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Can markets provide for future generations? A general equilibrium model of capital and natural resource markets

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The Ohio State University, 1993
Can Markets Provide for Future Generations?

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Graduate School of The Ohio State University

By

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*****

The Ohio State University
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DEDICATION

To the memory of Joe Havlicek whose unwavering vision and boundless optimism created opportunities for so many faculty and students.
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"Let us Look Beyond our own Short Lives."
Cicero, The Defense of Archias

CHAPTER I
Introduction

It would be difficult to identify an issue in sustainability to stimulate more controversy than a discussion regarding the power of markets to provide for the welfare of distant generations. Certainly some discussants are extremely skeptical of economic efficiency criteria as the guide to policy on natural resource use. Conversely there are those confident that idealized markets free of economic inefficiencies nearly guarantee sustained future opportunities.

Skeptics of economic efficiency worry that resource policy decisions of today's economic agents prejudicially favor the present against the unrepresented interests of the future. However proponents of economic efficiency guided policy note that an unwise over-extraction of renewable natural resources will increase the economic price of the resource to reflect this scarcity and encourage conservation.

Both sides of the sustainability debate offer compelling arguments. Consider first the skeptics critique the power of
markets to provide for the future.

Some skeptics posit that the order of economic markets improperly regard biological order. The economic way of conditionally establishing value simply does not respect the inherent, unchanging and impersonal biological properties of natural phenomena. The incentives that motivate economic agents to establish resource prices are simply incommensurate to the real value of the natural world in sustaining human existence.

Agents value natural resources according to highest current economic price - a price that perpetually changes with current wealth and assumes substitutability of resources and man-made goods. The focus on conditional and substitutable economic value encourages a gamble with an immovable nature and ignores the considerable risks imposed on the perhaps not to distant future for the benefit of satisfying often trivial current material demands. The incentives that allow markets to clear permit the relative trade-off between the destruction of society and the satisfaction of some non-essential desire, particularly if the destruction is a long time away. This introduces the second critique.

Another critique emphasizes the incomparability between very long ecological cycles and any planning horizon subject to economic discounting. Future humans inherit a world shaped by immediate choices; but they are not present when these choices are made. The time horizon that guides the
action of current agents may be limited to a single life-time or even to the life of progeny. Yet the consequences of agent choices may not materialize until well beyond this personal time horizon. If agents are additionally myopic and actually prefer current to future payoffs within their planning horizon, then even consequences near the end of the plausible time horizon may have almost no value. Intertemporal discounting, the skeptics argue, represents this weakness. Enormous future opportunities may be sacrificed as their current market value may be swamped by the economic value of the most trivial immediate consumption needs.

Economic optimists instead emphasize that market prices are formed by agents who rationally and completely consider foregone opportunities in pursuing their objectives. Processes of the natural world do affect market supply and demand schedules. Even though agent preferences are individually identified, agents must account for constraints to realize their objectives. Actions that increase the risk of a natural disaster make those actions more expensive in the market.

It is also perfectly rational that the economic costs of risks to biological integrity change even though biological laws do not change. Agents evaluate the risk of a biological collapse in relation to risks of a collapse of economic productivity, a relation that may change. That is, agents evaluate comparable consequences - magnitudes and
probabilities of dramatic erosion or gain in human welfare—which may be driven by a natural disaster or an economic collapse. Similarly the substitution of man-made goods for natural resources is not a naive dismissal of the uniqueness of goods; but rather it reflects the ability to secure human welfare, our objective here, through a number of possible scenarios that stress environmental inputs differently.

The skeptics' second concern that markets discount future benefits ignores the benefits of efficient markets. Discounting indicates only the efficient trade in Fischerian markets between agents who demand access to immediate capital (borrowers) and savers willing to lend that capital. Interest prices are positive only because savers forego current consumption to make those loans available. As more and more current resources are loaned, savers become less willing to part with ever more scarce resources without some more than proportional future payoff for the amounts loaned. If borrowers demand capital for consumption, no decline in available resources in the future occurs barring asset depreciation. So lending is neutral. Yet if borrowers demand capital for productive investment, then same markets that make interest rates positive also enable production of resources for the future. Economic surpluses identified from efficient capital trade reflect the highest aggregate economic value for deferring current consumption in order to gain more than proportional future consumption opportunities, arguably an
improvement in future prospects. Discounting of future benefits is therefore a very reasonable value for value comparison that measures foregone opportunities sacrificed to secure some future good. Economic values, therefore, are a valid way of valuing the prospects for sustaining future human welfare.

Since our discussion considers sustaining welfare opportunities for humans, economic optimists may demand that skeptics reconcile their misgivings about maximizing economic surplus, a measure of welfare opportunity, with an aim of enabling greater consumption benefits. Skeptics on the other hand demand that the economic optimists demonstrate an equivalence between maximizing economic surplus among existing trading agents and sustained future consumption. Particularly skeptics demand proof that the properties of the natural world are adequately reconciled with the structure of market trade in a fashion that does not systematically expose natural resources to exhaustion with devastating consequences for future humans.

Perhaps the language of the debate is forbidding, drawing on several subspecialties from several distinct academic disciplines. Perhaps the passion of the debate pre-empt a reasoned consensus. Still there may be a legitimate conservation question representing the skeptics' concern that can be articulated coherently within a theoretically sound economic model. The statement of such a model would surely
enlighten the sustainability debate. In addition we would hope that such a model would be able to guide our evaluation of the likely effects of various resource management policies.

The purpose of this study is to appraise the role of the market as a steward of material wealth for the future. We operationally define stewardship by the degree to which human consumption can be sustained from time period to time period. Any intrinsic value to sustaining a biological system beyond human evaluation is extra-topical to our study. We are especially concerned in this work with the conditions under which perfectly informed agents guided by fully efficient price signals might harvest to exhaustion essential renewable resources and devastate future societies. So we equate sustainability with maintained human consumption. The exhaustion of a highly productive renewable resource is a subset of this question. We call this the conservation question and it assumes dramatic unsustainable consumption.

Outline of Work

This work considers whether perfectly efficient markets can secure a basic level of consumption for a very distant future, many generations beyond our own. Before we undertake this largely positive effort, it seems reasonable to inquire if there is any ethical reason why we should care about the distant future. If we establish that we should care, we need to justify the relevance of our positive approach.
Particularly we should be concerned, we need to show why we wouldn’t recommend policies that directly implement moral principles and forego our positive study. That is, while our concern is relevant, our strategy to investigate this concern as an economic question may be irrelevant.

If several well developed, competing value theories each in their turn wholly resolve our obligations to the future and can completely dictate current savings and production decisions, then the core of the sustainability debate shifts from economics and ecology disciplines to philosophy and centers around these well defined competing value theories.

In chapter two we find the state of affairs in the discipline of ethics unable to suggest a well defined set of moral theories. Yet there are sufficient grounds that enable us to adopt two very general moral heuristics. These motivate us to take seriously the implications of our actions on the future but provide only limited specific guidance. So there may be a unanimous demand for policy action but no unique action to be identified. We may want to know generally how well consumption is sustained without a policy intervention and may be able to justify intervention only when the future looks much worse than the present. That is unsustainable consumption in which future consumption is merely lower may not motivate a policy response while a conservation crisis may be severe enough to unanimously warrant concern.

Without a detailed social objective to regulate a savings
production rule, an essentially positive investigation of the stewardship prospects implied through unregulated markets is justified as a relevant and legitimate exercise at the very front of the current sustainability debate. This motivates a search for a simple economic model that can adequately characterize changes in the consumption opportunities available to agents through time.

We start with an observation that man-made capital, natural resources and human population are produced, grown or born and consumed, harvested or die respectively in any time period. Agent consumption prospects are determined by the relative magnitude of these stocks available in any period. Therefore it is the transfer and delivery of these stocks from one generation to the next that defines the fundamental social phenomenon behind sustaining future consumption prospects. Any economic incentives that stimulate the terms of these transfers form the basis of a relevant macro-economic model of sustainability.

If adjoining generations have different consumption prospects, if generations overlap and if those overlapping generations trade productive stocks, then this trade is central to a model that aspires to appraise the role of the market as a steward of material wealth for the future. In chapter three we find current models of economic growth fail to fully specify the economic incentives that directly motivate the production/ creation and transfer/ delivery of
productive stocks between generations. Since transfer of assets by trade between adjoining generations is not incorporated in current growth models, these models cannot adequately address the very long run sustainability concern. In chapter four we develop a model that fully specifies these markets.

The model specifies the sale of productive assets between generations as the primary method of intertemporal asset transfer. The young purchase assets from the middle-aged in every period in our model. The model also considers the economic responses of human reproduction to levels of wealth. Inheritance is introduced though it is not assumed to evolve from agent centered altruism to the future; and a resource regeneration function is introduced. All of these are accounted simultaneously.

It is through this model that we are able to pose a relevant conservation question in chapter five to address our skeptic's reservations regarding market directed natural resource policy. However the conditions under which perfectly informed agents might exhaust a renewable resource necessity and devastate future prospects has implications for conducting policy that may counter many of the skeptic's intuitions.

Naive concerns about discount rates are replaced with a more considered vulnerability of the physically unrepresented future agent to the current trade of living agents. Yet we
find that this vulnerability may or may not result in injury to future consumption prospects relative to present consumption prospects. The iterated effect of an expected long sequence of anticipated future asset sales may sufficiently reward present savings and result in greater future consumption prospects relative to those of the present.

There are powerful self-enforcing incentives inherent in our modelled economy that benefit stewardship goals. These benefits undermine the simplistic charge that efficient market outcomes are endemically myopic and destructive to future interests. It may surprise our skeptic that these benefits exist even though our self-interested agents possess only finite (life-cycle) planning horizons. The implications of policies that fail to acknowledge these inherent strengths are discussed in chapter six.

Nonetheless a legitimate conservation question exists; and we cannot confidently presume a single coherent planning objective to resolve our moral duties in formulating policy. Simple moral heuristics are enough however to justify policy initiatives that seek to mitigate only very generally accepted bad outcomes – such as exhaustion of an essential resource.

Using the developed economic model as our guide and cautious not to overstep legitimate moral authority, we find that the Safe Minimum Standard (SMS) has some very appealing attributes. In chapter seven we reinterpret this classic policy instrument to fit our considered conservation question
in the context of a resource necessity. We find that the SMS is a robust policy instrument; and we broaden the practical scope of the policy beyond the original SMS defense.

Early warning conservation efforts initiated before an immediate threat to the minimal carrying capacity of a renewable resource are rationalized by a logical extension of the SMS. In our case the safety standard is set to assure minimal resource use at a cost not intolerably high to living agents. This assurance may require immediate efforts long before actual resource extinction is upon us in order to circumvent an intolerably high cost of adherence later. These early warning efforts may include of course direct reductions in resource harvests; but they include other initiative as well. Such strategies as targeted research and development or population control are two examples offered in the text. The SMS developed that protects the resource necessity offers more policy latitude than the simple resource use moratoria inferred from early developments of the SMS; but it also requires more attentive resource management.

OBJECTIVES

OBJECTIVE 1

The first objective of this study is to review literature in philosophy to determine if there is a coherent moral theory which derives positive obligations to the future.

We establish the legitimacy of two heuristic moral principles to guide our obligations to the future showing that
no fully coherent value theories have yet emerged on this subject.

**OBJECTIVE 2**

The second objective of this study is to critique the two most popular economic growth models for their adequacy to specify from micro-economic principles the process by which productive capital is transferred between the generations.

We demonstrate that prominent growth models do not fully specify the economic incentives considered fundamental to the question of very long-run sustainability.

**OBJECTIVE 3**

The third objective of this study is to offer a model of the economy that specifies the incentives that induce the transfer of asset stocks between overlapping generations.

Such a model is developed to plausibly assess long-run sustainability. Overlapping generations are on opposite sides of asset market transactions with young demanders and middle aged suppliers. Demographics and long term trends in wealth directly affect the supply and demand schedules for productive assets at any moment; and these transactions determine future consumption prospects.

Population growth responses to agent wealth are endogenized. The regenerative process of renewable natural resources is included and an aggregate production function is specified. So the first order optimality conditions that generate period by period supply and demand schedules for the
markets that transfer productive capital between generations endogenously - simultaneously - depend on all of these considerations. These considerations form the general equilibrium conditions that ultimately determine long-run sustainability in our model through efficient market trade.

**OBJECTIVE 4**

The forth objective of this work uses this model to investigate if a legitimate conservation question exists. Specifically we inquire if it is indeed possible through fully efficient market trade to exhaust a valuable renewable resource. This resource is at least partly substitutable by man-made capital but its exhaustion means the welfare of future generations is uniformly diminished.

Considering reasonable biological resource renewal processes for our resource renewal function, non-convexities are introduced into the agent choice set that can induce the exhaustion of an essential renewable natural resource even though all market efficiency criteria have been satisfied.

**OBJECTIVE 5**

The fifth objective of this study is to use the model to investigate the adequacy of two proposed solutions to the conservation question found in the literature. These proposals are:

* Reduce discount rates to reduce current Natural Resource Extraction.
* Assign property rights over current resources to the
succeeding unborn generation in every period to assure the distant future veto authority over current savings and production decisions.

Both proposals are unlikely to adequately resolve the conservation crisis that could arise given the conservation question that we have admitted into the sustainability debate.

**OBJECTIVE 6**

The sixth objective of this study investigates the effectiveness of a Safe Minimum Standard (SMS) program to answer a legitimate conservation concern.

We revisit the SMS and conclude that it is a rational conservation policy. The SMS presented evolves from an acceptance of our simple heuristic moral principles and the conservation question posed. The SMS is reconsidered in light of the specific conservation question introduced and is extended from its original articulation in the literature.

A single chapter is devoted to each of these six objectives. Chapters two through seven outline the structure of our argument. The argument begins with a justification for exploring the ability of markets to provide for future generations from a largely economic view through the recommendation that society is at least justified in pursuing economic efficiency subject to a safety standard that affords special protection to essential natural capital. Chapter eight is devoted to a synopsis of this argument and offers suggestions for follow up work on this subject.
Chapter II

OBLIGATIONS TO THE FUTURE

Our objective in this chapter is to warn the economist interested in the sustainability question against identifying a planning objective for an economic model that directly articulates a complete moral theory to manage our obligations to the future. As argued below the value theories that enjoy currency among ethicists are not adequately formulated to coherently identify a set of principles to resolve our obligations to the future.

The problem is beyond a lack of professional consensus among philosophers. The very nature of our obligations to potential persons, we argue, is far from adequately addressed in any of these moral theories except those that deny such positive duties exist at all. The core epistemic assumptions, views about what is known and can be known, that currently justify our obligations to existing agents in contractarian or utilitarian theories are not robust enough to include our concerns for potential persons. Prominent moral theories need to be extended in some fashion. But we argue that simple 'extensions' will likely conflict with the very epistemic assumptions used to defend the moral theory in the first
place, throwing us back to a total reconstruction of our epistemology.

This places the economist squarely in a position to defend on moral grounds a moral theory used to identify a planning object, such as a Rawlsian contract or a utility-based consequentialist theory. We cannot confidently simulate a social plan based on a number of established yet competing moral objectives and then defer to philosophy discourse communities. Rather in the current climate, the articulation of such an objective goes well beyond accepted existing theories and places the modeler directly into the disciplinary debate in ethics.

Indeed if such a consensus regarding the moral issues existed, the sustainability concern reduces first to arguing the fine points of philosophy. Then economists and scientists, well-versed in objective maximization, would be assigned to the engineering details. However given the likely stalemate among ethicists, we suppose a resource manager (planner) must adopt some simple moral heuristics to guide her efforts. That she manages without a fully specified objective essentially justifies this exercise.

Unable to wholly justify dramatic intervention into the process of economic activity, our manager desires at least to
monitor the implications of efficient markets. If markets themselves suggest a future no worse than our own, our manager may hesitate to adopt any special efforts on behalf of the future in managing natural resource use and conservation. If future prospects seem poor or if certain alarms of a much worse future are sounded, our manager will likely entertain some conservation proposals. Again without a well-defined objective to uniquely regulate all economic activity, if market forces normally embed protections for the future that can fail in some circumstances, our manager will likely adopt policies that respect economic incentives and act on the economy in a very limited and specific fashion.

We identify certain scenarios where an unwanted resource exhaustion can indicate a very poor future even though all markets efficiently clear. The model suggests two complementary sources of this event: the natural process of resource regeneration and the response of population growth to individual wealth. Our moral heuristic typically justifies intervention when the economy faces inevitable resource exhaustion with serious consequences; and these interventions are consistent with a more specific definition of the Safe Minimum Standard (SMS).

The entire work hinges in many ways on the argument that moral philosophy fails to offer a small, well-defined set of competing theories of value, each of which are internally consistent. Without the burden to act within a heuristic of
likely moral concerns, the manager could simply recommend the direct control of economic activity according to some specific principle. So we address in this chapter the hazards of adopting an 'off the shelf' moral theory.

The Manager's Concern

Let us consider a public resource manager charged with determining resource policy. The manager, well versed in objective maximization, may hope to adopt directly a moral theory as her guiding objective. With this simple objective she can exactly resolve conflicts between conservation and production versus resource extraction and consumption.

The manager's decision environment, of course, presupposes an available objective. This chapter contends that philosophy has not presented our manager with an objective that reveals a disciplinary consensus.

Still our manager is charged to decide even though no single comprehensive objective is identified. She must try to adopt policy rules and procedures which are likely to be acceptable to plausible moral theories that define our duties to the future. This chapter concludes with a submission of two very general guiding principles that comprise a moral heuristic for our manager. Yet the principles are so general that the manager feels unjustified in acting positively unless the principles are dramatically violated by the scope of economic activity.

The remaining chapters consider how we might appraise the
adherence to these general guidelines and what policies may reasonably conform to these principles.

**Epistemic Assumptions and Ethics**

To motivate the warning to our manager, we critique moral systems most familiar to economists and their basic value assumptions.

Economists are probably most familiar with utilitarianism (Bentham, Mills and Sidgwick) and contractarianism (Locke, Nozick, Rawls and Gauthier).

Utilitarian theories value the consequent outcomes of an action. For instance, actions that maximize utility among social agents constitute what is good. For this reason, utilitarians fall under so-called consequentialist moral theories.

Contractarians on the other hand are not teleological, or consequence motivated. Rather they fall under so-called deontological moral theories that presume justice is that which emerges from just *processes*. Specific consequences are irrelevant. What is just to a contractarian is only that which people unanimously agree to under specified ideal conditions - the just original position.

The point of departure between consequentialist and deontological theories centers around their essential epistemic assumptions. These assumptions help to expose the
challenge of resolving duties to future generations.¹

Kant identifies intuitions and conceptions as distinct components of the class of things we know (Kant, 1793). His own principles of ethics favor conceptions as the only practical form of cognition. Intuitions are theoretical, useful for geometry and mathematics, and are therefore essentially tautological. It is the transcendental logic of conceptions that generates practical principles of ethics. The outcomes are simple imperatives, rules for resolving problems of a particular type or category identifiable a priori. Hence Kant's famous categorical imperatives.

The derivation applies basic inherent reason to our experiences. Only principles that unambiguously filter experience through Kant's reasoning process produce conceptions that can be considered true or just. All other notions of truth are unwarranted metaphysical speculations or mere empiricism. The filter, however, will unlikely let us piece together a holistic puzzle of a single over-arching Truth. Rather true inviolable facts or imperatives (components of Truth) are all we can legitimately define. Clear and direct rules alone legitimize processes to define our moral duties.

Consequentialists disagree that intuitions about moral

¹ This distinction is really too general. A more modern dichotomy separates deontological rules from axiomatic criteria of which consequence evaluation is one axiological system of moral value (Vallentyne, 1984).
good are mere tautological exercises with no prescriptive content to guide the moral agent. Good is more objective, they argue. A classic example illustrates this rift in epistemology.

A murderer pursues an intended victim, sure that you know the location of the victim. An imperative that bans lying means you are not exculped from misleading the murderer away from the intended victim - Kant’s own example.

Consequentialists decry this over-restricted view of ethics. Surely, the consequentialist argues, our objective intuitions about right and wrong suggest that lying to the murderer is a small cost to a value that respects truth compared to the substantial contribution to good by avoiding this violation to another value that respects human life. However, this does not define an absolute rule such as: respect for human life always trumps respect for truth. At some point a threat to our object respect for truth may justify the loss of human life. This of course is the type of relative consequence maximizing Kant wishes to avoid.

