science* 253:754–757.

Karp, L. and Newbery, D.M. (1993). Intertemporal Consistency Issues in Depletable Resources. *In* A.V. Kneese and J.L. Sweeney (eds.), *Handbook of Natural Resource and Energy Economics*, Vol. 3. Amsterdam, The Netherlands: Elsevier.

Kleemeier, E. (2000). The Impact of Participation on Sustainability: An Analysis of the Malawi Rural Piped Scheme Program. *World Development* 28:929–944.

Krugman, P.R. and Obstfeld, M. (2000). *International Economics*, 5th edn. Reading, MA: Addison-Wesley.

Lekakis, J.N. (1991). Employment Effects of Environmental Policies in Greece. *Environment and Planning A* 23:1627–1637.

Mehmet, O. (1995). Employment Creation and Green Development Strategy. *Ecological Economics* 15:11–19.

Munasinghe, M. (1992). *Water Supply and Environmental Management: Developing World Applications.* Boulder, CO: Westview Press.

Obstfeld, M. and Rogoff, K. (1996). *Foundations of International Macroeconomics.* Cambridge, MA: MIT Press.

Pearce, D.W. and Warford, J.J. (1993). *World Without End: Economics, Environment, and Sustainable Development*. Oxford, UK: Oxford University Press.

Perrings, C. (1996). Ecological Resilience in the Sustainability of Economic Development. *In* S. Faucheux, D. Pearce and J. Proops (eds.), *Models of Sustainable Development*. Cheltenham, UK: Edward Elgar.

Peters, W.J. and Neuenschwander, L.F. (1988). *Slash and Burn: Farming in the Third World Forest*. Moscow, ID: University of Idaho Press.

Pezzey, J.C.V. (1997). Sustainability Constraints versus "Optimality" versus Intertemporal Concern, and Axioms versus Data. *Land Economics* 73:448–466.

Pimm, S.L. (1984). The Complexity and Stability of Ecosystems. *Nature* 307:321–326.

Pimm, S.L., Russell, G.J. and Gittleman, J.L. (1995). The Future of Biodiversity. *Science* 269:347–350.

Reddy, V.R. (1999). Pricing of Rural Drinking Water: A Study of Willingness and Ability to Pay in Western India. *Journal of Social and Economic Development* 2:101–122.

Ross, S.M. (1996). *Stochastic Processes*, 2nd edn. New York: John Wiley and Sons.

Ross, S.M. (2003). *Introduction to Probability Models*, 8th edn. San Diego, CA: Academic Press.

Sinkule, B.J. and Ortolano, L. (1995). *Implementing Environmental Policy in China*. Westport, CT: Praeger.

Southgate, D. (1990). The Causes of Land Degradation along Spontaneously Expanding Agricultural Frontiers in the Third World. *Land Economics* 66:93–101.

Wade, R. (1988). *Village Republics*. Cambridge, UK: Cambridge University Press.

Walters, C.J. (1986). *Adaptive Management of Renewable Resources*. New York: Macmillan.

Xu, Q. and Batabyal, A.A. (2001a). Price Competition, Pollution, and Environmental Policy in an Open Economy. *Annals of Regional Science* 35: 59–79.

Xu, Q. and Batabyal, A.A. (2001b). A Bertrand Model of Trade and Environmental Policy in an Open Economy. *Keio Economic Studies* 38:53–70.