Both deontological and consequential moral theories are motivated principally by issues of moral obligation among co-existing agents. Considering potential future agents may not challenge the fundamental assumptions that separate moral theories. Yet this different type of agent interaction must at least be addressed in delineating a theory of value. We pose the following concern. Can we extend contractarian or
utilitarian theories to define positive obligations to the future without evoking principles that undermine the fundamental epistemic assumptions used to rationalize those theories?

**Contractarian Problem**

Kant outlines the essential contractarian argument in the *Metaphysical Elements of Justice* (Kant, 1797). The categorical imperative assumes a just Public Law is one that originates from rational agents who unanimously agree to judicial terms under idealized initial conditions. Interpretations of Kantian ethics have been wide enough to include Nozickian and Rawlsian contracts as well as non-contractarian moral systems. Not all deontological, including contractarian, moral theories developed by Kantians admit positive duties to the future (Delattre, 1972). If ethics is about our obligations to persons we encounter, then ethics applies only to rules of engagement between actual persons. Future persons may not qualify as agents eligible to make claims on us. The practical reasoning of the imperative, these theorists argue, can derive no positive duty to the future. Lockian style contractarians including Nozick represent this position.

Lockian contracts allow the agent to know her identity in the ideal original position (Locke, 1690). Therefore self sacrifice required to protect the future cannot be generated. Real harm to a contracting agent could not be rationally
accepted by that agent. Barring a creative extension of Locke's discussion of the obligations regarding children or Nozick's proposals for bringing children into the State, no explicit obligations to the future are derived. We assume our resource manager rejects this minimalist conclusion.

Contractarians that remove the agent from knowledge of their personal identity can admit positive obligations to the future. A Rawslian contracting agent, veiled from the particular knowledge of personal identity in the ideal contracting position, may be personally motivated to a future in which she may in fact exist. The rational response to this uncertainty (extreme risk aversion to Rawls) defends obligations to secure basic levels of welfare for the future through an idealized unanimous consent process (Rawls, 1971).

There are problems with this Rawlsian solution to potential persons. Extreme risk aversion suggests that all possible states in which an agent could exist correspond to a relevant potential person. For instance, if the future is expected to be better but there is a risk, however remote, that our actions could result in a worse off future, the Rawlsian contract obliges us to refrain from those acts, taking seriously the potentially worse off agent representing this remote possibility. It is not only extreme risk aversion that generates this problem. As we relax the extreme risk aversion of Rawls' Difference Principle to simple relative risk aversion, we moderate but do not eliminate this problem.
This is why Rawls wants the agent veiled from particular knowledge of self - not from general certainty about the state of the world.

The considerable uncertainty about future prospects will almost certainly imply considerable sacrifice by the present under the contract. The range of future contingencies is so vast that the present may commonly be the worst off generation. Even further, the scope of uncertainty can reasonably be so severe that the contracting agents face real or absolute scarcity.

Current agents may be deprived initially of a certain basic minimal standard of living in order to secure all contingencies according to the Difference Principle. This possibility challenges the Humian condition of justice (Hubin, 1976), widely accepted as a precursor to any just original position, making the contract impossible to implement.

This leads to a more fundamental challenge. The present may decide not may to bring about the future agent to avoid an apocalyptic future. This option, perhaps an a priori right, of the present competes with the rights of the contracting agent from a future generation to exist. The entire extension of the Rawlsian contract to include potential future agents begs the question: Who has the right to sit at the bargaining table?

The Rawlsian veil itself cannot resolve this question. Perhaps another Kantian conception and its resulting
categorical imperative could be grafted onto Rawls' theory; but the conception of who has moral standing is a non-contractarian question. This question is logically antecedent to the contract and cannot be derived from it. In this way the Rawlsian contract must be extended or amended by a non-contractarian principle.

Since resolution of future uncertainty comes only at a time when the some contracting agents can no longer alter their actions, the set of contracting agents cannot be availed upon to reconcile the unfortunate state of affairs. Adding logical concerns that the Humian conditions of justice may never be satisfied in a Rawlsian contract that admits agents from future generation, future agents may reasonably lie beyond the scope of contractarian theories of justice.

Positive concerns for the future, derived from these other Kantian rules will have to be ordered against the value of the contract. If positive duties to the future are assured and if these duties emerge from non-contractarian principles, it must be true that these duties trump contractarian concerns. This minimizes the relevance of contractarian concerns for the future.

On the other hand, some resolution of which potential future agents are admitted to the contract lets the Rawlsian contract regulate duties to the future. But we have to inspect the justifications by which some potential futures constitute legitimate contract signators and some do not. The
reconciliation these concerns may be axiomatic. Admission of a future agent to the contract may depend on current conditions, the degree of severity of potential catastrophes relative to current welfare, the desire of agents to bear children, et cetera. These relative conditions used to admit contracting agents are not categorical. In this case the intuitional basis for ethics rejected by Kantians becomes the vehicle for implementing concerns for the future. This also erodes the contractarian justification for deriving positive obligations to the future.

Such an amendment calls into question the very possibility of a deontological moral imperative to resolve our duties to the future. Relative trade-offs may be unavoidable in order to articulate any moral principle if we admit the future as a legitimate concern. The contingencies may be so overwhelming when we consider the dynamics of an infinite future that any agent action could only be evaluated as conforming to a set of objective principles, reducing to a maximizing appraisal of value benefits to value costs.

More importantly for our manager the prospects for a stand alone contractarian value theory need to overcome considerable challenges to the epistemic assumptions that initially rationalize the theory if the contract itself is to reasonably inform our obligations to potential future persons. The economic modeler who undertakes a Rawlsian contract as an objective for intergenerational concerns cannot rely on
standing defenses for their position. Rather the modeler must resolve the issues raised above with the burden to defend the objective proposition directly.

With this review under our belts the consequentialist critique, faced with the same set of questions, is a bit quicker.

**Utilitarian Problem**

Utilitarians also have difficulties with potential persons. The problem reduces simply to what we might call the 'Quagmire of Utilitarian Arithmetic'. That is our utility maximizing resource manager, charged to create the Greatest Good for the Greatest Number, can now require the creation of both Great Good and Great Numbers. Initial efforts to work around this paradox failed to derive a theory consistent exception to the utilitarian arithmetic (Sikora, 1977).

Surely we can imagine values that resolve this impasse. Some trade-off between average utility (a single well endowed agent) and total utility (many poor agents) must exist. Yet the value must be a non-utilitarian value. Again articulating this new value logically precedes the delineation of the basic utilitarian morality.

Utilitarians face the same two challenges as contractarian theories. This non-utilitarian resolution to concerns for future generations may dominate moral concerns for the future, making the resulting utility calculus largely irrelevant to evaluating actions to benefit the future. Also
the resulting theory of value begins to lose its immediate intuitive appeal, challenging the consequentialist epistemology that fundamentally rationalizes utilitarianism.

Sidgwick employs a simple axiom. Since we care about that which people aim, we ought to optimize that for which agents aggregately aim. Yet when we introduce obligations to potential agents and resolve choices targeting average or total utility or determine which agents ought to be brought into existence and how these considerations weigh against immediate value concerns, intuition becomes less defensible. The resulting trade-off may either reduce to mere empirical contingencies (rejected by nearly all ethicists ¹) or defer to a conceptually reasoned categorical imperative, undermining the entire consequentialist experiment. That is, arguments to resolve our obligation to bring about a future agent don't seem so intuitive.

We are concerned with the economic modeler who assumes the central planner's objective \( \int_s^u(c_t) e^{-r(t-s)}dt \), or \( \int_s^N_t u(c_t) e^{-r(t-s)}dt \) where \( N_t \) are the number of agents living at time \( t \). If the objective defines a normative goal, that modeler must respond first to the moral content of her claim. On the other hand, the utility based objectives may be simple shorthand for the modeler to characterize how an economy operates and

¹ Empiricists or positivists in philosophy of science are unlikely to grant much latitude to ethics as separate from theology or metaphysics. So an ethicists typically emerges from other epistemic positions.
constitute only a positive statement. That is, in the short run at least, the outcome of an efficient economy may be equivalent to the maximization of a discounted utility stream.

We encourage the modeler to clearly specify which rationale justifies her objective. We have strongly criticized the normative justification of a utility objective when it is used to address very long run sustainability. In the next chapter we critique the limits of a positive motivation for a utility based model to address the sustainability question.

Again the problem of the ethical demands of potential persons strikes at the core epistemic position of value theory.

The Manager's Slippery Slope

The problem of positive obligations to the future is not a simple unresolved puzzle in ethics. Rather it is a core concern, generating a reason for challenging ethics at its most basic epistemology - how can we know what is good.

The economic modeler concerned with sustainability cannot directly adopt either a utilitarian value theory or a consequentialist value theory without admitting at least some non-utilitarian or non-contractarian value to resolve our moral attitude toward future potential persons. These theory extensions may so dominate the moral calculus that the utility or contract based principles become irrelevant. Even more damaging, a reasonable resolution to this issue may force one
of the theories into an epistemic inconsistency: contracts may realize consequential justifications for defining agents eligible for moral concern, utilitarians may find only categorical principles can regulate our competing concerns for the future and the present.

The discipline of ethics is not well rehearsed on this issue. Our prominent moral theories have only really begun to incorporate the issue of potential persons into the scope of inquiry, presumably because for the first time the modern world makes the question relevant. The issue requires a lot more work before we can begin to intelligently and securely take strong positions on this issue.

Surely this leaves our resource manager in a very dangerous position. She cannot legitimately pull a complete moral theory directly off the shelf. Even well defined moral theories fail to detail how to consider the future. To work directly from a complete social objective, she must literally derive a theory of value resolving core issues in moral epistemology on the way. Given the paradoxical problem outlined above, this is certainly a slippery slope.

Implications for the Economic Modeler

Instead the manager may seek a set of plausible general principles likely to conform to moral theories that will generate positive duties to the future. Two values toward these moral heuristics are suggested.
First, the existence of future humans is valuable, but it is not a pre-eminent value. The end of human existence while an extreme concern must be over-ridable by some other principle at some point. At some point we cannot require agents to create the future if the act imposes some horrendous burden on those existing agents and/or creates horrendous conditions for those future persons. This leads to our second value. The welfare of future humans is valued, but this welfare is realized by the actions of the present with valid moral concerns within its own time.

There is no claim to completeness of a value theory. Rather a plausible moral theory, deontological or consequentialist, that generates positive duties to the future would likely admit these two concerns.

Armed with only these vague heuristics our resource manager will be sensitive to actions that generate irreversible circumstances. Elimination of human existence, exhaustion of resources that may be necessary to sustain human welfare or any act that could create an impoverished future yet leave the future little or no room to manoeuvre to move out of the impoverished state will certainly concern our manager.

The economic modeler, or resource manager, has no uniform principle to centrally control economic activity. Nonetheless, there are relevant reasons to monitor activity and to justify interventions to avoid irreversible
consequences offending our general value statements.

To monitor our economy requires a model flexible enough to address our question. Concerns for the future are very long run. We require a modelling framework that at least considers the ephemerity of any partial equilibrium condition (especially prices) and allows all relevant aggregate economic decisions to change according to agent based incentives.

Such a general model will likely elude empirical application. Nonetheless, returning to core microeconomic theory based models of an economy may help us expose vulnerabilities in an economy that endanger our valued concerns. The model may also assist our general understanding of policies that can defend these concerns.

The next two chapters argue for a modelling framework that allows sufficient flexibility to discuss and appraise the degree of success of our society in conforming to moral concerns about the future. The two following chapters use that model to identify circumstances likely to require policy intervention and interventions likely to be effective.
CHAPTER III
Growth Models

This chapter evaluates several noted economic growth models in terms of their applicability to the issue of long run sustainability. The question would seem a little surprising were it not for the fact that sustainability has seldom been a central issue in growth modelling; the central issue typically concerns the business cycle.

Sustainability research in economic growth models is really interested in the mechanics of transferring productive assets from one generation to the next; followed by an investigation of the implications of that transfer on the welfare of distant future generations.

So in order to evaluate the selected growth models, a set of modelling criteria are identified that we consider relevant to the sustainability question. Explaining both savings and investment decisions directly from the agent optimization problem is presented as central to any concern about future welfare. Therefore we judge the salience of selected growth models especially by their ability to explain savings and investment decisions directly from the agent’s objective.

Three selected incarnations of growth models over the last half century are critiqued: Harrod-Domar Models; the
Issues for a Long Run Model

If sustainability inquires into the transfer of productive assets between generations and the implications of that transfer on per capita future welfare, then the behaviors to accumulate and transfer wealth between generations, the behavior to create future generations and the structure of the agent objective are the crucial social science questions regarding sustainability.

As economists it seems natural to draw out the collective implications of self-interested agents rationally pursuing their individual interests. With respect to sustainability then the economic modeler wants to explore the behavioral incentives of production, consumption, savings and investment decisions derived as much as possible from the statement of an individual agent's objective.

Then of course if the fundamental incentives to accumulate and transfer productive capital between generations involve trade between agents, we want to generate both the supply and demand schedules for those markets from agents' objectives. The dynamics of these markets may imply that the quantities exchanged and the prices of the productive assets exchanged differ systematically from period to period. Since these markets affect the accumulation and transfer of productive assets between generations, large price and
quantity changes in the asset markets that transfer wealth between generations will also concern an economist interested in sustainability. It is important that these changes be tractable directly through optimal behavioral responses.

The savings/investment decisions are central to our question; Does the economy generate sufficient incentives for agents to leave adequate stocks for the future?. Simple endogeneity of a pre-specified aggregate savings function is not enough, particularly if savings is affected by trade in a capital asset market.

Given the prominence of the decision to save and to invest productive assets to the sustainability question, we want to minimize the mechanization, or prior specification, of these economic responses in a model. We want to avoid characterizing either the aggregate savings rate or the investment decision as a simple function of other economic decisions and isolate it from the agent’s optimization problem.

We also note that the existence of future humans and the welfare of the representative agent concerns us. Therefore the dynamics of population growth should be addressed in the model as well. If population changes respond to an economic phenomenon such as wealth and if population dynamics itself is essential to the determination of aggregate and per capita economic output, then population growth should be endogenized into the model.
We also want the description of the agent’s objective to be theoretically reasonable. Agent preferences should reflect the basic rationality criteria of reflexivity, completeness and transitivity as well as plausible preference behavior such as monotonicity and convexity.

Finally technological improvement is a consideration for sustainability. If technological change requires investment of goods and services, then it becomes an economic choice variable as well. The Solow model and to some extent OLG models are able to appropriately endogenize the decision to invest in research and development. Therefore technological change is left out of the critique and the development of the economy in the next chapter. We will briefly return to this issue at the end of the work to demonstrate the capacity of the model developed to incorporate investment in research decisions. This later discussion will hopefully add some clarity to the discussion of technological change generally into the sustainability debate.

A plausible model of the economy developed to address the sustainability question should be able to address each of these issues directly from basic micro-economic principles. The three growth models critiqued fail in some material way to determine a critical decision relevant to sustainability. The savings/investment decisions are addressed in these models in a fashion that may seem quite reasonable for investigating economic dynamics over a short time horizon; but not for the
time horizon often relevant to the sustainability question.

**Harrod and Domar Models**

Although Ramsey's economic model was published in 1928 (Ramsey, 1928), the first serious professional notice of growth models occurred at the end of the Depression with Harrod's 1939 (Harrod, 1939) article and after WWII with Domar's 1946 (Domar, 1946) work. Each work intends to explain the Great Depression and the sequence of serious recessions in the four decades preceding the Depression. Both authors model a disturbing natural failure of capitalist markets to sustain welfare over time.

Harrod initially defines the identity:

\[ G_w = \frac{s}{C} \]

s is the fixed savings rate for the economy; C is the productive value of capital goods required to produce a unit of output; and \( G_w \) becomes the equilibrium or 'warranted' rate of growth in output for the economy given s and C. However this equilibrium rate of economic growth, according to Harrod, is unstable.

He offers the following example.

If the savings rate (s) is exogenously fixed, then the assumption of a perfect input complimentary production technology is sufficient to evaporate any prospects for self correction in the economy.

If the economy happens to over-expand making G too large relative to \( G_w \), then C is too small. This means that there
has been too small an increase of capital goods per unit of output and available labor in the economy. This shortage will heat up demand for productive capital. This further fuels the over-expansion of G. Similarly, a slow rate of growth in output below the equilibrating level depresses the investment incentive and the economy indefinitely contracts.

The model relies on very naive expectations structures. Investment decisions, how much capital is demanded, and savings decisions, s, are entirely separate from any expectation regarding the return to capital next period - a very strange investment strategy.

Domar's model is similar. Domar focusses on deviations between the "potential average investment productivity" described as: $Q = \frac{(dP/dt)}{I}$ and the rate of potential final value added investment to the annual amount invested, s. P is the level of productivity and I is aggregate investment.

If the chosen level of s, delineated in capital units, is either too large or too small for labor on hand, unemployment of either capital (too much s) or labor (too little s) will result.

A fixed coefficient technology assures that such a disequilibrium cannot be corrected in the period. Therefore productivity loss is assured in every period unless savings happens to be exactly equal to what is tolerated in the market.

Naive expectations about the future and no
substitutability between inputs assure that future losses can not be anticipated and that agents have no latitude to respond and minimize the impact of loss within the period.

These models pose a terrifying prospect if their modelling assumptions actually hold in an economy. It seems almost certain that capitalism shakes apart with its anarchical, unstable decentralization; but the implausibility of their modelling assumptions launched modern growth theory. The profound insight of the initial reply to Harrod and Domar was so important that it was recognized by the Nobel committee in 1987.

**Single Agent Ramsey-Solow Models**

The lack of input substitutability between capital and labor in these early models was challenged by Solow in 1956 (Solow, 1956). Solow cites substitutability as the primary motivation for his seminal piece. The aggregate production in the Solow economy is modelled by a constant elasticity of substitution (CES) function rather than a Leontief, fixed coefficient production technology. Therefore the lack of productivity of the excess input found in early models does not occur.

Though not acknowledged directly in the article, Solow in fact introduces rational expectations (when there is random variation) or perfect foresight (when there is no random variation) into his model. The anticipation of expected capital needs next period is accurately reflected in current
capital prices. This embedded modelling assumption helps to resolve the crippling market assumptions of inadequate savings levels in the Harrod and Domar models. If savings is too small, expected high future prices for capital will induce savings today. Similarly over-savings can be avoided by the expectation of low capital prices.

Solow posits a single representative agent in the economy. The representative agent is a self-employed productive family that exists through the generations. So our agent has an infinite planning horizon as well as prefect foresight over which she maximizes consumption by planning a consumption and investment stream. Solow builds his model by borrowing the Ramsey economy objective function presented in 1928, which posits an infinite horizon economic planner wishing to maximize the utility of per capita consumption through time. The optimand in the Ramsey-Solow growth models is:

\[
\text{MAX } U_s = \int_s^{\infty} u(c_t) e^{-r(t-s)} dt
\]

Solow constrains this objective by the CES production function and endogenizes the movement of the relevant stock identities in the economy. One form of the modelled economy is given below:

1. \(\frac{dk}{dt} = s*f(k) - nk\)
2. \(k = K/L\)
3. \(L(t) = L_0 e^{nt}\)
4. \(F'_{L} = w \text{ and } F'_{K} = r\)
5. \[ n = n(C) \]

6. \[ \frac{F}{L} = \frac{(AK^nL^{1-n})}{L} = f(k) = A^*k^n \]

7. \[ s = s(k) \text{ and } c = f(k)(1-s) \]

K is capital, L is Labor, k is per capita capital, n is population growth, C is agent consumption, f is per capita production and s is savings.

Equation 1 is the fundamental equation of growth: next period’s per capita wealth is determined by the percentage of today’s per capita output saved less the percentage increase in population pressure on per capita capital. Equation 2 defines per capita stocks, k, as aggregate stocks divided by population; and equation 3 defines aggregate population growth.

Following these identities, equation four assumes the equilibrium conditions: marginal labor productivity and capital productivity equal the price of the input. Equation 5 links relative population growth with the level of agent consumption. Equation six allows the capital/labor production function to be aggregated as a single input and described in per capita terms. This is because "f" exhibits the properties of CES and CRTS from a Cobb-Douglas functional form. Finally equation seven associates the rate of agent savings to the level of on-hand agent capital, or wealth, and identifies consumption as total production less savings.

The problem statement at least includes the important ingredients of a long run growth model. A monotone, concave
utility function defines the agent's objective. Production and the role of savings are endogenized. Population growth is defined. Prices are set to their marginal productivity levels and may change from period to period.

Note that the above is a perfect foresight version of the model. In a later paper, Solow (Solow, 1957) introduces uncertainty in production, presumably from variations in the rate of technological discovery, to estimate the local stability of the macro-economy. This is probably the first rational expectations model of the macro-economy formally presented though the implication is largely suppressed in the work.

The implications for economic stability are much more encouraging than the world Harrod and Domar present. Steady-state solutions for k and steady-state consumption can be defined by the simultaneous solution to the differential equations: \( \frac{dk}{dt} = 0 \) and \( \frac{dc}{dt} = 0 \). These steady-state conditions imply that the bounds for stable self correction of production / savings choices toward a steady-state are not infinitely narrow - distinct from the single stable point in the Harrod-Domar models.

Instability is still possible, but is often correctable with a one shot intervention. The latitude for the economy to be dynamically stable in this model emerges from the substitutability of the inputs.

The Single Agent Assumption
The principal difficulty with this model is that the savings function is characterized solely by the level of per capita wealth. The function $s(k)$ does allow the marginal savings rate to vary; but the entire economic content to savings is embedded in the functional form for $s$. $s$ reflects an internal optimization by the representative agents to save and invest and as such is determined outside of a market. Nonetheless we may well expect that some households are net lenders (savers) while others are net borrowers (investors). Therefore this mechanistic specification of savings obscures any intergenerational trade that may affect asset movements between generations.

It is true that random differences between agent endowments in the Ramsey-Solow economy can permit trade in a capital market; but these differences are not structurally relevant to the transfer of assets between generations. Introducing trade in a single agent economy emerges only from random differences in income among existing agents. The differences are not systematic in the model. This allows the representative self-employed agent economy to be a reasonable modelling simplification, ignoring trade in asset markets completely.

It seem implausible that the single agent model is useful for describing movements in the economy across generations. Agents are not infinitely lived. They may not possess an infinite time horizon consistent with the Ramsey optimand.
Certainly productive stocks are purchased by agents with the expectation of future capital sale.

If capital at retirement is sold to a younger agent, demographic changes are no longer neutral across the economy. Relative population sizes between agents through their life-cycle have a systematic effect on the relative distribution of productive stocks (wealth) between age groups. As agents enter productive life, they purchase capital inputs. If there are proportionally more future agents, this expands input demand to the benefit of the sellers and the individual detriment of the buyers. Similarly a decline in relative population allows buyers to 'bid' down prices, reducing individual surplus to sellers. Therefore there are definable differences between capital demanders and capital suppliers beyond simple random wealth differences; differences that affect the decision to save and to invest. The position of an agent in their life-cycle places the agent on a different side of the capital market and identifies a systematic difference between agents that is generation specific.

Over several generations these differences are clearly able to determine the level of investment and the scarcity of capital. The economy of finite lived agents with finite time horizons trading productive capital with overlapping generations moves away from the Ramsey-Solow economy. This determination of savings and investment is likely to differ significantly from a uniform s(k) function to define the
investment level from per capita wealth because the relative demographic mix could yield very different quantities of assets transferred to the future for the same absolute magnitude of on-hand per capita capital.

Investigating the transfer of assets between generations through trade should show a relation between interest rates and demographics. If on the other hand interest rates are determined in markets with savers and borrowers distinguished only by random income differences, then the simple relationship between wealth and the price of capital should be estimable.

The historic difficulties in estimating the relationship between wealth and interest rates are attributable to a number of reasonable difficulties: defining "real" interest rates, defining "real" GNP, correcting for expected and unexpected technical change, measuring wealth et cetera. But the difficulty in estimation may also be due to the fundamental structure of capital markets. Young investors demand capital along a marginal rate of transformation of capital into output schedule, and older savers supply capital along a marginal rate of substitution in consumption between time periods schedule. If this occurs, a regression estimation between interest rates and GNP comprises a classic misspecification problem, ignoring that the data reflect period specific equilibria between supply and demand.

If our hypothesis that demographics do significantly
affect the price of capital, then an observed surge in population ought to increase real interest rates as the more numerous generation enters productive life. This will then be followed by a decline in real interest rates as the same generation enters a period of middle age net savings. Correcting for technological change and overcoming considerable measurement error, this more basic specification problem may explain the difficulty in estimating interest rates consistent with the Ramsey-Solow specification of aggregate investment, \( s(k) \).

If one accepts that real interest rates have increased through the late 1970s and 1980s but have begun to decline in recent years, this is consistent \textit{prima facie} with the statistics on entry of first-time workers into the labor market and post-war demographics. Admittedly, demographic differences are unlikely to affect aggregate output in the short run. The modelling shorthand permitted by the single agent assumption was an exceptionally insightful tool in 1956. It established the general feasible existence of a dynamically stable macro-economy and could trace short run business cycles. Yet this shorthand represses much of the interesting behavior that drives the dynamics of the long run economy. If we are concerned with the possible erosion of agent welfare in the future, a full specification of the agent based incentives that deliver productive stocks to the future via market clearing conditions is required.
Two Agent OLG Models

The infinite horizon Ramsey-Solow growth model is inconsistent with life-cycle motivated agents. Overlapping generations models (OLGs) were designed to further detail the impact of various fiscal and monetary policies by accounting for systematic differences between agents based on an agent's position in her life cycle. The models were designed specifically as an alternative to the Solow model of the economy (Diamond, 1965).

The goal of these models is to better explain business cycles and to better articulate the impact of various fiscal and monetary policies on the scope of current economic activity. Considering the economic agent as motivated by finite life-cycle objectives, the OLG model can analyze the impact of the structure of social security, the transactions demand for money and especially the role of expectations in establishing prices and generating business cycles. Theoretically reasonable, the model also elegantly generates reduced form equations for the various economic decisions, making estimation of the economic parameters feasible.

The OLG model presumes an agent life plan (objective) defined by:

\[ \text{MAX } U(C_t) + (1-\Psi)^{-1}U(C_{t+1}) \]

subject to:

\[ C_t + s_t = w_t \]

\[ C_{t+1} = (1+r_t) s_t \]

where \( C \) is consumption by an agent in the \( i \)th period of life at time \( t \). \( \Psi \) is the rate of time preference, \( r \) is the rate of
interest, \( w \) is the wage rate and \( s \) is the quantity saved.

The initial application of the model was designed to detail impacts of macro-economic policies over the short run (which again may be decades). The model was not designed to answer questions regarding long run economic prosperity. The OLG economy has agents save, consume and produce in period one. They then consume savings in period two (sometimes they produce and consume savings). Capital is transferred to succeeding generations by bequest motives or through perpetual youth insurance schemes.

Savers and borrowers are not distinguished by generations. Rather in this economy savings and investment occur entirely among the first period agents. The existence of a labor market or a credit market simply means that among the young are workers and employers, household savers and entrepreneur investors. These distinctions may not be irrelevant in the determination of aggregate output, depending on the structure of expectations and employment contracts. However, the asset trading prospects of succeeding overlapping generations do not enter the economic decisions of agents.\(^1\)

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\(^1\)The OLG model that considers perpetual youth insurance schemes could be adapted to include changing economic opportunities. In these economies agents are able to secure up front capital out of expected life time earnings as a consumption hedge against early death. Premiums could change, reflecting changing future prospects. Nonetheless such an extension of the OLG model presupposes the changing price of capital through the generations. It does not substitute for a derivation of those changes and of the expectations by the present used to transfer productive assets to future agents by way of capital sales, loans or insurance premiums.
Random variation of a single aggregable agent in financial markets describes the current form of OLG models just as it does in the Ramsey-Solow model.

Similar to the Ramsey-Solow economy, Saving / Investment decisions reflect an internal optimization by period one agents. Period one agents as a group forego consumption to invest in their own immediate production. Any capital markets that do arise emerge only from random differences between period one agents. Period two agents of course are not active in the capital market as they are consuming already accumulated savings and (depending on the model) engaged in production in their final period of life. So capital markets continue to be largely irrelevant to final production and to savings decisions in current OLG models. An exogenous market interest rate (or pre-specified interest rate function) paying returns to savings is simply assumed.

The contribution of the second period permits a richness to the analysis of policy unavailable in earlier growth models. However we still have no intergenerational trade. There is no borrowing through early productive life to acquire capital, lending through middle productive life and ending with the consumption of retirement savings. Two generation OLGs have been used to address sustainability by Howarth and Norgaard (1990). However, as we will demonstrate in chapter six, the trace of production and savings is not derived in the model. The level of aggregate output is exogenously given
because the incentives that create a market interest rate paying returns are not modelled. This "fixed" output, or more realistically "fixed" price model allows the authors to conclude that altering property rights between adjacent generations assures protections for the future, a conclusion that erodes if overlapping generations exchange productive capital in asset markets.

One way to model this trade is to specify a three period life plan for the economic agent. We could also establish market asset trade between the first and second generations, if agents produce in both periods, a specify a model of equal complexity to that detailed in chapter four. Both forms, a two period and a three period life plan, rationalize the stylized fact that income increases through the productive years. The three period life-cycle however also assumes negative savings in the first and third periods with positive savings through the middle years, a principle feature of the original life cycle hypothesis (Ando and Modigliani, 1963). We need to model trade between overlapping generations; and the three generation OLG most directly captures the behavior that interests us in addressing sustainability.

Adoption of a three period OLG model now permits systematic differences between agents based on demographics. We can now identify first period agents as demanders and second period agents as suppliers of productive stocks.

We don’t do this casually. What we gain in theoretical
structure must be weighed against the costs of empirical accessibility. Nonetheless, the sustainability question for the economist must consider any critical market exchange between generations that transfer productive assets from one generation to the next as this is the core issue. Empirical accessibility regarding investigations into the welfare of far distant generations is bound to limit sustainability research. Given this limitation there is a particular premium on sound structural models with which to consider and discuss the sustainability question.

Conclusion

Three growth models have been critiqued. None of the models as constructed is adequate to address the sustainability question. Harrod-Domar models hoping to explain the inevitability of economic depressions succeeded in demonstrating that if production functions permit no substitutability between inputs and agents use only immediate unemployment statistics (labor or unused capital) to form expectations that instability in the economy will be the rule. This model was rejected because its assumptions are too rigid.

Ramsey-Solow models introduce both input substitutability and some expectation of changes in economic prices through time. The model convincingly demonstrates the potential for an economy to correct an off equilibrium set of prices, asset stocks and consumption levels - the purpose for which the model was developed. However the single agent assumption and
the infinite time horizon of the agent assumes a personal identification with the future that guarantees incentives to conserve resources for the future. So the model is considered inadequate for the sustainability question. We return to the infinite horizon assumption in chapter five.

Finally OLG model are considered to offer significant potential for addressing the sustainability question. A finite time horizon is assumed and a life-cycle motive is presumed. However the two generation life continues the limiting Ramsey-Solow single agent assumptions for purposes of sustainability by forbidding trade between overlapping generations to be a mechanism for transfer of productive assets through time.

The two modern growth models - Ramsey-Solow and OLGs - that enjoy currency in our profession are considered inadequate for explaining the long term prospects for the future from an economy regulated solely by market clearing conditions. This is because one important form of market trade is ignored. The exchange of residual capital assets set aside for retirement savings by the middle-aged is invested by the young in their productive enterprises. The young pay the marginal productivity of capital to secure these assets to the middle aged who then enjoy appreciation of value on the stocks that they deferred for retirement.

In aggregate this reduces to the young purchasing productive stocks at the commencement of productive life with
the expectation of selling off remaining productive stocks at the end of their productive life. This foreseen capital sale affects the current price of capital and the quantity of capital exchanged. The prospect of capital appreciation motivates decisions to regenerate productive stocks, conserved for anticipated sale at retirement. The exchange therefore presents an opportunity to improve individual welfare by direct trade between overlapping generations - a trade that directly impacts the behavioral incentives behind the movement of productive capital from the present to future generations. The trade is therefore essential to a coherent discussion of the ability of markets to provide for future generations. Adding a third generation to OLG models, consistent with the original articulation of the life-cycle hypothesis, resolves this issue. The next chapter outlines a structure of long run economy that incorporates this trade, drawing implications for the future from the incentives that affect equilibrium in these markets.

We don't want to separate the modern growth models from the purposes for which they are designed. A lot of simplicity is sacrificed with the introduction of overlapping generation trade to the models and little additional shorter run implications are likely to emerge. Yet it seems reasonable that longer run concerns can be explained from agent self interest by the extension of modern growth models to include direct intergenerational trade.
CHAPTER IV
A Three Generation OLG Model

Having introduced the advantages of a three generation OLG model to address the issue of sustainability, this chapter introduces an economy in which agents maximize utility over a three generation life-cycle.

First an argument regarding the incentives that make intergenerational trade likely is introduced.

Next the conditions of trade that allow resources to be transferred between overlapping generations are derived from the agent’s objective. Each component of the model is explained independently. These constraints on the agent objective are consistent with the requirements for a plausible discussion of long run welfare (or consumption levels) outlined at the start of the previous chapter. The structure of preferences, the process of production and population growth, and the regenerative capacity of renewable resources are all defined. Then the material balance identities for an equilibrium are identified to complete the general equilibrium in which productive assets are transferred through trade between generations.

The sustainability question delineated in the previous chapter identifies the concern that resources will not be
saved in sufficient quantities to secure adequate future consumption levels. The specific conservation question considered in the next chapter focusses on the exhaustion of a natural resource as the critical event that creates inadequate resource savings needed to sustain welfare. So in detailing the components of an economy that transfers resources between generations by trade, there is a particular focus on renewable natural resources.

The model herein breaks from the models critiqued (as these models were presented) by extending the process of production to include both capital and renewable natural resource inputs. It also breaks with many works that address renewable resources by including a natural resource that cannot be aggregated with capital. This pre-empts the imposition of over-optimistic properties regarding input substitution between man-made and natural assets (i.e. CES assumptions). Relaxing the aggregability assumption becomes important to the relevance of the conservation question posed in the next chapter.

Since it is considered important to include both renewable natural resources and man-made capital inputs into the production function, the natural process of resource renewal is addressed in the delineation of the model. The form of this natural process turns out to be very important in establishing the relevance of the conservation question posed in the following chapter.
Finally this chapter notes that solutions to this equilibrium do not determine that consumption will increase or decrease through time. The steady-state conditions specify a set of simultaneous equations. Using the steady-state conditions to represent the future, long run per capita asset holdings can be greater than or less than current holdings. Even the addition of endogenous technological change cannot assure consumption will inevitably increase. This result does not differ from many other growth models but is identified as a property of our modelled economy as well.

Why Trade Emerges Between Generations

We model the agent as optimizing the following objective:

$$\text{MAX} \{ U(C_y) + U(C_n) + U(C_r) \}.$$ 

This model of agent behavior does not delineate motives beyond an agent's own life. The agent considers only individual consumption during the young, middle and retirement years in the objective. This is important since we don't want to generate protection for the future by merely imposing beneficence at the outset.

Man made capital, which may be consumed or employed to production, and the renewable natural resource, which may be drawn down for production or held over for future sale, are both exchanged between adjacent generations. Therefore these productive stocks move from one generation to the next by this exchange.
We model trade between generations directly from the agent utility problem above. Income and demographic differences between agents generate supply and demand schedules for productive assets in any given period. The potential for welfare to be sustained is therefore interpreted through these input markets. So the emergence of these markets and the incentives to trade are critical to the sustainability of welfare.

The simplest rational for the emergence of trade follows. Since period one and period two agents coexist and each anticipates at least one future period of life, gains from trade may exist.

Period two agents own capital that they saved from the prior period. Some of this capital will be set aside to production. This secures their consumption capital for retirement. At the same moment period one agents are attempting to secure any productive assets, barring inherited capital. The capital acquisitions by the young enable production and meet first period consumption demands.

The better endowed middle aged are willing to accept compensation for parting with the marginal productive asset unit as long as the sale price at least equals the marginal productivity of that asset otherwise employed to production. If the young offer this price for capital or for the natural resource, then the young can borrow capital or purchase natural resources from the middle aged.
If marginal productivity of inputs decline and/or the marginal utility of consumption declines, the willingness to pay by the young for the first units of capital and LAND acquired is likely to exceed the productivity of the marginal capital unit by the middle aged. That is the demand schedules for productive assets lie above the supply schedules along the price line at zero quantity exchanged. So there are sufficient incentives to induce positive exchange of assets in these markets. In this fashion capital moves by free exchange between generations.

To specify the outline of the economy we will begin with a further consideration of the assumed properties of utility.

Utility

Recall again the agent objective:

\[ \text{MAX} \{ U(C_y) + U(C_n) + U(C_s) \}. \]

There exists a single output which the agent consumes over three periods. Utility is additively separable in time, and no inherent time preference is assumed.

Since the interest rate is determined by credit supply and demand schedules in any period, we do not have to impose inherent time preference in order to generate marginal agent discounting. Market opportunities that induce saving or investing can generate positive interest rates without imposing technical innovation or inherent utility discounting on the system.
Utility is also modelled by the following properties:
\[ U'_c > 0 , \ U''_c < 0 . \]
This establishes the assumption that preference relations are first of all functions and that the preferences are convex. The later assumption is crucial to the existence of an equilibrium. Strong inequalities above are assumed in all of the discussions in the text so are imposed here.

Consider now the technical production process.

Production

The production process employs land and capital as the factors of production. One unit of labor is supplied inelastically by each self-employed agent in a given time period. For simplicity the young and the middle aged face the same technology.

The production function is described as:
\[ Y = f(X,D;\phi), \]
where \( X \) is the capital input, \( D \) is the natural resource input and is not aggregable into \( X,^{1} \) \( \phi \) is the parameterization of the model, and \( Y \) is output expressed in

\[ ^{1}\text{Non-aggregable here means the goods are strongly or weakly separable from one another.} \]

Also the representation of natural resources a second input that is not itself a final good cannot be interpreted as non-consumable installed capital (Blanchard and Fischer, 1990). Our production function above does not impose the requisite separability conditions necessary to aggregate the two inputs. This further implies the price of the natural resource stock can exceed the normalized price of capital and allows the good to be modelled as a necessity.
f is assumed to be a function and it increases globally in both of its arguments. Also,

\[ f''_x \leq 0, \]

and

\[ f''_d \leq 0, \]

or simply, \( f'_i > 0 \) & \( f''_i \leq 0 \) given \( j > 0 \) and \( \phi \).

This implies that the input requirement set is everywhere convex, an especially important assumption. Another property that we typically employ is:

\[ f'_{ij} > 0. \]

We describe this property as revealing some production complementarity among inputs. It is not required to generate an equilibrium though as we will show it is important to generating the conservation question posed in the next chapter.

Constant elasticity of substitution (CES) is not required to generate our conclusions although substitutability between inputs is assumed. Essentiality of inputs, embedded in the CES form, is also not imposed; but essentiality is considered through much of the remaining chapters. Essentiality means that each input in some small quantity is required for production to be positive. Specifically,

\[ f'_i = 0 \text{ when } j = 0. \]

We discuss essentiality as a specific value assumption in the complementarity property above. For most of our discussions we only need \( f'_i \) to be small when \( j = 0 \).
The production function also exhibits the following property:

\[ I'y \geq f(I'x, I'D: \phi) \geq y, \]

\( I \geq 1 \). Or production can be characterized by either constant returns to scale (CRTS) economies or by declining scale economies; but never by increasing economies.

So production is considered to exhibit typical neoclassically assumed properties though no explicit functional form is defined. Also each input is frequently considered to be necessary to production.

Before moving from a discussion of production, some comment regarding CRTS is important since its imposition is often criticized in growth models. CRTS is reasonable. It implies nothing more than the technical replicability of production. However in a macro-economic model CRTS assumptions are often criticized for obscuring limits to resource accessibility.

What is relevant to concerns that CRTS recognizes no limits is not that the technology is inherently subject to constant scaling but that the availability of some resource is limited in a fashion that pre-empts perpetual replication. Endogenizing the renewal process of the natural resource, discussed below, does this job for us. By a more complete specification we accommodate two common sense notions. If all inputs are duplicated, we ought to double output. Yet the natural world implies that there are limits to input
availability which systematically prevent inputs from being accessed at constant marginal costs.

We do explicitly exclude increasing returns, in part to assure existence of equilibria. We note that increasing returns assumptions in growth models (Romer, 1986) really emerge as a way to characterize accelerating technical change. We discuss technical change briefly; but it is a maintained hypothesis that Arrow's Learning by Doing (Arrow, 1963) and Romer's increasing returns from capital externalities (Romer, 1986) do not characterize very long term technical change over generations. Rather it is assumed here that on-going long term technical change across generations is a by-product of direct R&D investments with productivity of R&D a function that itself exhibits decreasing returns. R&D investments employ Land and Capital inputs also are purchased in competitive markets. This characterization can be reconciled with the empirical results of Romer without assuming increasing scale economies.

Having given the agent problem statement and having outlined the production technology, we need only to define the regeneration process of natural resources to articulate the agent's problem.

**NATURAL RESOURCE RENEWAL**

Natural Resources are employed to production out of draws from LAND stocks purchased in period one. We assume that the
renewal rate of the resource depends on the quantity of LAND stocks deferred from period one production by the young. The convention adopted assumes the resource renews through a period and that draws occur at the beginning of a period. Middle aged agents do not defer Land. Of the natural resources carried forward from period one, agents draw some stocks for production and sell remaining stocks to the young. Without the opportunity to sell, agents would exhaust the natural resource in period two.

The stock of LAND that is sold in period two must balance the following identity. The amount purchased in period one less period one draws for production less period two draws for production plus any growth in stocks deferred in period one defines stock sales in period two. Specifically,

\[
\text{LAND}_a = \text{LAND}_y - D_y - D_a + h(\text{Land}_y - D_y).
\]

where \(\text{LAND}_a\) is the quantity of stock sold during middle aged; \(\text{LAND}_y\) is the quantity of stock purchased at the beginning of period one; \(D_y\) and \(D_a\) are the draws of Land for production during period one and period two respectively; and \(h\) is net growth in resource stocks deferred in period one.

The decisions to sell, draw or defer resource stocks are driven by LAND and capital prices, production technology and preferences. In addition, the natural process of resource regeneration affects the dynamics of the economy.
The properties of \( h \) form the basis of many of the policy scenarios in this work. \( h \) is the net resource renewal realized by a single resource owner. There may be concave and convex regions for \( h \). \( h \) may increase or decrease over parts of its range. There is no CRTS assumption that if an owner doubles her deferments of natural resources that the agent will double the net returns, \( h \).

It is important to keep in mind another implied feature of \( h \). There is a CRTS assumption on growth with respect to Labor. Aggregate stock growth depends on the number of agents over which the aggregate Land stock is divided and permits scale intensity to affect marginal growth of the resource. For instance, if \( h \) is locally concave, two agents splitting a quantity of Land will regenerate more resources than a single agent owning the same quantity alone. The implications of this assumption mask the possible impact of population growth on sustainability. This is discussed in the next chapter.

Growth could be delineated by aggregate, not individual stocks of the resource, meaning \( \frac{dh}{d\text{Labor}} = 0 \). This does not affect the basic conclusions of this exercise; but it does complicate the stock identity above.

**Resource Renewal and General Equilibrium Models**

Several attempts have been made to incorporate natural resources into macro-planning models.

Steady-state conditions suggest that the resource renewal rate is equal to the steady-state discount rate (Solow, 1974).
Or \( h' = r \) in the steady-state. A model should be able to derive this condition for interior solutions; and our model does. Our model differs however because it also permits an economy to exhaust a renewable resource by permitting functional properties for \( h \) other than simple global concavity or by imposing CES production properties. These assumptions however are necessary to generate the analytic solutions to these models.

In 1970 Kneese, Ayers and d'Arge (before Solow 1974) voiced a concern that planning models had failed to include the equation of motion for natural resource stocks (Kneese, Ayers and d'Arge, 1970). Partial equilibrium presentations - I-O models, externality pricing models, et cetera - could not completely endogenize concerns for long term reductions in the natural resource base. Also general equilibrium growth models similar to Solow had no vehicle to adequately model the movement of natural resource stocks without imposing considerable restrictions to secure analytic results. Materials balance at least would trace these stock changes and report these simple stocks changes along with national income accounts, or I-O reports. More recent attempts to directly adjust national income accounts is the attempt to provide the flow value of these resource stock movements.

The model proposed here easily incorporates the materials balance question into a more robust general equilibrium frame. If the functional form of \( h \) is biologically reasonable and the
resource is fully incorporated into a general equilibrium economic model, a contribution of this work is the presentation of an economy that provides a coherent expression of the issues raised by the materials balance literature.

**Optimal Life Plan**

Three periods of consumption and two periods of production are modelled. LAND and capital trade is modelled with the agent demanding inputs for period one production and supplying inputs in period two.

The optimal life plan can now be delineated by the Lagrange equation below.

\[
\begin{align*}
\text{MAX } L &= U(C_{1,y}) + U(C_{1+1,\pi}) + U(K_{1+2,\pi}) \\
-\lambda_y (K_n - f(K_y - C_y - P_1*LAND_y + B_y, D_y) - (1+r_1)*B_y) \\
-\lambda_n (K_r - f(K_n - C_n + P_1*[LAND_y - D_y - D_n + h(LAND_y - D_y)] - B_n, D_n) + (1+r_{1+1})*B_n)
\end{align*}
\]

where C represents consumption during productive life. K is capital on hand at the beginning of a period. P and r are LAND and capital prices respectively in a given period and are taken as exogenous by the agent. f of course is the production function, B is the quantity of capital borrowed or loaned in a productive period of life, and LAND is the quantity of Land bought or sold in a productive period. D is the amount of Land drawn for production in a period by an agent.

\(X_y\), the amount of capital employed to period one
production, is given by \([K_y - C_y - P_1*LAND_y + B_y]\). Similarly,
\[X_n = K_n - C_n + P_{i+1}*[LAND_y - D_y - D_n + h(LAND_y - D_y) - B_n].\]
That is, Middle-aged capital used in production equals capital saved from period one less period two consumption less capital loans plus Land sales. Substitution for \(LAND_n\), defined earlier, is imposed. \(\lambda_c\) represents the shadow price of capital in a given period. As modelled, \(\lambda_y\) is the shadow price of an additional capital unit available in period two. \(\lambda_n\) is the shadow price of capital available in retirement and will therefore be equivalent to the marginal utility of consumption in retirement.

The definitions are summarized below.

Definition of Variables

- \(C_{ij}\): consumption in period \(i\) by agent \(j\) of the homogenous output (good)
- \(K_{ij}\): available stock in period \(i\) by agent \(j\) of the homogenous output (good)
- \(B_{ij}\): amount borrowed (loaned) in period \(i\) by agent \(j\) of homogenous output (good)
- \(r_i\): prevailing rate of interest in period \(i\) of invested (borrowed) homogenous output
- \(LAND_{ij}\): stock of land input in period \(i\) by agent \(j\) bought (sold) used in production of homogenous output
- \(D_{ij}\): amount of LAND stock used in period \(i\) by agent \(j\) in production of homogenous output
- \(P_i\): price prevailing in period \(i\) of exchange of a unit
of LAND

$\lambda_{ij}$: shadow price of homogenous output (good) assessed by agent $i$ in period $j$

$\text{DEF}_{iy}$: Amount of the Natural Resource conserved in period $i$ by the existing young.

The agent has nine separate decisions in pursuing her optimal life plan. The agent must simultaneously determine consumption and capital exchange in each of the two productive periods, the amount of Land to employ to production in each period, how much of the natural resource to purchase in period one and how much capital to carry forward from each productive period ($K_m$ & $K_r$). Any decisions remaining are linear combinations of other decisions and are not explicitly derived. For instance, the amount of Land $y$ deferred (DEF) in period one equals $\text{LAND}_y - D_y$.

This optimal life plan implies the following first order optimality conditions for an interior solution.

1. $L'_{cy} = 0$: $U'_{cy} = \lambda_y f'_{xy}$
2. $L'_{cm} = 0$: $U'_{cm} = \lambda_m f'_{xm}$
3. $L'_{Kr} = 0$: $U'_{Kr} = \lambda_m$
4. $L'_{By} = 0$: $f'_{xy} = (1 + r_i)$
5. $L'_{bm} = 0$: $f'_{xm} = (1 + r_{i+1})$
6. \( L'_{Dy} = 0: \quad \lambda_y f'_{Dy} = \lambda_m f'_{Xm} p_{i+1} (1 + h') \)

7. \( L'_{Dm} = 0: \quad f'_{Dm} = p_{i+1} f'_{Xm} \)

8. \( L'_{Landy} = 0: \quad \lambda_y p_i f'_{xy} = \lambda_m f'_{Xm} p_{i+1} (1 + h') \)

**NOTE:**

\[ X_y = K_y - C_y - P*Land_y + B_y \]
\[ X_m = K_m - C_m + P*[Land_y - D_y - D_m + h(Land_y - D_y)] - B_m \]

The first eight equations represent the decisions defined earlier. Equation nine represents a target condition for the agent in determining the amount of capital to carry into period two, \( K_m^* \). Also for an interior solution, the nine explicit decision variables are positive, prices \( r_t \) and \( P_t \) are positive, and the implied decision variable (\( X_m, X_y, \) and DEF) are positive.

**Behavioral Implications and Micro-foundations**

The first order conditions from the optimal life plan conform to theoretical expectations from economics and finance.

Equations 4 and 5 identify that the marginal product of a capital input is the price of capital \((1 + r_t)\) as we expect.

Equations 1 and 2 identify the marginal utility of consumption in a period as the product of the price of capital \((1+r)\) and the implicit value in units of utility of an additional unit of capital available in the next period. That is, the marginal utility of consuming an additional unit today equals the opportunity costs in utility of foregone future
consumption for that unit.

Also note equation 9. This condition indicates that the ratio of the implicit price of period two capital, $\lambda_y$, to the implicit price of period three capital, $\lambda_3$, equals the lending rate of capital, $(1+r_{1,1})$. This means that the relative utility value of capital between periods equals the relative price of capital between time periods, a condition consistent with theory.

The rate of interest is frequently interpreted as future consumption is intrinsically less valued to the agent. This is what Ramsey referred to as theft by the present. It assumes future consumption declines from agent myopia undervaluing future consumption. However convex preferences mean that consumption increases through the agent's life-cycle when the agent is time neutral with respect to consumption. The time neutral agent modelled in our economy may be marginally myopic with respect to consumption, but by the same condition the agent on average is future conserving with respect to consumption.

Savings and investing opportunities induce the agent to defer consumption in any period. Optimizing agents equate the ratio of tomorrow's lower marginal utility (greater total consumption) relative to today's greater marginal utility of consumption to the marginal productivity of capital, expressed by the following identities:

$$\frac{MUC_y}{MUC_3} = (1 + r_y)$$
\[ \frac{\text{MUC}_a}{\text{MUC}_x} = (1 + r_a). \]

As an example if utility is logarithmic in consumption \( (C_y^a, a<1) \), this implies the total consumption ratio: \( C_a = (1+r_y)^{1-a} \). If \( a \) is close to unity, then even small values of \( r \) can realize \( C_a \) much larger than \( C_y \). For the agent, marginal discounting reflects the sacrifice of marginal savings. Building this behavior directly into a growth model is essential to any critique of interest rate policies to secure future welfare levels. This method of introducing discounting is more consistent with micro-economic principles of supply and demand for credit.

LAND price, \( P \), reflects the capitalized value of rent through a period. Equation 7 for \( P_2 \) and equations 6 & 8 for \( P_1 \) generate the identity:

\[ P = f_a' / (1 + r), \]

Or the value of an asset equates rental value, the marginal productivity, of the resource divided by the intertemporal price of borrowed funds. This assumes that the resource can be purchased on credit with no downpayment, precisely how the acquisition of \( \text{LAND}_y \) is modelled.

Finally substitution of equations 4, 5 & 9 into equation 8 generates the condition:

\[ P_1 = P_{1+a} (1 + h') / (1 + r_1) \]

This price relation is derived from the agent's targeting condition for \( K_a \). This generates the Hotelling rule for
natural resource prices, modified for a renewable resource. This condition will hold in the general equilibrium.

A summary of some of the relevant identities drawn from the first order conditions is provided as a quick reference for discussions through the rest of this work.

Relevant Identities:

\[
\begin{align*}
\lambda_y / \lambda_n &= (1 + r_2) \\
f'_{xa} &= (1 + r_2) \\
f'_{xy} &= (1 + r_1) \\
MUC_y &= \lambda_y (1 + r_1) \\
MUC_n &= \lambda_n (1 + r_2) \\
\frac{MUC_y}{MUC_n} &= (1 + r_1) \\
\frac{MUC_y}{MUC_n} &= (1 + r_2)
\end{align*}
\]

So it appears that the model conforms to our prior theoretical assumptions regarding agent and market behavior. Our critique through the rest of this work depends on these identities.

Market Equilibrium

Market exchange in this system occurs because there exist agents in each period of life at any given moment.

We can collect decisions that the agent makes in period one and define the optimality conditions for these agents. Similarly optimality conditions for the existing middle aged can be collected. From this representative supply and demand schedules can be derived.
Specifically, we can identify the behavioral conditions derived from the agent's problem for a general equilibrium as:

**Young Agent:**

1. \( L'_{cy,t} = 0 \):
   \[ U'_{cy,t} = \lambda_{y,t} f'_{xy,t} \]
2. \( L'_{By,t} = 0 \):
   \[ f'_{xy,y} = (1 + r_t) \]
3. \( L'_{dy,t} = 0 \):
   \[ \lambda_{y,t} f'_{dy,t} = \lambda_{n,t} f'_{xm,t} P_{t+1}(1 + h') \]
4. \( L'_{LANDy,t} = 0 \):
   \[ \lambda_{y,t} P_t f'_{xy,y} = \lambda_{n,t} f'_{xm,t} P_{t+1}(1 + h') \]

**Middle Aged Agent:**

5. \( L'_{cm,t} = 0 \):
   \[ U'_{cm,t} = \lambda_{y,t} f'_{xm,t} \]
6. \( L'_{Kn,t+1} = 0 \):
   \[ U'_{Kn,t+1} = \lambda_{n,t} \]
7. \( L'_{Bm,t} = 0 \):
   \[ f'_{xm,t} = (1 + r_{t+1}) \]
8. \( L'_{Dm,t} = 0 \):
   \[ f'_{Dm,t} = P_{t+1} f'_{xm,t} \]

However in order for this system to solve a core solution for \( B_{y,t}, B_{n,t}, 1 + r_t, \text{LAND}_{y,t}, \text{LAND}_{n,t} \) and \( P_t \) several material balance conditions must be articulated.

First we need to know how many period one and period two agents exist in order to determine the aggregate market schedules. Since this system must progress through many generations, the essential dynamics of population growth will be specified. Therefore, relative population sizes between generations at any point in time must be explained in terms of prior decisions. This in turn also means next period's population levels must be determinable.
Also some bequested capital is permitted in the model. \( K_y \) in the agent's problem is not assumed to be zero. The observation that real world inheritance exists motivates an introduction of capital bequests. We interpret this as a non-altruistic result for the purposes of this study.

Finally after introducing these two concerns, the basic material balance conditions for the system are listed and the system can be completely defined.

**POPULATION CHANGE**

The number of agents that exist within a particular generation reflects a simple demographic phenomenon: as per capita consumption begins to increase, population growth follows until, at a developed standard of living, population growth rates begin to fall.

This phenomenon has been a well documented stylized fact through the 20th century. T.P. Schultz offers a micro-economic interpretation of this phenomenon (Schultz, T.P., 1971).

Schultz cites the decline in death rates as development commences as the initial boost to population growth. As the process continues, however, the opportunity costs of children increase dramatically.

The economic impact of raising children shifts from a financially positive prospect to a liability. Increases in wage opportunities for women and rising education costs of children make child rearing less attractive. So agents have
fewer children. At lower incomes children may be considered assets that provide long term security for the parents. This is eventually outstripped, however, by a rise in income opportunities.

The description of this social phenomenon in this work is very simplistic; yet it captures the basic features of the demographics. In our model the relative number of new-borns next period to the number of current period two agents is functionally dependent only on the per capita consumption of period two agents - the middle aged. Or,

\[ \frac{N_a}{N_y} = \rho(C_n). \]

\( N_a \) is the average number of children born to a period two agent at time, \( t \).

The equation \( \rho \), is assumed to exhibit the following properties:

1) \( N_a = \rho = 0 \) when \( 0 < C_n < C_n^{\text{min}} \)

and when \( C_n > C_n^{\text{max}} \) at some \( C_n^{\text{max}} > C_n^{\text{min}} \),

2) \( \rho' = 0 \) at a point \( C_n^o \) such that \( C_n^{\text{min}} < C_n^o < C_n^{\text{max}} \)

and where \( \rho \) reaches its maximum value.

So,

2a) \( \rho'_n > 0 \) for all \( C_n \) where \( C_n^{\text{min}} < C_n < C_n^o \)

2b) \( \rho'_n < 0 \) for all \( C_n \) where \( C_n^{\text{max}} > C_n > C_n^o \).
A quadratic function intersecting $\rho = 0$ at $C_{a}^{\text{min}}$ and $C_{a}^{\text{max}}$ with the restriction $N_{a}$ non-negative, for example, would characterize the properties defined. The interested reader may wish to look ahead to Figure 5.6 and also note the implications of the constant returns to labor assumption embedded in the $\rho$ function defined as explained in the text in chapter five under 'Constant Returns to Labor and Resource Stocks'.

The decision to bear children is an internal agent optimization problem. Schultz associates this decision theoretically with the individual's level of income and level of social development. So unless we embed the entire decision process into the utility function, the relation ordered generally by the properties of $\rho$ above is considered a reasonable method to endogenize population growth.

INITIAL ENDOWMENTS

Bequest motives (Bernheim, Shleifer, & Summers, 1985) and incidental bequests (Abel, 1985) provide strong theoretical arguments for inheritance. The behavioral foundation is not modelled here. Still capital inheritance is considered to be significant enough to enter the model.²

² The debate between Modigliani's life-cycle savings as the primary generator of wealth or permanent income models have different predictions as to the size of inheritances. Yet all of the exchanges grant non-trivial capital inheritances. I'm not convinced this literature, while interesting, is really relevant to long term growth. The identification assumed for the future in permanent income
Inheritance is described by:
\[ K_{t+1,A} = N_a/N_r \mu K_{t,r}, \quad 0<\mu<1 \]

\( N_a \) is the number of newborns entering next period as young. 
\( N_r \) is the number of retired today. \( K_{t,r} \) is the retirement savings at \( t \) of a third period agent. \( \mu \) is just the simple percentage of capital available to a retired agent that will be left to endow newborns entering as young next period.

Specific care for the future by agents is not something we want this model to impose as the psychological attitude could erode in any given generation. If the reader conceives of \( \mu \) as small, limited only to accidental inheritance which represents no intrinsic care for the future (Abel, 1985), that would be consistent with a life-cycle motivated agent. For our purpose we want to experiment with the power of the market to provide for future generations. We don’t want to model specific altruism if our project is to be meaningful.

Still we don’t ignore the existence of endowments to the future by the present as it seems to explain such a large share of existing capital stock in the real world. Empirical estimates in the U.S. economy range from as high as 70% of existing capital stock attributable to bequests (Kotlikoff and Summers, 1981) to about 30% (Modigliani, 1988). The level of bequested capital is substantial in either case so it is

models leads to a higher though still a flat level of consumption through time if the pace of technology is quick.
expressly incorporated into this discussion.

We are now prepared to describe an aggregate description of this model, normalizing the number of agents in the middle generation to unity. A summary of the system factors follows.

System in Aggregate for Period i

Equations of motion: capital

Young (y): \( K_{1n} = f(K_{1y} - C_i y - P*Land_{1y} + B_{1y}, D_{1y}) - (1+r)*B_{1y} \)

Middle-aged (M):

\( (N_m = 1) \quad K_{1i} = f(K_{1m} - C_{im} + P*Land_{1m} - B_{1m}, D_{1m}) + (1+r)*B_{1m}. \)

Retired (R)

consumption \( N_n C_{iR} = (1-\mu) K_{1R} \)

Aggregate bequested capital \( N_A K_{1+1, A} = N_R . \mu . K_{1R} \) (left for generation A, born at end of i)

Population growth

\( (N_n/N_y) \quad N_{A, i+1}/N_{A, i} = \rho(C_n) \)

Initial capital (per capita) of next generation (A) \( K_{1+1, A} = N_R/N_A . \mu . K_{1R} \)

Resource growth or renewal \( LAND_{i+1y} = LAND_{1y} - D_{1y} - D_{i+1.m} + h(Land_{1y} - D_{1y}) \)

Utility agent j \( U(C_{1j}) = U(C_{1j}) + U(C_{1+1,j}) + U(K_{1+2,j}) \)
$N_j$ is the number of $j$ generation agents living. For a given period the number of middle aged is normalized to unity.

At any point in time there are agents in period one and in period two stages of life who trade with each other. So we can introduce a set of market clearing identities and material balance conditions to complete the characterization of an equilibrium and stock dynamics.
GENERAL EQUILIBRIUM SYSTEM

Young Agent:
1. \( L'_{cy} = 0 \): \( U'_{cy} = \lambda_y f'_{xy} \)
2. \( L'_{by} = 0 \): \( f'_{xy} = (1 + r_t) \)
3. \( L'_{dy} = 0 \): \( \lambda_y f'_{dy} = \lambda_m f'_{xm} p_{t+1} (1 + h') \)
4. \( L'_{landy} = 0 \): \( \lambda_y p_t f'_{xy} = \lambda_m f'_{xm} p_{t+1} (1 + h') \)

Middle Aged Agent:
5. \( L'_{cm} = 0 \): \( U'_{cm} = \lambda_m f'_{xm} \)
6. \( L'_{kr} = 0 \): \( U'_{kr} = \lambda_m \)
7. \( L'_{nm} = 0 \): \( f'_{xm} = (1 + r_t) \)
8. \( L'_{dm} = 0 \): \( f'_{dm} = p_t f'_{xm} \)

Identities:
9. \( N_y B_y = N_m B_m \)
10. \( N_y Land_y = N_m [Land_{y,t-1} - D_{y,t-1} - D_m + h(Land_{y,t-1} - D_{y,t-1})] \)
11. \( K_n = f (K_n - C_n + P_t [Land_y - D_y - D_n + h(Land_y - D_y)] - B_n, D_n) + (1 + r_t) B_n \)
12. \( K_r = f (K_n - C_n + P_t [Land_y - D_y - D_n + h(Land_y - D_y)] - B_n, D_n) + (1 + r_t) B_n \)
13. \( N_m / N_y = p(C_n,t-1 ; Q) \) given: \( C_n,t-1 \) in t-1
14. \( K_y = N_r,t-1 / N_y \mu \cdot K_r,t-1 \) given: \( N_r,t-1 ; K_r,t-1 \) in t-1
15. \( P_t = (1 + r_{t-1}) P_{t-1} h'^{-1} \) given: \( r_{t-1} ; P_{t-1} ; Land_{y,t-1} ; D_{y,t-1} \)
Endogenous Variables: (15 in all)

\[ C_y, B_y, D_y, K_y, \text{Land}_y, \lambda_y, C_n, B_n, D_n, K_n, \lambda_n, \]
\[ K_r, r, P, \text{Nm} / \text{Ny} \]

There are 15 endogenous variables and 15 equations for each time period.

Equation 13 depends on last period’s consumption by the middle aged \((C_{n,t-1})\) and 14 depends on last period’s number of retired \((N_{r,t-1})\) and their on-hand capital \((K_{r,t-1})\).

These equations operate at any point in time. They reflect the carry forward of stocks from last period decisions which are in turn responding to last period’s prices. It is in this sense that the model is dynamic.

The first four equations reflect the optimal choices of period one agents found in the optimal life plan. The next four equations are the conditions of an optimal life plan for existing period two agents. These occur of course simultaneously and generate the motivations for trade. All agents are price taking agents.

The identities simply indicate that the amount of capital borrowed must equal the amount loaned (equation 9), the amount of land bought must equal the land sold (equation 10), the movement of capital between life periods must obey the accounting identities in the equations of motion, the number of agents in a generation is determined by the period two
consumption level of agents two generations ahead, endowed capital is determined by the exogenous bequest factor and the ratio of the number of retired agents to the number of new borns.

Finally the price movement of land (equation 15) follows the Hotelling rule. This is derived from the agent optimization condition: \( L'_{k_m} \) implies \( \lambda_y = \lambda_n \times f'_{x_m} \). Since prices change from period to period, the modified Hotelling rule is an observable consequence of this condition. The translation of the individual's problem completes the identification of the equilibrium.

We can now identify the steady-state conditions. This presentation assumes the renewable resource is not exhausted and all markets realize interior solutions. Therefore in the steady-state used for discussion in this project, all stocks (including population levels) are constant. Therefore, in this steady-state prices are also constant.
STADY-STATE

Young Agent:
1. \( L'_{cy} = 0: \quad U'_{cy} = \lambda_y f'_{xy} \)
2. \( L'_{by} = 0: \quad f'_{xy} = (1 + r) \)
3. \( L'_{dy} = 0: \quad \lambda_y f'_{dy} = \lambda_m f'_{xm} \cdot P \cdot (1 + h') \)
4. \( L'_{Landy} = 0: \quad \lambda_y P f'_{xy} = \lambda_m f'_{xm} \cdot P \cdot (1 + h') \)

Middle Aged Agent:
5. \( L'_{cm} = 0: \quad U'_{cm} = \lambda_m f'_{xm} \)
6. \( L'_{Kr} = 0: \quad U'_{Kr} = \lambda_m \)
7. \( L'_{Bm} = 0: \quad f'_{xm} = (1 + r) \)
8. \( L'_{Dm} = 0: \quad f'_{Dm} = P f'_{xm} \)

Identities:
9. \( N_y B_y = N_m B_m \)
10. \( N_y Land_y = N_m [Land_y - D_y - D_m + h(Land_y - D_y)] \)
11. \( K_m = f(K_y - C_y - P*Land_y + B_y, D_y) - (1+r)*B_y \)
12. \( K_r = f(K_m - C_m + P*[Land_y - D_y - D_m + h(Land_y - D_y)] \)
\[-B_m, D_m) + (1+r)*B_m \)
13. \( N_m / N_y = \rho(C_m ; Q) \)
14. \( K_y = N_r / N_y \cdot \mu \cdot K_r \)
15a. \( 1+r = 1+h' \) or 15b. \( \lambda_y / \lambda_m = 1+r \)

Endogenous Variables: (15 in all)
- \( C_y, B_y, D_y, K_y, Land_y, \lambda_y, C_m, B_m, D_m, K_m, \lambda_m, \)
- \( K_r, r, P, N_m / N_y \).
We do not presume the existence of a steady-state for this economy. Rather we use the steady-state definition as a simple representation of future interests in order to assess policy proposals. If a proposal can uniformly improve or diminish future welfare, use of the steady-state is relevant without requiring an appeal to the existence or natural movement of the economy to a steady-state.

Finally the impact of no, multiple or unstable "this period" equilibria on future welfare is beyond the scope of this exercise. It is an important body of research that will inevitably expand discussion of the prospects of markets to provide for future generations. The objective of this work is to ascertain if we are given unique and stable equilibria through time that this will guarantee a satisfactory provision of future agent welfare consistent with the moral considerations introduced in chapter one.

The properties of production and utility, the assumption that demand is generated by identical agents and that supply is generated by identical agents are all consistent with properties required to establish the existence, uniqueness and stability of equilibria by assuring the conditions that satisfy WARP in these markets (see Lancaster, 1968). If a core exists in these markets, WARP can be tested because there are no 'corner' solutions. For our purposes, existence, uniqueness and stability of equilibria essentially reduces to the additional assumption that supply schedules lie below
demand schedules along the price line at the zero quantity level. This condition is assumed for the initial period for the same reasons that we assume trade exists. For the first units traded, the value to the young exceeds the value to the middle-aged. This is assumed for the initial period; yet in the case of resource exhaustion, eventually the ability to pay by the young is insufficient to induce trade. However as we will discover later in this work, the renewal function can not be assumed to give rise to an everywhere convex set of points in period t and period t+1 space. This non-convexity introduced into the general equilibrium cor may permit multiple equilibria. Nonetheless a single equilibrium is assumed for expositional ease.

The real task of this work is to demonstrate that under fairly ideal conditions an economy may continue to devolve toward low consumption levels. The task of rooting out market failure or stabilizing stock levels in unstable markets is important for the benefit of current and future agents. Our question asks the additional question: can fully efficient markets sustain future welfare?

**Agent Information**

The general equilibrium equations identified operate for any point in time. They reveal the carry forward of stocks resulting from last period decisions which in turn are a response to last period prices. It is in this sense that the
model is dynamic.

Overlapping generations trades imply that the young make current decisions according to an optimal three period life plan. So the young are concerned with next period trading opportunities. In bidding for assets today, period one agents account for the input demands of the next period young. Similarly the demands of next period young account for the young two periods hence which reflect in part the demands of young three periods hence and so on.

In this OLG model future generations are not silent in their ability to motivate market behavior. In a simple quip - potential agents mean potential opportunities.

We find that current trades in this economy consider the demands of an infinite stream of future agents. The direction of future welfare will depend wholly on the initial conditions: initial stocks, the functional forms and the parameterization of the aggregate system as well as the number of agents in the economy.

The information available to an agent is no less than the infinite sequence of all future prices. Though the agent only cares about next period prices to set her willingness to pay or accept schedules, tomorrow’s prices are determined jointly with an endless sequence of future prices. This model does assume that information is costless and perfect. With no random variation around expected prices expectations become perfect foresight - that is anticipated prices are perfectly
realized. So the economy presumes perfect common knowledge of the economic structure. If we add rational agent motives to perfect common knowledge, then future events correspond with the realization of those events.3

The implications about uncertainty do not motivate the basic policy questions considered. The conservation question posed asks if this idealized economy with no market failure, perfect information and well ordered market schedules can still leave the future worse than the present. Implications for uncertainty are largely extra-topical to our discussion.

**The Nature of Solutions**

Given the economy modelled, the entire trace of economic activity through time is determined solely by the seven initial stocks and the parameterization of the functions. These stocks include the relative number of period one, period two and period three agents. Capital stocks on hand are accounted for by capital held each representative agent in a particular life period at the beginning of a period. Finally all natural resources held by the middle aged define on-hand Land stocks.

This idealized one shot solution delineates the trace of

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3 We have asked the reader to consider inheritance as emerging from some uncertainty about death during retirement. Since all decisions are predetermined by retirement, an assumption that in aggregate inherited capital is precisely foreseen is enough to maintain perfect foresight regarding prices.
consumption through the generations. Since consumption increases through life in direct proportion to the price of capital, the value of the agent objective problem (L) must be compared from generation to generation. A trace of consumption by agents in a particular period of life from generation to generation will not strictly signal whether overall life-time utility is increasing or decreasing through the generations. So we compare the trace of the value of the Lagrangian, L, through time. Henceforth, references to the 'trace of consumption' through the generations are equivalent to a comparison of the value of the agent objective between generations.

Initial stocks determine if the trace of consumption increases or decreases through time. If we imagine the general equilibrium converging to a steady state, initial wealth levels of agents (measured as the economic value of on hand productive stocks) may be greater than or less than those that prevail in the corresponding steady-state. If wealth is below that which exists in the steady-state, consumption is higher in the steady-state. If current wealth is greater than wealth in the steady-state, consumption in the steady-state is

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4 Many steady-state solutions are possible. There are as many steady-states as there are solutions to the fifteen non-linear equations that define a steady-state. If general equilibrium solutions emerge uniquely from the points in $\mathbb{R}^7$ (stock space), then there is a correspondence between steady-state solutions and points in $\mathbb{R}^7$. Given the possibility that no steady-state exists, the correspondence might not be a relation or an inverse function.
less than current consumption.

There may be many steady-state consistent with the parameterization of the functions in the model. Yet only one of these solutions can be consistent with the parameterizations and initial stocks. Initial stocks determine which solution to the simultaneous equations of the steady-state could be realized. Since a finite number of steady-state exists and equilibria are unique, each steady-state will be consistent with a subset of points in $\mathbb{R}^7$ (the space of possible stock combinations) that uniquely correspond to that steady-state. For discussion here, we assume initial stocks fall into one of these elements of $\mathbb{R}^7$ so a steady-state exists. Nothing inherent in the model indicates that the spot value of the on-hand stocks in $\mathbb{R}^7$ consistent with a steady-state are higher or lower than the value of stocks that will prevail in the eventual steady-state.

So there is nothing inherent in the nature of solutions in this economy that assures current consumption levels will likely improve or deteriorate through the generations.

CONCLUSION

Our model presumes perfectly efficient markets, guided by infinite perfect foresight. Market equilibria are assumed to exist uniquely and they are stable. We do not relax these conditions on the model since our stated task is to
investigate the sustainability question within a highly idealized market. We are not here interested in market failures, instability or systematic uncertainty. What we show in the next chapter is the possibility of a resource exhaustion in this idealized environment. We specifically ask if the serious deterioration of future prospects can be approached with our eyes wide open, guided by perfect foresight and fully efficient equilibria.

We show in the next chapter that exhaustion of a natural resource that dramatically limits future prospects is possible even in this ideal setting because of the structure of the market modelled. An ideal structure with more realistic parameterizations of the economic functions can be shown to generate this result. However the model developed does embed many protections against this unfortunate event so that conservation solutions will likely rely on market incentives to complement efforts to prevent an unwanted resource exhaustion.
CHAPTER V
The Conservation Question

This chapter introduces a conservation question. We inquire generally if the exhaustion of a renewable resource can occur when this implies a dramatic erosion. This question is motivated by the three previous chapters and can now be articulated within the general equilibrium model introduced. Before proceeding, the argument to this point is reviewed.

Chapter two argues that no consensus in moral philosophy provides a complete and coherent theory of value to address the concern for future generations. We only assert two heuristic value statements that recognize the continuity of human existence and the level of future welfare is valuable. We can identify a consensus to intervene on behalf of the future to pre-empt truly dramatic declines in future opportunities, but no unique guide to a moral social order. This justifies tracking the economy to monitor future economic prospects and check for dramatic welfare declines.

Chapter three demonstrates that our prominent economic models are inadequate to appraise the success of the economy to sustain welfare as required by our two simple value statements. Modern growth models fail to delineate the means by which capital is passed from one generation to the next without an appeal to individual agent altruism, something we
don't want to depend upon. As a result chapter four builds a model of the economy based on agent self interest. That model embeds both savings and investment decisions in an OLG model and explains the movement of capital between generations directly from life-cycle motives and market transaction. The model, though highly idealized, conforms to the several stylized facts about consumption and savings patterns through an agent's life-cycle.

The object of this chapter is to investigate the conservationists' concern regarding the power of markets to provide for the future using the proposed economic model. Specifically this conservation question asks if economic agents will exhaust essential renewable natural capital and launch a sustainability crisis.

First the scope of the conservation question is noted. Non-renewable necessities with no immediate or potential substitutes are defined as extra-topical to this investigation. A sustainability crisis is inevitable regardless of market allocation of resources. Rather the exhaustion of renewable, substitutable natural resource necessary to sustain adequate production defines the scope of our concern. For the purposes of our study the exhaustion of a vital renewable resource, a conservation crisis, is the
event that initiates a threat to sustaining future consumption. The irreversibility of a resource exhaustion elevates our conservation question to prominence in the larger sustainability question. Therefore we focus on this aspect of the sustainability question; Can efficient market incentives induce the exhaustion of a highly valuable renewable resource?

To respond to our conservation question we first outline the incentives in the modelled economy that reduce the threat of this undesirable outcome. These strengths reveal that the emergence of discounting in the economy is not inherently a behavioral weakness, but rather the product of the very behavior that makes sustainability feasible at all.

However these protections are not guarantees. The potential for exhaustion of the renewable resource is then explained. By considering a resource stock regeneration set that is not everywhere convex, we admit the feasibility of resource exhaustion consistent with economic incentives (prices). The prospect of pressing our resource stock beyond its level of tolerance or carrying capacity after which the resource cannot reproduce itself is admitted in our economy. We show exhaustion is more likely with population pressures; and we conclude that this vulnerability to resource exhaustion is a reasonable possibility that warrants serious attention when we jointly consider the economic theory of population growth, the biological model of resource growth and the micro-
economic assumptions of our model.

The next two chapters demonstrate the inadequacy of interest rate ceilings and reversals of property rights between the young and the middle aged to robustly defend against resource extinction. Direct conservation targets in the form of Safe Minimum Standard (SMS) strategies are offered as one protection program.

The Question Defined

The first task in evaluating this question is to narrow the conservation question to an argument that is both economically and ethically relevant.

The prospect of an unwanted and devastating exhaustion of a natural resource arises naturally when we observe our possible dependence on non-renewable resources. By definition these resource stocks erode with use. If the resource is also essential to production, then use must be positive in every period. So if the production technology includes a non-renewable necessity with no substitutes and the resource is not infinitely divisible, it is trivially the case that any allocation scheme using the resource will also somewhere destroy future prospects. The maximizing behavior of existing agents in no fashion uniquely creates a disaster in this economy, but rather market processes identify only one allocation scheme to time the disaster.

This circumstance is entirely separate from our
conservation question. Our question asks if economic processes create otherwise avoidable disasters. The policy challenge for an economy dependent on a non-renewable necessity reduces merely to the optimal timing of an inevitable disaster. By positing this 'cake-eating' model of the world, we impose an assumption in which any active resource conserving scheme must improve the welfare of some future generation. The effect of future demand to affect prices and decrease current use in a cake-eating world can never be sufficient to permit infinite sustainability; but this is because sustainability axiomatically impossible. Therefore conclusions drawn from models that assume this state of the world should be viewed with suspicion if generalized to our economy and the question constructed here. Cake eating models assume a fixed and pre-determined set of total production opportunities that can be allocated over the generations and restricts the effect of trade to create the set of future productive opportunities.

Our definition of the conservation question is important to our critique of policies presented in the next chapter. Conservation policies, perhaps unintentionally, frequently ignore the continuity of production and derive their results from a 'cake-eating' view of the world. The next chapter shows that moving away from this assumption explicitly alters the policy implications of a model.

So we first note that the optimal allocation of a non-
renewable resource necessity with no technical substitutes is beyond the scope of our conservation question. We allow our resources to be essential to production but they can be regenerated and exhibit at least some degree of substitutability with capital.

Renewability and essentiality of the resource may be non-controversial; but there are certainly ecologists and some prominent economists who challenge the conclusions of economic growth models for imposing over-optimistic assumptions regarding substitution.

Herman Daly for instance argues that natural and man-made capital are probably closer to pure complements than to linear substitutes (Daly, 1990). Discussing the 'inherent' degree of substitutability seems awkward, however, if isoquants are not perfect compliments that can be illustrated by right angles. The degree of substitutability / complementarity will change along an isoquant. As use of one input is restricted, the ability to maintain the same output level with further substitution of another input becomes more difficult. This is all we assume.

This detracts from an articulation of a conservation question. A more cogent alternative is a skepticism of conclusions based on very restrictive functional properties of substitutability (i.e. CES); so restrictive that Land and capital can be aggregated. We can be better define our concern as an uncertainty about the properties of substitution.
at the extreme tails of an isoquant. A more coherent caution is that erosion of the natural resource to a very low quantity implies a marked reduction in output. At these tails near or even perfect complementarity defines the local degree of substitution. We are therefore legitimately skeptical of functional forms that fail to allow this property at the 'tails' of an isoquant.

From our point of view all we wish to establish is that exhaustion generates a crisis without eliminating any substitution between inputs. Inputs can be both necessities and substitutes without imposing idealistic functional forms that force optimistic conclusions. Our analysis merely presumes that given an arbitrary, feasible output level produced with both capital and Land, the same output level can be realized by using less of at least one input and substituting some finite amount of the other input. This assumption only specifically disqualifies perfect input complementarity. We also of course rule out perfect substitutability since natural resources and capital cannot be aggregated.

So a more coherent conservation question can be posed. We assume a production function in which inputs are neither perfectly complimentary or substitutable; and in which the exhaustion of Land will bound production to very small or even zero production possibilities. The concern that exhaustion of Land will likely devastate future production possibilities
given our limited experience with extreme real resource scarcity is a concern that both economists and conservationists could admit as a legitimate modelling assumption to frame a conservation question.

To summarize these issues, the legitimate conservation question for the economist is not a concern for the extraction of a natural resource necessity that is non-renewable or a perfect production compliment to man-made capital. Rather this work asks if it is possible through fully efficient market trade to exhaust a valuable renewable resource that is partly substitutable with capital even though the exhaustion of that resource uniformly diminishes the welfare of future generations.

**Protections from Exhaustion**

To discuss the prospect of an unwanted exhaustion, we rely heavily on the basic economic identities that directly reflect the opportunity costs of extracting resources.

Using equations (7 & 8) from the Optimal Agent Life Plan we observe the identities:

1. \((1+r_t) = \frac{P_2}{P_1}(1+h')\)
2. \(P_1 = \frac{MPD_1}{MPK}\)

The first equation is what we have called the modified Hotelling Rule in chapter four. The second equation represents a simple substitution of the first order conditions
7 & 8 from the optimal agent life plan by equating the right hand sides of 7 & 8. Using the modified Hotelling Rule, another identity relevant to the argument can be induced. This identity equates current LAND prices to any future LAND price.

3. \( P_t = P_i \times \Pi_t^i \{ (1+h_i')/(1+r_i) \} \).

The reader may be more familiar with the continuous time definition of this equation: \( P_t = P_i \times \int_s^t e^{-(r+h')s} ds \). With both interest rates and growth rates varying, current prices equate to future prices by a factor, \( \int_s^t e^{-(r+h')s} ds \) in continuous time or \( \Pi_t^i \{ (1+h_i')/(1+r_i) \} \) in discrete time. In either case the factor can be greater than unity (net compounding), less than unity (net discounting) or equal to unity (present and future price equivalence).

Recall that our agents possess perfect foresight. All equilibria through time are solved simultaneously. Anticipation of \( P_i \) and \( 1+r_i \) affects the decisions of our young and middle aged agents. This anticipation affords considerable protection for the future. Consider the structure of the weighting factor derived.

Identity 3 demonstrates that even far distant future preferences can affect current behavior. In addition the weighting factor, \( \Pi_t^i \{ (1+h_i')/(1+r_i) \} \), can exceed unity. So within life-cycle borrowing where the young anticipate future prices in their optimization plans, market forces cannot be
robustly characterized to inherently discount future preferences.

If the exhaustion of the natural resource is to be triggered by market forces, the anticipation of future scarcity will likely place upward pressure on future prices. This future scarcity then raises the opportunity cost of Land draws today. At the same time, the approach to exhaustion may likely imply several periods of ever increasing marginal growth rates, h_t'. This further increases the value of the factor. These increases can generate relatively very large values of h' in some periods relative to the price of capital such that the weighting factor at some period between the present and exhaustion become very large. In some growth models this factor always approaches infinity near exhaustion.

With both P_i large and the weighting factor greater than unity for at least some periods, exhaustion is possible only if current marginal productivity of Land employed to production is equally very large. If not, it is optimal for the young to defer the marginal Land unit to next period sale. That is, given zero arbitrage profits in an equilibrium, all agents will employ this conservation strategy and make exhaustion untenable in the market.

As draws increase, opportunity costs of those draws also increase by these arguments. In addition, we might expect the current payoff to diminish. Conservation will be further
encouraged by the convexity of $f$, the production technology.\textsuperscript{1} Diminishing marginal productivity of Land, given a level of capital employed to production, means that as more Land stocks are drawn for current production, the marginal current payoff declines at the same moment that the future opportunity costs of those draws increase. So there are systematic incentives to conserve resources as more and more resources are committed to production.

Opportunity Costs and Protection

These protections are afforded to future generations because future preferences are sources of future trading possibilities to our forward looking life-cycle agents. These future trading possibilities introduce an opportunity cost, represented by the weighting factor, to draws of resource stocks employed to current production.

The product of the compounded regenerated growth of a unit of Land, $\Pi_t (1+h'_i)$, and its value upon use, $P_i$, represent the production opportunities foregone when the agent extracts the marginal Land unit already purchased today rather than deferring its use until period $i$. This however overstates the real economic opportunity cost.

We also need to consider the value of converting the

\textsuperscript{1} If Land and capital purchases increase proportionally along a CRTS production function, there may not be diminishing marginal productivity of Land. Yet if the preference set is convex, at some point the middle-aged input supply schedules are upward sloping. So the profit function at least is concave since the marginal cost of inputs is increasing.
marginal Land unit into capital via production over the same time horizon. This is represented by the product of the capital value of acquiring Land today, \( \frac{MPD_t}{1+r_t} \) or its price \( P_t \), and the compounded value of that same capital unit continuously reinvested into production until period \( i \), \( \Pi^i_t(1+r_i) \). If we compare the value of the marginal Land purchase between its value as capital to its value as Land held in store until period \( i \), we can re-write equation 3 as:

\[
P_t \Pi^i_t (1+r_i) = P_i \Pi^i_t (1+h'_i).
\]

The LHS represents the value of a Land unit purchased and then employed to current production while the RHS represents the value of Land as a store of value that is finally sold in period \( i \). This equality of course holds for any arbitrarily defined \( i \). If, over any time subsequence, the future price \( P_i \) or the marginal growth rate \( h'_i \) approaches infinite value, draws that forego this opportunity stream will be too costly to be tenable in the market unless marginal capital productivity \( 1+r_i \) becomes nearly infinite as well.

Discounting

Working against conservation in the optimal agent decision in equation one and three is the price signal of the productivity of capital through time \( \Pi^i_t (1+r_i) \). At the margin the substitution of Land and capital implies that if the capital committed to purchase Land is marginally more valuable to the agent than the capital received from the sale of that
unit of Land tomorrow, that Land unit will be used today.\textsuperscript{2} To prevent this draw, either tomorrow's LAND price must be higher or the marginal rate of resource renewal, $h'$, must be large enough to compensate for the value of the marginal capital unit employed to current production. In this sense discounting behavior is seen to compete directly with resource sustainability. Yet it is simply incorrect to conclude that this identifies a perpetual bias against future concerns over the present.

Discounting insures the optimal productive value of stocks delivered to the future in terms of future agent preferences given the market structure (i.e. life-cycle agents trading in overlapping generations). Therefore the existence of the capital market and intergenerational trade generally simply enable consumption to be sustained at all.

If period two agents were unable to sell LAND or loan capital, they would simply consume on-hand capital or invest their capital in period two production. Similarly without trade between over-lapping generations, the middle aged would draw all on-hand Land into current production, exhausting the resource with certainty. The ability to borrow resources makes it possible for an agent to accumulate productive assets through productive life. Then as assets accumulate the agent can eventually identify gains from sale of some of those

\textsuperscript{2} This really means the young will not purchase the unit and the middle-aged will commit that unit to their current production.
accumulated assets to less well endowed agents just entering productive life. Without this systematic structure of trading opportunities through the life-cycle, it would not be possible to sustain welfare without the reliance on extensive capital bequests.

The marginal time preference derived in this OLG model emerges only because agents are future looking. Investors, the borrowing young, have a positive marginal time preference because they forego consumption at the margin this period. This enables production of some amount of goods greater than the amount of goods that the young deferred from consumption or immediate use. Similarly the middle aged save with the expectation of a more than proportional return on savings for retirement. That is throughout the life-cycle agents reduce current consumption a little today in order to be able to consume tomorrow in real terms some amount more than the amount they saved or invested. If preferences are convex, some limit to this sacrifice of present consumption for future gain is identified by equating $\frac{MUC_{t+1}}{MUC_t} = 1+r_t$, or equating the marginal willingness to forego current consumption to the productive return of the consumption foregone.

This forward looking deferment of consumption is the behavior that motivates trade between the generations. This is the reason an opportunity cost is defined at all. Without this behavior, the transfer of productive stocks from one generation to the next is not possible in our model without
altruism. More directly without the behavior that induces positive marginal time preference the prospects for future generations would reduce to devastation.

 Nonetheless we will show that the conservation question has relevance; but we need to take into account the entire economic decision process of an agent not a single price indicator.

Problems of Infinite Opportunity Costs

Many of the optimistic results from economic growth models taking up the conservation question rely on the likelihood of nearly infinite opportunity costs of resource exhaustion.

In single agent models the problem is defined by the objective: \( \int_{s}^{\infty} U(C_t)e^{-(\delta+s)t}dt \). In Solow this objective is sufficient to generate an infinite price for the non-renewable necessity at exhaustion (Solow, 1974). Since the objective units are expressed in terms of utility, the anticipated value of preserving some Land equals the discounted value of the first unit consumed by an agent in utility terms. An everywhere convex preference set implies that the marginal utility of consumption in a time period for the survival unit can be reasonably viewed as infinite. The infinite horizon agent would surely avoid such an event if it were possible. In Solow's model, a CES production function and infinite divisibility of the resource provide the conditions necessary
for allowing catastrophe to be avoided even though the good is non-renewable.

The derivation of an infinite value for the last resource unit \( (P_i \text{ approaches infinity}) \) is only possible given the single agent model maximand. As stated in the previous chapter, only the maximization of social surplus, measured in capital units is a valid characterization of our OLG economy. Therefore the price of the last Land unit at the point of exhaustion is bounded by the willingness to pay for that unit by the representative period one agent that exists in that time period. The possibility that Land price will approach infinite value is only possible if future agent budgets grow to be infinitely large.

Infinite opportunity costs associated with exhaustion can be generated instead by assuming that the growth function is globally concave and that the function achieves infinite slope at its origin. This assumes \( h' \) is infinitely valued at the origin. Yet we have no economic basis for this assumption. The technical assumptions about the regenerative capacity of the resource may differ from global concavity. Modelling assumptions about the functional form of the growth function should be consistent with assumptions that hold currency among biologists. So while the general protections against exhaustion may operate in a market, we cannot be sure that these protections so dominate current decisions to assure that the opportunity costs associated with exhaustion are infinite.
Arbitrage Conditions for Conservation

Protections from exhaustion cannot rely on an infinite future opportunity cost associated with exhaustion. But we can offer a more general statement of the incentives assumed in the models that generate infinite opportunity costs. Two additional scenarios will also be defined.

Define the opportunity cost of current draws by:

\[ OC = P_t \times \Pi_t^i \{(1+h_t^i)/(1+r_t)\} \times (1+r_t). \]

Recall at the margin Land is purchased on credit by the young; therefore \( P_t = \frac{MPD_t}{(1+r_t)}. \) In order to compare the current productivity of Land (\( MPD_t \)) to the complete stream of opportunity costs, \( OC \) includes today's alternative use of the capital borrowed to purchase LAND as well as future opportunity costs. \( OC \) then is defined as the product of future uses for the Land unit, \( P_t \times \Pi_t^i \{(1+h_t^i)\} \), the current productivity of capital foregone to purchase the Land, \( (1+r_t) \), and then discounted by the re-capitalized value of capital employed to production through time, \( \Pi_t^{i*(1+r_t)^{-1}}. \)

Since equilibrium equates \( MPD_t \) and \( OC \) for any \( i \), models that generate near infinite values for \( OC \) can more generally be characterized as modelling the following condition. Given any stock of Land, the opportunity cost of a Land draw that leads to resource exhaustion, \( OC_e \), is always greater than \( MPD \). Even for the first unit of Land employed to production, which
we label \( MPD_{ft} \), this condition holds. So the resource is necessarily sustained and the actual equilibrium opportunity cost, \( OC_s \), can be identified. Or,

\[
OC_e > MPD_{ft} \geq OC_s,
\]

and

\[
OC_e > MPD^*_t = OC_s,
\]

where \( MPD^*_t \) is the equilibrium marginal productivity of Land.

The high opportunity cost associated with exhausting the resource dominates the incentive to extract the resource to extinction. Any agent that perceives the possibility of eventual resource exhaustion can identify arbitrage gains to conservation. She could realize gains equal to \( OC_e - MPD^*_t \) by holding over the resource for sale tomorrow. This makes the preservation position the true equilibrium. Exhaustion could only be achieved by some market intervention or market failure in this case; but if markets are efficient, exhaustion is inconsistent with agent optimizing behavior under these circumstances.

The scenario above does not assume future opportunity costs are infinite. Rather it more realistically assumes that \( OC_e \) is large enough to exceed the productivity of any given resource unit.

Incentives consistent with preservation are not limited to the optimistic case above. Consider a second scenario in which \( OC_s > OC_e \). Under this general condition it also will always be optimal to identify the general equilibrium solution with the resource sustaining outcome.
If the first unit employed to production is defined by:

$$MPD_{ft} > OC_s > OC_e,$$

then Land will be added to production until $MPD_{ft} = OC_s$. Additional draws toward $MPD_{ft} = OC_e$ will be suboptimal since the young realize a higher value by deferring those units to next period sale, expressed by the present value equivalent, $OC_s$.

Similarly if we find either

$$OC_s > MPD_{ft} \geq OC_e$$

or

$$OC_s > OC_e \geq MPD_{ft},$$

then a corner solution for this period is realized for Land draws. In this case it is optimal to entirely forego period one production of capital if Land is required for production. The period one agent optimally specializes instead in the regeneration of the renewable resource. Optimal behavior in each case still implies that conservation consistent with sustainability is the unique equilibrium as long as $OC_s > OC_e$.

The payoff of any Land draw by an agent is less than the payoff in current capital terms of holding that unit over for resale. This can continue over time until $OC_{si} = MPD_{fi}$.

The conditions under which zero draws are possible may seem strange. Yet since utility considerations along with technical restrictions define prices, this world must be one that has a fairly generous stock of on-hand consumable capital, but finds itself relatively natural resource short.

Finally, the world may be characterized by an equilibrium
solution trace that reflects the following:

\[ \text{MPD}_t \geq \text{OC}_e > \text{OC}_s. \]

Eventual exhaustion now defines the ultimate outcome of this third scenario. The eventual payoff from conserving resources is not as high as current productivity of the marginal Land unit employed to production. If initial stocks are very small so that even the slightest draws, presumably at relatively high marginal productivities, press Land stocks below a biologically sustainable level, then the current cost of foregoing production can be much higher than \( \text{OC}_s \). Land stocks may be so short that sustainability requires zero or near zero draws for several periods; however there is not sufficient capital on-hand to finance conservation. Therefore \( \text{OC}_s \) is small. Further if exhaustion is immanent in one or two periods, \( \text{OC}_e \) could still be large relative to \( \text{OC}_s \). The current unborn will pay a premium for the remaining Land stock, but they find it suboptimal to trade with the following generation. The circumstances that permit this last scenario will be explored at the conclusion of this chapter.

These abstract possibilities broadly outline the possible incentive choices between a resource sustainable path and a resource exhaustion path. While infinite \( \text{OC}_e \) is considered an unrealistic description of the real world, the first scenario \( (\text{OC}_e > \text{MPD}_t) \) is arguably plausible. This work, however, does not determine the relative likelihood of finding a world characterized by any one of the three general scenarios
described but seeks to explore their possibility.

In the next sections, several examples are offered that represent the three basic scenarios just presented. Each example considers a particular growth curve and an initial resource stock purchase by the young. As each case example is presented, it will be associated with one of the three possible scenarios just outlined.

CASE 1

Concave Regeneration Function

We have already referred to this case above.

The problem of unsustained use from over-extraction begins with the resource regeneration function. If at some small stock level the resource begins to depreciate rather than regenerate, the optimizing conditions above may permit the exhaustion of the resource.

Consider the first case. Here unsustainable production is not possible by following market signals. Characterize \( h \) by the following properties:

\[
h'(S_t) > 0 \text{ and } h''(S_t) < 0, \quad S_t \geq 0.
\]

Also

\[
h'(S_t) \rightarrow \infty \text{ as } S_t \rightarrow 0
\]

And

\[
h'(S_t) \rightarrow 0 \text{ as } S_t \rightarrow \infty.
\]

Let

\[
S_t = (\text{LAND}_t - D_{yt}) \cup t.
\]

And

\[
g = S_{t+1} = S_t + h(S_t).
\]

\[ S_t \text{ is the total deferred resource stock. } S_{t+1} \text{ is total carry forward stocks. Next period deferred stocks equal } S_{t+1} \text{ less draws by the middle aged and the young.} \]
Recall that $g$ is the total Land stock on-hand at the beginning of the next period made available from stocks deferred today. $h$ is the net growth of resource stocks. Refer to Figure 5.1.

If $h$ and $g$ are so characterized, it is impossible to exhaust Land through market forces unless capital becomes infinitely productive. Then of course exhaustion cannot matter.

In fact this corresponds to the case where $OC_s$ is infinite.

As long as $g$ lies everywhere above the 45° line even for very small $S_t$ ($g$ globally concave), then the general equilibrium must locate positive resource growth ($h > 0$) for any $S_t > 0$ strictly.

This happy condition is due only to the functional form of $g$ defined by a convex set of all feasible $\{S_{t+1}, S_t\}$ pairs and an infinitely sloped tangent to $g$ at $S_t = 0$. At some point the effect of current and future growth, $\Pi_t^i (1+h'_i)$, must overcome the impact of finitely productive capital so that current and future prices regulate use away from resource extinction.

However there is little justification from biological evidence that this characterization of regeneration is reasonable. Conclusions from models assuming the concavity of $g$ are not robust with respect to this assumption.
Figure 5.1
The Sigmoid Growth Function

Protection of a biological resource typically ensure that an unsustainable small stock of a species is not reached. The mere preservation of a positive stock of a resource is not enough to assure positive growth of the resource. That is, growth reveals \( g(S_t) < S_t \) or \( h < 0 \) for some stock level defined as: \( 0 < S_t < S_t^{\text{min}} \) (see Figure 5.2). Specifically, there exists a minimum sustainable stock level or resource carrying capacity, \( S_t^{\text{min}} \).

Consider a sigmoid functional form for \( h \). This implies that there exists a range of \( S_t \) somewhere in \( 0 < S_t \leq S_t^{\text{min}} \) in Figure 5.2 where \( h \) is convex. This function also assumes that there exists a concave region in the range of \( h(S_t) \) where \( S_t^{\text{min}} < S_t \). The function however does not presume that the entire convex range falls below \( S_t^{\text{min}} \) or that the entire concave range is above \( S_t^{\text{min}} \).

Further assume that the function is continuous and that \( h > 0 \) strictly at some point in the range of \( g \). That is \( g \) lies somewhere above the 45 degree line. Since \( h \) achieves its maximum at \( h' = 0 \), or \( g' = 1 \), if \( h > 0 \) strictly for at least one point, then the point where \( h \) achieves its maximum also will lie above the 45 degree line.

If \( h \) is strictly positive at a point, \( S \), where \( g'(S) = 1 \),

\[ ^4 \text{ If there is no concave portion above } S_t^{\text{min}}, \text{ then } g \text{ falls everywhere below the 45 degree line. This reduces to a non-renewable good - a circumstance we have considered uninteresting to our question.} \]
Figure 5.2
then by continuity there also exists a set of points in an epsilon neighborhood of $S$ where $h > 0$ strictly. This implies that there is more than a single feasible point available in the range of $g$ that admits a sustainable general equilibrium solution where positive draws are permitted.

Figure 5.2 shows a dotted line that indicates a point tangent to $g$ and parallel to the 45° line, $h' = 0$ or $g' = 1$. The concave region where $h$ is positive may encompass a large range of $g$. The slope of a line tangent to $g$ at stock levels just above $S_{t}^{min}$ may be quite large. Similarly, if much of the concave region of $g$ lies below the 45° line, the slope tangent to $g$ just beyond $S_{t}^{min}$ may be quite small.

Case Two

Case II considers the concave region of $g$ to lie entirely above $S_{t}^{min}$. See Figure 5.3.

In this case tangencies to $g$ may achieve all values from unity to infinity between $S_{t}^{min}$ and $S$. This situation is similar in some ways to the functional form for $h$ that is purely concave as in Figure 5.1.

The marginality conditions of the general equilibrium and steady-state allow interior Land stock solutions even at very high capital productivity levels. The possibility of draw solutions that place deferred stocks directly into the convex region are considered in case five. In this case we know that the form of $g$ does not rule out sustainable growth levels at
Figure 5.3
very high levels of capital productivity.

As long as initial marginal Land productivity does not reflect Land scarcity such that $\text{MPD}_{tf} > \text{OC}_e$, the equilibrium will not identify a solution below $S_t^{\text{min}}$ into the convex region of $g$. Barring this exhaustion possibility, discussed in case five, solutions in the concave region mean that sustainability is optimal. This is because $h'$ takes on infinite value above the $45^\circ$ line.

This again corresponds to our first possible sustainability scenario where

$$\text{OC}_e > \text{MPD}_{ft} \geq \text{OC}_s,$$

and

$$\text{OC}_e > \text{MPD}^*_t = \text{OC}_s.$$

Case Three

Figure 5.4 depicts a renewal function $g$ in which portions of the concave region lie below the $45^\circ$.

This shape of $g$ makes it easy to represent a sustainability possibility that does not rely on infinite opportunity costs (Case Three). This same figure will also be used to illustrate the possibility of resource exhaustion even though deferred stocks still lie in the concave region of $g$ (Case Four). Finally both Figure 5.3 and Figure 5.4 represent exhaustion possibilities in which the final quantity of stocks deferred fall into the convex region of $g$ (Case Five).

Consider the possibility of sustainable use of Land marked by the incentive: $\text{MPD}_{ft} > \text{OC}_s > \text{OC}_e$. In this case,
reasonably small values for $h'$ may occur at stock levels below $S_t^{\text{min}}$. Nonetheless, with substantial on-hand stocks available prior to any draws, as draws increase, the relative opportunity cost of deferring versus drawing stocks will increase.

$h'$ takes on values that may well be in the plausible range of values for the marginal productivity of capital, preventing $OC_e$ from dominating the incentives away from exhausting the resource. Rather the future offers better trading opportunities for the present when current resource use permits a sustainable stock level for natural resources. Therefore it is not that the opportunities suggested by resource exhaustion are so high that arbitrage gains to conservation are always generated. Instead the future trading opportunities associated with the exhaustion of a productive resource are so low relative to the trading opportunities afforded by future agents that are able sustain use of the resource that the future successfully 'bids' current agents away from unsustainable high draws.

The increase in opportunity costs associated with successive draws results because of the long term productivity of the resource. The future that maintains the resource is sufficiently endowed to affect current prices and to encourage resource conservation. Exhaustion on the other hand does not induce near infinite bids from future agents. Rather exhaustion, should it occur, impoverishes the future. This
Fig. 5.4
means that future endowment opportunities can only offer relatively weak trading opportunities from a future that faces the ultimate scarcity of a highly productive asset.

We might expect a sufficiently well endowed present to be able to finance current capital production and consumption while also save sufficient input stocks to be sold to a future generation. Sufficient sales of assets between generations implies that the next generation will also be wealthy enough to offer a price for those saved stocks to prevent over-exploitation of current assets that eventually lead to the exhaustion of an asset.

This is consistent with our case three. Sufficient Land and capital stocks are available to allow both substantial current resource draws and a large enough deferment of resources for sale next period so that the next generation purchasing LAND can also afford to purchase enough LAND to satisfy their production plans and to induce enough speculative holding of resource stocks for sale to their succeeding generation two periods hence. With sufficient current wealth and with sound prospects for future wealth, ongoing incentives sustaining the resource can occur with relatively low opportunity costs associated with exhaustion.

CASE FOUR

Exhaustion occurs any time the future generation values marginal resource stocks associated with exhaustion more
highly than that it can offer for current resource stocks associated with sustainability unless, of course, the future value of current resources is wholly dominated by the future's willingness to pay for resource stocks in an economy that will eventually exhaust the natural resource.

Since the marginality conditions on renewability do not imply a sign to net growth ($h_t$), a solution to $S_t^*$ may lie below $S_t^{\text{min}}$ and still satisfy the optimality identities of the economy. That is there is no special signal or self-corrective device other than expected price increases that prevents draws of Land near $S_t^{\text{min}}$ from falling below $S_t^{\text{min}}$.

Refer again to Figure 5.4. Consider a solution to deferred stocks that lies in the concave region of $g$ below $S_t^{\text{min}}$. The incentives that correspond to this case must be defined by:

$$\text{MPD}_{ft} \geq OC_e > OC_s.$$

With $(1+r_t)$ large and $P_2/P_1 > 1$ (expected as the stock falls below the sustainable level), the solution must identify $h_t' < (1+r_t)$. However if the slope of the line tangent to $g$ at $S_t^{\text{min}}$ is small relative to $1+r$, then the price increase implied by the draw moving $S_t^*$ into the unsustainable range of $g$ may not be large enough to prevent that draw. The environment that might produce this will be discussed following Case Five.

CASE FIVE

Exhaustion is not restricted to solutions below $S_t^{\text{min}}$ in
the concave region of $g$. Deferred stocks may also move directly into the convex region of $g$. Figure 5.5 illustrates an initial quantity of Land purchased, $S$, and a final deferred stock level, $S^*$. 

Given appropriate initial conditions, solutions into the convex region of $g$ can be generated from either Figure 5.3 above where the concave region lies entirely above $S_t^{\text{min}}$ or from Figure 5.4 where portions of the concave region are below $S_t^{\text{min}}$.

In either case the corresponding incentives must be defined by:

$$\text{MPD}_t > 0, \text{Ce} > 0, \text{CS},$$

as in Case Four above. In this case, however, the equilibrium solution $\text{MPD}^* = 0, \text{Ce}$ is achieved after considerable draws of on-hand stocks.

Case Five is important later in evaluating interest rate policies designed to induce conservation. The possibility of Case Four or Case Five exhaustion is itself uninteresting; but the prospect of a solution into the convex region of $g$ offers a warning to market interventions that fix prices and lower current social welfare to benefit the future. Declines in wealth generally make the future vulnerable as explained below. Conservation policies that appear to stimulate conservation in the neighborhood of prior solutions need to be strategically targeted to avoid dramatic shifts in stock deferral into the convex region of $g$. 
Figure 5.5
The Possibility of Exhaustion

The inherent protections in this economy against natural resource exhaustion, the structure of arbitrage incentives implied by sustainability and the Case Two and Case Three illustrations of these protections are reasonably quite strong. The circumstances that make possible resource exhaustion however are more elusive. Specifically what conditions could plausibly permit an environment characterized by: \( MPD_{ft} \geq OC_{e} > OC_{s} \)?

A special concern for exhaustion exists in this model for economies defined by small per capita wealth that makes the incentive structure above feasible. The problem of population increases is considered a likely cause of the erosion of per capita wealth and introduces a vulnerability to adequate resource conservation.

Therefore consider the current value of stocks on-hand to be small, meaning wealth is small. This means that there is a limited ability to generate sufficient production from on-hand stocks. It also means that the wealth of the succeeding generation is also small since their wealth is derived from asset purchases from the preceding generation.

If Land stocks fall close to \( S_{t}^{min} \), conservation necessarily implies even further current production constraints. This will further reduce the wealth that can be transferred through sale to the young next period. If capital too is in short supply, \( OC_{s} \) will likely be small relative to
the current production payoff from using the critical resource stocks just above $S_{t,\text{min}}$.

$OC_e$ may also be high. $OC_e$ represents the willingness to pay by the next generation for the stocks deferred with an anticipation of exhaustion. With stocks depreciating ($h < 0$), stocks will be quickly employed to production over the next periods until exhaustion, suggesting incentives to use remaining stocks quickly. For simplicity, suppose exhaustion occurs one period hence.

$OC_e$ reflects the value of Land stocks employed to production by the next generation. There are no remaining speculative motives for purchasing LAND as the next generation intends no LAND sales. Marginal productivity of the few, but unsustainable, units of the resource next period is likely relatively large. In fact if the distance between $S_{t,\text{min}}$ and the origin is also very small, this real scarcity of Land may generate demand for Land next period that approaches the entire productive capacity of assets purchased by the next generation, or the choke price for LAND. This accelerates the opportunity cost, $OC_e$.

The distant future of course may be very poor following exhaustion; but the next generation is able to realize greater wealth and therefore offer a higher price for the unsustainable small stock of Land carried into the next period by 'inducing' the present to commit a larger share of remaining resource stocks to current production. If the
present instead suppresses production to accommodate sustainable resource stocks, so few stocks would be available for sale to this alternative future that the relative value of Land stocks delivered suggests a relatively unprofitable opportunity to conserving. That is OC_e > OC_s. Similarly the high initial productivity of the first draws implies MPD_{ft} > OC_e.

Returning to the identity:

\[ P_t \Pi_t (1+r_i) = P_i \Pi_t (1+h'_i) , \]

Case Four and Case Five illustrate the possibility that a relatively poor economy can realize a value of Land transformed into capital today (the LHS) that outstrips the value of transforming the Land unit into capital at a future period i (the RHS). This encourages resource use to the point that the renewable resource cannot be sustained indefinitely.

The possibility of exhaustion of a natural resource asset that is renewable and highly valuable to production can exists in purely efficient markets in this economy. This is true even though that exhaustion may surely impose catastrophic hardship on distant future generations.

**Population Growth and Welfare**

The possibility that an economy could emerge so asset poor in both Land and capital is a condition that may seem implausible. The original motive for Capital and Land growth
models was to explain economic growth from a world that starts Land rich but capital poor. Technology permits efficiency gains in moving to a lower resource stock level in exchange for a more highly valued stock of capital. So how does an economy become so Capital and Land short that it is inefficient to sustain the natural resource?

An economist's response may be that markets were historically prevented from clearing: non-rivalry or nonexclusiveness of goods, intrusive public policy et cetera. These problems could erode the value of assets owned by agents and effectively throw away Land stocks. However the optimization problem in which agents engage in their childbearing decision systematically frustrates the process of development.

To consider the effect of population pressure, we use the steady-state and the difficulties of developing to an adequate steady-state consumption level in the presence of population increases. If population growth is inconsistent with a steady-state, the possibility that the functional form and parameters of the population growth function, \( \rho \), may systematically challenge future welfare makes the issue of population growth part of the conservation question generally.

Consider the following steady-state conditions.

1. \( (1 + r) = (1 + h') \)
2. \( h = g - S_t = \rho \cdot D_y + D_m \)
3. \( N_y/N_m = \rho \cdot (C_m) \)
Equations (1) and (3) are simple steady-state conditions defined in chapter three. Equation (2) is a material balance identity for a steady-state.

Steady-state stocks of Capital and Land are per capita stocks. Therefore, equation 2 equates \( h \), the magnitude of natural resource growth in a period by the representative owner, to the use of that net growth: Land draws by the representative middle-aged plus the draws by a young agent scaled by the relative increase in population.

For discussion we divide equation (2) through by \( S_t^* \). This permits (2) to be expressed wholly in terms of proportions. Or, (i) \( \eta = \rho \cdot d_y + d_m \).

\( \eta \) is the proportion of resource growth relative to steady-state stocks and \( \rho \), of course, is the ratio of population increase.

It is true that Land can be sustained in the steady-state only if \( \eta > \rho \) strictly whenever \( d_y + d_m > 0 \). Otherwise draws must be decreasing from period to period.

Now recall that \( \rho \) contains only \( C_m \) as its argument. Figure 5.6 illustrates a shape of \( \rho \) consistent with the stylized facts regarding population growth. There is a minimum consumption level, \( C_{\text{min}} \), and a maximum consumption level, \( C_{\text{max}} \), at which \( \rho \) is zero. Between these two points \( \rho \) is positive. If \( \rho > 0 \) in a steady-state, consumption must be equal to levels typified by \( C_{ML}^* \) or \( C_{MH}^* \) to satisfy identity (i).
Growth (percent)

$\rho_{\text{MAX}}$

$\nu^*$

$\rho^*$

$\nu^* = \rho^* d_y + d_M > \rho^*$

Figure 5.6
The concern is simple. The amount of $S_{t+1}$ that is eventually sold, $\text{LAND}_{t+1,m}$ must equal $S_{t+1} - D_{t+1,m}$. $\text{LAND}_{t+1,m}$ must be then be allocated over a newborn generation which is proportionally larger than generation $y$ by $\rho$. If a Land rich/Capital poor economy hopes to develop to a steady-state with consumption equal to $C_{\text{HH}}^*$, this will imply initial reductions in deferred stocks. The range of $\rho' > 0$ and the magnitude (height) of $\rho_{\text{max}}$ determine if resource stock reductions to the steady-state permit $C_{\text{HH}}^*$ to be a solution.

We can compare the ability of a growing economy to tolerate the dual pressures of population increases and resource draw increases.

The tolerance of the resource to accept deferred stock reductions is found in the ratio:

$$\frac{(h_t - \rho_t^*D_{ty} - D_{tm})}{S_t - S_t^{\text{min}}}.$$

If this ratio equals minus one, resource stocks reduce to $S_t^{\text{min}}$. If $D_y$ and $D_m$ are required to sustain a rise in consumption toward $C_{\text{HH}}$ for $\rho > 0$, then the ratio above tracks the ability of the resource stock to tolerate declines toward the steady-state. The smaller the ratio, the lower the tolerance.

If the ratio is negative, stocks are declining. Tolerance can never equal minus one in any period. This index will also be useful in motivating Safe Minimum Standard (SMS) policies later.
This, of course, describes the race between accelerated welfare and the accelerated population increases in economic development. The restrictions on Land draws necessary to offset population growth and assume stocks above $S^{\text{min}}$ make steady-state solutions at $C_{\text{ML}}^*$ very plausible.

As stocks are drawn down to accumulate capital stocks, the overall value of on-hand assets may improve initially. This permits increased consumption but this also increases population growth. If the pace of wealth increases are not sufficiently large to offset population growth, the surge in wealth is not sustainable and the economy may settle into a steady-state position, $C_{\text{ML}}^*$.

The conservation question however sees a future position where stocks of both Land and capital become so short that intolerance could fall below minus one and the resource erodes.

In this case the incentives in the initial position identify an equilibrium:

$$\text{MPD}^* = OC_e > OC_s.$$ 

In the original Land rich/capital short position the value of land transformed into capital is high enough to pace the decline in land stocks beyond their sustainable capacity.

Anticipation of population growth increases effective demand for assets while making it more difficult to accumulate per capita wealth.

The higher the value of assets on-hand, the greater is
agent wealth and expected future agent wealth. As argued wealth enables the agent to finance adequate Land purchases to accommodate production through both periods of their productive life and to purchase enough additional Land that will be later resold to sustain Land draws through time. Wealth increases the opportunity costs associated with sustainability, \( OC_s \). Therefore population increases suppress \( OC_s \) increases.

At the same time population increases do increase the derived demand for inputs for production purposes by adding more demanders. This accelerates the magnitude of \( OC_e \), the opportunity cost associated with resource exhaustion. If population growth is large enough to stimulate the current production demand for Land relative to the speculative demand for Land, the conservation incentives may not be strong enough to sustain the resource. The identity

\[
P_t \Pi_t (1+r_i) = P_i \Pi_i (1+h'_i),
\]

equates the transformation of Land to capital today (period t) rather than transforming the Land unit to capital in period i at a level of current Land draws that cannot sustain production. The pressures of population growth highlight a reasonable feature of our economic model that permit the incentives that induce exhaustion to exist.

**Constant Returns to Labor and Resource Stocks**

Using a more fully specified model, the simple arithmetic
of the three accounting identities is sufficient to generate concern that population growth can pose a serious threat to the exhaustion of natural resources. Population increases can certainly restrict per-capita production growth enough to limit long run consumption possibilities. Even so, this discussion regarding the regenerative function, \( g \), is itself optimistic. This is because the resource growth function modelled reflects net resource renewal that increases by exact proportion according to per capita holdings.

As modelled, aggregate growth is not determined simply by aggregate stocks. Rather aggregate growth is determined only by per capita stocks scaled by the number of resource owners. The presumption in the model is that the agent purchases natural resource stocks some of which are deferred for growth and eventual sale. Therefore, growth reflects this individual decision process and individual caretaking. For simplicity the model as presented reflects constant returns to per capita net growth as total resources and the number of agents increase by the same proportion. So \( g \) is independent of aggregate resource stocks; and per capita renewal is the same if \( n \) agents own \( m \) units of the resource as if \( K \times n \) agents own \( K \times m \) resources (\( K \) non-negative). Although \( g \) eventually reflects diminishing returns to scale for the individual agent expanding individual deferred holdings, total stock renewal increases in constant proportions to per capita holdings.

The strength of identity (i) and relation (ii) rests with
this description of the regenerative capacity of natural resources.

Suppose instead that \( g \) is defined exclusively by global stocks rather than per capita stocks. Agents can then be considered share-holders of resource stocks that will renew at the same magnitude regardless of per capita holdings. Therefore the marginal productivity of labor on resource renewal at this other extreme is zero. In this case a steady-state that continues to use Land is not consistent with any permanent population increase. If draws are to remain positive and constant from period to period, then net growth in stocks, \( h \), must be defined in the steady-state by:

\[
h = \sum_y D_y + \sum_M D_M
\]

Any growth in population must be realized at the expense of draws when \( h \) is invariant to the distribution of stocks. The prospect of non-individuated renewal of natural resources augments the possibility of exhausting these resources or of realizing low consumption levels in the future. The three steady-state conditions outlined earlier become:

1. \((l=r) = g'\)
2. \( h = \sum_y D_y + \sum_M D_M = (g - \sum_i S_i) \quad S_m = 0 \)
3. \( N_A = N_y = N_M \)

That is no balanced growth is possible given the form of \( g \) without exhausting the natural resource. This is particularly
discouraging if we look again at Figure 5.6. If \( \frac{dN_y}{dt} \) increases through time, \( h \) must fall. Stocks allow only steady-state solutions less than \( C_{\text{min}} \) or greater than \( C_{\text{max}} \).

None of the basic theoretical conclusions of this work are altered by this change. Yet this characterization of \( g \) accelerates the urgency of the conservation question with respect to population growth. Population pressures over time lead commonly to either exhaustion of the resource or to a limited employment of the resource. This can cause low production and low consumption in the long run as we have seen. But any sustained population increase is not possible if one admits a regenerative function that admits total resource stock levels as an argument in the individual owner's renewal process such that per capita growth increases at a decreasing rate with global resource stock levels. This accents our conservation question and the feasibility of population growth to affect the likelihood of exhaustion of a renewable natural resource input.

**Conclusion**

This chapter legitimizes the conservation question. The intuition that there are natural phenomena that may be antithetical to an economy's ability to sustain human welfare exclusively through individual agent incentives is rationalized. Even if preferences are well-ordered, expressible as a utility function that is both monotone and
globally concave, and no market failure is present, the shape of the growth function can allow the exhaustion of an important natural resource.

Similarly, conservationists maintain the intuition that population pressures inherently challenge the long-run sustainability of welfare. This intuition is demonstrated to be relevant in the context of the modelled economy. Even moving away from Malthusian prospects, an economic explanation for the motives to bear children is insufficient to assure fully efficient markets will pre-empt an unwanted exhaustion of a natural resource from population growth pressures.

Nonetheless the protections for the future embedded in our economic model are substantial. The dynamics of the savings and investment behavior of agents suggests that future preferences, even distant future preferences, motivate agents to hold over capital from period to period. Solutions to a conservation crisis that try to preserve these incentives are likely to be more effective.

In the next chapter two conservation policies are evaluated. We take into account the legitimacy of the conservation question and the savings incentives that drive the Land and capital markets in our model in this evaluation. Both policies investigated fail in some material way to account for the economic incentives of agents, making the policies either ineffective or themselves damaging to future prospects.
Variations of these two policies are identified. Each variation relies on principles of a Safe Minimum Standard (SMS) policy. However the variant policies are either too erratic to be workable or too strategic so as to be implementable only through a fully specified moral theory. Out of this discussion, a direct SMS policy framework is introduced. This framework is considered sufficient to assist our resource manager in providing for the future in a fashion that minimizes control of economic activity and is justifiable under a broad set of plausible moral theories.
CHAPTER VI

Conservation Policies

We determined that our economy permits the exhaustion of a natural resource input highly valued in production. This possibility introduces a legitimate conservation concern regarding the ability of an economy to sustain consumption levels far into the future under certain plausible conditions. A sigmoid resource renewal function, asset markets that transfer productive inputs between overlapping generations and an economy that produces essential outputs using man-made and natural resource inputs that partly complement each other in production combine to admit a relevant conservation question.

The prospect of an unwanted resource exhaustion confronts our resource manager with the challenge to identify robust policies that can answer the conservation question. Yet the manager is not justified in directing all economic activity through time according to a centrally defined objective without considerable cause.

In this chapter two conservation policies are entertained. A reduced interest rate policy designed to mitigate or eliminate the discounting of future demands is offered. Another policy offers that we endow the imminent future generation with all productive assets of the economy,
turning young agents into suppliers and the middle aged into asset demanders.

Both policies ignore the impact of intergenerational trade on aggregate production. Therefore we conclude our critique of these policies with an application of Coasian principles operating in our economy.

Finally strategic variants of these policies are considered. The strategic interest rate policy that we introduce is considered too erratic to reliably guide our manager. Conversely the strategic property rights policy is too ambitious to be adopted given the ambiguities of our moral obligations to the future.

However both of the strategic policies reflect some elements of a solution to the conservation question. The insight of these common elements motivates the policies in the next chapter.

The Interest Rate Advocate

Real World Advocates

The strong advocate endorses economy-wide interest rate reductions in order to increase the opportunity cost of drawing Land today. Recall the identity,

\[ p_t \Pi_t^i (1+r_i) = p_i * \Pi_t^i (1+h_i'). \]

By reducing the LHS of the equation above, the relative opportunity cost of drawing Land represented by the RHS increases. The argument claims more Land will be diverted
from production to conservation until relative current prices, $P_t$, increase to bring about a new equilibrium. That is the advocate relies on agents substituting capital for Land in their current production plans.

This argument seems to maintain enough real standing in the literature to warrant our critique. Certainly among non-economists the rhetoric about discounting has come to mean that positive interest rates express a myopia that literally discounts future demand relative to the present. Noted conservationist Paul Erlich remarks that economists "...assume that we can live in a world of high discount rates forever - no need to worry about how today's action will influence people a decade hence..." (Erlich, 1989).

We might ignore these polemics (the quotation above being an extremely polite representative) if the arguments were not considered compelling and influential among policy-makers. Current Vice-President Albert Gore echoes the conclusion of intergenerational injustice from discounting. "The effect [of discounting] to magnify the power of one generation to compromise all future generations" (Gore, 1992). This 'discrimination' is embedded in "the accepted formulas of conventional economic analysis [that contain short-sighted and arguably illogical assumptions about what is valuable in the future as opposed to the present .... [allowing] to continue to act as if it is perfectly all right to use up as many natural resources in our own lifetime as we possibly can"
The confusion, however, goes well beyond a simple call to economists to educate our policy-makers. The lack of comprehension of the problem of reducing the discount rate, demonstrated below, to achieve intergenerational equity emerges from inside our own discipline. The Vice-President can hardly be blamed for his conclusion. In these same passages he cites a well positioned Harvard trained economist, Herman Daly, decrying the effect of discounting procedures in public decision analyses with the conclusion that "there is something fundamentally wrong in treating the earth as if it were a business in liquidation" (Daly & Cobb, 1989 quoted in Gore, 1992). Daly is not alone.

The concerns that discounting is systematic theft from the future is repeated by Mishan and Page in their classic 1970 texts regarding cost-benefit analysis and resource conservation (Mishan, 1976 & Page, 1977). The search for an ethically responsible discounting rule to manage the conservation question persists in the most current literature. The Journal of Environmental Economics and Management devoted a series of supplementary articles dedicated to this question in March 1990. Confident that very recent examples would emerge, two articles, Young and Burton (Young, December, 1992 & Burton, March, 1993), were located just prior to closing this work. Both of the later articles explicitly associate the interest rate with intertemporal equity. Each offers a
scheme to exempt projects with extra-generational welfare effects from interest rate rules. Each derives a new current consumption/savings formula to mitigate intergenerational inequity.

All of these authors fail to realize that equation 1) above reflects indifference between transforming the marginal unit of Land into capital today or leaving it to grow until period i. Not only is the present generation indifferent but period i agents are indifferent to the transformation as well. As long as a policy intervention does not make the price stream invalid, the use of current prices, including interest rates, in guiding policy records marginal optimality by the future to current decisions. It is not clear from the literature that our best economists are mindful of this as they discuss long run sustainability. We seem to accept that marginal discounting represents global disregard.

Even Solow (Solow, 1992) in his address to Resources for the Future (RFF) marking its fortieth anniversary throws up his hands and simply accepts that discounting inherently represents market myopia. It's worth a moment to consider his response to this myopia as an illustration of some of the confusion that surrounds the role of interest rates in an economy.

Solow proposes a savings plan to reinvest all producer surplus from resource use in any period into productive assets. This assures that we convert the rental value of
productive natural capital used in any period directly into productive man-made capital. Yet this is a condition that would already exist in an idealized perfectly competitive market. If natural resource owners are to remain competitive and not be outbid by other natural resource owners, then the Land value from which the resource is harvested will already capture this rental value. Solow's advice to our resource manager is restricted to the command: Allocate resources according to economic efficiency! Therefore Solow's plan fails to resolve our conservation question that finds exhaustion of a renewable necessity possible inside a perfectly efficient market. Even further this highly visible proposal embeds assumptions about the discount rate that empowers our interest rate advocate.

Even within the context of its own model, the proposal may indeed dissolve from a failure to be aware of embedded assumptions about the origin of positive market interest rates and input substitutability. The reader is referred to a review of the Hartwick Rule (Hartwick, 1977) which is the rule Solow is recommending. Using the same basic modelling structure, Svenson points out that if interest rates change though time, an adoption of the Hartwick rule (which implicitly assumes constant capital returns) will generate solutions in which long run consumption can either improve or
decline (Svenson, 1986). This failure to insure sustainability echoes conclusions from our model in which we endogenize the process of changing interest rates.

This confusion about the role of discounting in an economy may divert our conservationist from articulating an economically valid conservation question. If one takes Solow's acceptance that discounting implies myopia and then notes that his program only replicates a market efficient outcome, one could see in the Hartwick economy a reason to interfere in resource markets and impose a conservation friendly constant interest rate on the economy. This price ceiling will manage the rapid transformation of the economy to the most technically feasible sustainable steady-state in a fashion not too dissimilar to the steady-state program detailed by Daly (Daly, 1990).

Our inability as a discipline to ask and answer a legitimately posed conservation concern is a failure that can motivate our policy advocate's proposal. So from several sources in current literature, the reduced interest rate agenda is not without its real world advocates. The confusion

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1 Maler (Maler, 1986) also notes that the Hartwick Rule breaks down if the elasticity of substitution between Land and capital is less than unity and does not follow the Cobb-Douglas form of CES.

2 Daly does not actually propose initiating the movement toward a steady-state by first reducing interest rates in this 1990 work though he is critical of positive interest rates generally.
I submit emerges from the lack of a clear, fully specified model to delineate the role of interest rates in transferring capital to succeeding generations. Therefore the advocated claim warrants our review within the context of our model.

The Advocate's Claim

In arguing her position, the reduced interest rate advocate also notes a long run conservation advantage. Using the steady-state identities and the resource renewal function, a threat to resource exhaustion can be mitigated with an interest rate reduction.

Figure 6.1 illustrates this argument. If a steady-state exists, the identity $P_t = P_i$ implies $r_i = h'_i$ for all $i$. The original equilibrium implies that deferred Land stocks fall below or near to $S_{min}^t$ given an interest rate $r^0$. Yet exhaustion occurs in the concave range of $g$. So reducing $r$ induces a movement to a new steady-state $1+r^1$. If the solution remains in the concave range of $g$, lower $h'$ will mean more Land is conserved. There is also a long run benefit as steady-state draws now increase because $h' > h^0$ when $h'' < h''$. Resulting social surplus losses only underscore a direct competition between existing and future agent welfare.

The claim needs to be substantiated however within the context of a general equilibrium and the conditions that are likely to generate a legitimate conservation concern.

Critique of the Strong Claim
Preview of the Critique

Our conservation question demonstrated that the renewable resource could be pressed to exhaustion inside efficient markets. Exhaustion translates into a relevant sustainability
Fig. 6.1

\[ 1 + r^1 = 1 + h^1 \]

\[ 1 + r^\circ = 1 + h^\circ \]

\[ h^1 = S_{t+1} - S_t \]

\[ h^\circ = 0 \]
concern if there are complementarities in production between Land and capital. This property leads us to associate exhaustion of the resource with a dramatic decline in long run consumption. Any legitimate conservation policy needs to respond to the same conditions that generate a legitimate conservation question.

Our critique of the interest rate policy begins with the economic surplus losses generated by that policy. We point out a dichotomy between a conservation question that emerges from conditions of inadequate per capita income and a conservation proposal that reduces incomes further. Though any conservation policy results in some economic losses since it must interfere with efficient market allocation, it is incumbent on a policy advocate to illustrate that the proposed intervention robustly reduces an exhaustion risk. We find that the interest rate policy is a very blunt instrument that likely results in severe economic losses with only chanced conservation protection.

Support for the policy assumes the price control shifts the relative opportunity costs away from drawing down the resource toward conservation. The advocate assumes that the substitution effect of a reduced interest rate will shift production plans away from Land and toward capital. They implicitly assume that this substitution effect swamps any income effects resulting from the price ceiling. The policy therefore initiates greater resource conservation.
We argue that a conservation benefit is possible but unlikely. We recall that the relevant conservation question is motivated by a concern that the inputs exhibit a strong degree of local complementarity. The high degree of substitutability required to affect conservation through this policy instrument contradicts the properties that make the conservation question relevant in the first place. In addition, the structure of the market means that the positive excess demand caused by the price ceiling will probably result in reduced capital sales to the young. The income effect of this restriction on the young is arguably quite severe, particularly if a conservation crisis is indicated. We argue that the income effect suppresses Land purchases and increases the appetite for production needs for Land relative to speculative demand incentives. So we argue that income effects are likely to dominate substitution effects following an interest rate ceiling. Therefore the policy will be ineffective. Because of insufficient per capita incomes and a high degree of complementarity between inputs, the same reasons that commonly induce a conservation crisis, the interest rate policy may accelerate the pace of the conservation crisis.

Given the initial intuitive appeal of the interest rate policy and its historic roots in the profession, we will detail the above argument. By drawing out the implications of a conservation crisis that emerges from a combination of low
per capita income and a high degree of local complementarity between Land and capital, we trace a scenario through the asset markets to illustrate the feasibility of decreasing conservation following a reduce interest rate policy. We show that the modified Hotelling Rule can be satisfied by young agents who increase stock draws into the convex range of the renewal function following the introduction of an interest rate ceiling.

The Critique

We want our policy to induce an increase in per capita Land deferments by the young under the same conditions that admit a relevant conservation question. Using the two asset markets of our modelled economy, we need to trace conservation first through LAND exchange decisions between the young and the middle aged as a result of the price ceiling on capital exchange. Then we need to investigate the draw or deferment decision of the young.

The demand for Land reflects the productive possibilities of Land in our economy. The demand curve represents a diminishing willingness to purchase LAND for current production by the young plus a declining discounted demand for Land draws at any time in the future, reflected as a 'speculative' demand by the young. The supply curve for Land represents an increasing requirement to be compensated for pulling Land stocks out of production for sale.

So to evaluate the strong advocate's claim, we return to
the properties of production that make our conservation question relevant to the ultimate sustainability question; and we investigate how these properties impact supply and demand in the productive asset markets.

Recall that Land and capital are not perfect compliments but reflect a non-trivial degree of complementarity. Zero application of one asset suggests very low or zero output. Similarly, low use of one input implies that a large marginal productivity of the other input is required for significant output. CRTS is permitted; but when one asset is fixed additional applications of the other realize diminishing returns. We illustrate these properties in Figure 6.2 below.

The figure maps capital output to units of input i employed to production for various levels of input j already
Fig. 6.2
committed to production. The example reflects both inputs necessary for production. Or \( f'_i = 0 \) whenever \( j=0 \). The rays could also intersect the \( y \)-axis above the origin.

As more of the given input \( j \) is used, the marginal productivity of a given unit of \( i \) increases. So \( f''_{ij} > 0 \). That is, \( MPK'_0 > 0 \) and \( MPD'_x > 0 \). But complementarity increases rise at a declining rate which can be seen along a vertical line through \( i > 0 \). So \( MPK''_0 < 0 \) and \( MPD''_x < 0 \) (i.e. \( df''_{ij} /dj < 0 \)). This later property, of course, is just equivalent to \( f''_i < 0 \) for a given \( j \) moving along any given ray with \( j \) fixed. Again CRTS need not be violated. As \( i \) doubles, a doubling of \( j \) also doubles output in this example and our price-taking agents produce along the path 'l,' tracing out points of price equilibrium. The nature of complementarity and substitutability represented makes the conservation question a serious sustainability question.

So given these production properties, how does a binding interest rate ceiling affect the supply and demand schedules in these two markets?

The price floor initially identifies a positive excess demand for borrowed goods in the capital market. Since a new structure is introduced into the economy, market schedules will readjust to a new equilibrium.

Middle aged suppliers still posses the same amount of on-hand capital and Land. Certainly there are gains from trade losses for period two agents identified by the producer
surplus loss identified in Figure 6.3 in the capital market; but this loss does not shift the supply curve. The value of reduced capital sales does come at the expense of consumption over the next two periods; yet this marginal loss of opportunity as trade falls exactly defines the marginal decision process that defines movement along the supply curve as the agent decides between sale and lending over a fixed stock of on hand capital.

The supply curve will shift with quantity sales of LAND. Supply in both markets expands if the quantity of Land sold grows and contracts if the quantity of Land exchanged falls. This is due to the complementarity of the inputs. More LAND sold means fewer draws by the middle aged. This reduces the marginal returns to capital in production and makes the middle aged more willing to sell capital. So in general conservation is encouraged by expanded LAND trade and discouraged falling LAND trade.
Fig. 6.3
Conservation and a drop in r

For the reasons above we expect the supply schedules to move together. In response to an interest rate drop these shifts depend on the movement of demand. If demand responses are trade reducing, both supply schedules respond by retraction.

The advocate notes that a drop in r has two conservation effects, making the policy trade expanding. First the current capital value of the deferred resource conserved increases as opportunity costs increase. This expands the so-called speculative returns to Land ownership, shifting out demand for LAND by the young and raising current prices. Simultaneously, the funds used to purchase the natural resource are borrowed in our economy. With reduced capital costs, the relative affordability of the marginal unit of Land, \( P_t = \frac{MPD_t}{1+r_t} \), increases. This further shifts out the demand for Land.

Figure 6.4 traces this happy outcome. An increase in Landy to Landy\(^1\) reduces Land available to the middle aged for production. This makes the middle-aged more willing to part with now marginally less productive capital, shifting \( B_m^0 \) to \( B_m^1 \), resulting in a consequent shift in Land supply to LAND\(_m^1\).

The increase LAND sales exactly record the draw decreases by the middle aged. The young, who have acquired both more
LAND and capital, commit some of the additional LAND to production and some to conservation. Additional capital is similarly apportioned between consumption and production. The relative increase in opportunity costs additional deferments are likely substantial.

The young increase LAND and capital use; but with relative price increases of Land to capital, the increase in draws is proportionally small. That is decrease draws by the middle aged exceed increase draws by the young, increasing deferments. Figure 6.5 records conservation increases defined by the total decrease in draws from \((n_y + n_m) * D\) to \(n_y D_y^1 + n_m D_m^1\) for an increase in deferments of: \((D - D_m^1)n_m - (D_y^1 - D)n_y > 0\). Further this conservation is achieved within the context of the production properties and market structures outlined by the model.

The example fails to trace the surplus losses of the price ceiling. In this example the young are able to produce and consume more since the middle aged are willing to sell more. Life-time budget opportunities of all agents increase from the policy. Additionally, all future generations benefit from increased wealth as the interest rate is dropped.

So within the context of this example, lower interest rates raise the discounting of future demands closer to unity.
\[ (D - D_m') \cdot n_m = L' - L^* \] (Figure 6.4)

\[ (X - X_m) \cdot n_m = B' - B^* \] (Figure 6.4)

**Fig. 6.5**
and erode the myopia of the market. By logical extension, an interest rate of almost zero will maximize conservation and generate the greatest benefit to the future.

General Equilibrium Arguments

This argument by the strong advocate however fails. Reviewing both markets as an entire general equilibrium really assists this critique. The price ceiling is presumed to pose no losses on the young and, by extension, the succeeding generations (only generations up to the point of resource exhaustion from the baseline). In fact these agents are made better off. This gain is recorded in Figure 6.4 as a real addition to consumer surplus for the young. However the entire process, stimulated by an interest rate reduction that shifts out demand in Land, creates a gain in total economic surpluses of trade to the economy from the price restriction.

The scenario presented by the advocate is not consistent with the micro-economic foundations of a general equilibrium. In the Land market, gains to both the young and the middle aged are identified - essential to claim of by the advocate. If these gains were available to the agents in the original position, the incentives of trade would have identified this mutual opportunity. The middle aged would have offered more goods for sale and the young would have purchased more LAND without the policy.

The original general equilibrium solution can be identified by modelling the economy as the maximization of
social surplus. Or,
\[
\text{Max} \{ \int_0^p (P(D) - P(S)) \, d\text{Land} + \int_0^r (r(D) - r(S)) \, dK \}
\]
subject to the life plans of the middle aged, the young, the stream of all future agents, the production function, the resource renewal function, the population growth function and market clearing condition that total quantity sold equals total quantity purchased in the Land and capital markets in any time period. This pre-empts the existence of another set of prices and traded quantities that realizes total social surplus strictly greater than that identified by an equilibrium.\(^2\) Therefore the argument that an interest rate reduction reverses discounting of future demands in the fashion argued above is untenable.

The surplus losses realized from the price ceiling must be accountable through changes in either asset market. For illustration, the welfare loss that can be identified from Figure 6.4 (areas A+B) must equal the difference between total surplus in the original baseline position and total surplus in the final position. This means either the supply or demand curve must retract, making the response in the Land market

\(^2\) A real economy may identify a local optimum because of information or transactions costs, entirely consistent with an efficient economy, that prevents a global optimum. It is encumbent on the advocate to demonstrate that drops in \(r\) systematically move from a local optimum to a higher surplus environment because of the price restriction. Nonetheless in our modelled economy with perfect common knowledge, the economy achieves a global optimum to surplus maximization and prevents the advocate's result.
posed by our advocate inconsistent with the underlying agent incentives embedded in our economic model.

The argument entirely ignores the income effects on the young from the reduction in interest rates. The life-time opportunities for the agent require access to productive capital in order to produce final consumption goods. If the trade restriction on the price of capital exchange induces the middle aged to divert resources to production and away from trade, then the access to productive capital by the young erodes. This reduces life-time opportunities, or the budget, of the young and generates a depressing income effect on demand during the crucial capital building first period of productive life. If we also note that future lending prices anticipated by young during their second period have also been reduced by the policy, the income effect on period one demand for inputs can be considerable.

The initial impact of the price drop motivates suppliers to extend fewer capital loans given positive excess demand. After this initial response the following readjustment is consistent with the micro-foundations of a general equilibrium.

Complementarity between Land and capital means that the increase in capital diverted to production by the price ceiling will make Land marginally more productive now. This will have a restrictive impact on the supply of Land by the middle aged as draws divert Land to production.
The young face reduced access to capital. Directly less credit is available to purchase Land. Indirectly, reduced capital employed by the young in production will shift inward the demand for Land, now marginally less productive. Figure 6.6 illustrates the shifts in both supply and demand in both asset markets stimulated by the reduced interest rate policy. Note that the total loss in social surplus in the two markets (areas C+D+E+F) will equal A+B from figure 6.5. The impact of reduced interest rates is trade reducing.

The ultimate impact on the price of LAND is ambiguous. Relatively small income effects favor conservation. Figure 6.7 illustrates the impact on input use implied by this scenario.

Originally both young and middle aged use $D^*$ Land in production, producing $Q^*$ for a given $X^*$\footnote{Production is equivalent if overall welfare is stable in the economy through time. For simplicity our example has both agent types adopting identical production plans. Also for illustration simplicity, the population ratio between generations is unity.}. The line tangent to the ray at $(D^*,Q^*)$ is the equilibrium marginal productivity of Land, $MPD^*$. After the policy introduction, middle aged production increases from increased asset use and young production falls. If income effects are small and Land price increases are strong, final Land use for the middle aged is $D_{m}^*$ and $D_{y}^*$ for the young. In this example increased conservation by the young, reflected in the decline in draws, is larger than the draw increases by the middle aged - equivalent to the
per capita decline in market sales by suppliers. This result reflects the positive conservation result indicated in figure 6.1 following an interest rate decline.
Fig. 6.6
Fig. 6.7
However if income effects are substantial, the policy can instead undermine the conservation objective. Figure 6.8 begins with the same initial solution \((D^*, Q^*)\). The decline in quantity of LAND exchanged is substantial. This is reflected in a new equilibrium for the middle aged, \(D_m^*\), with proportionally large increases in output, \(Q_m^*\) reflecting a larger increase in \(X_m^*\) as well. The young using less capital in production face reduced marginal productivity of Land draws. The need to generate production mitigates conservation or speculative purchases of LAND for period two resale which are now less affordable. So \(MPD_y^*\) finds a tangency at \(D_y^*\). The new equilibrium draws by the young may be only slightly less \(D^*\). Draws may even exceed \(D^*\) as in our example.

In this case conservation is actually inhibited by the reduction in interest rates. Figure 6.9 illustrates this lower equilibrium level of deferred stocks from the regeneration function, \(g\), consistent with a lower interest rate. Reduced production opportunities available to the young identify a solution to the modified Hotelling Rule wherein deferments fall below \(S_{min}^t\) directly into the convex range of \(g\). \(h'\) is still positive, of course, making the identity at least initially admissible. So it is plausible that the interest rate advocate succeeds entirely in emasculating the
\[ \text{MPD}' < \text{MPD}^* \]
\[ (D_m - D^*)N = L^* - L \]

\textit{Fig. 6.8}
Fig. 6.9

Graph showing the relationship between \( S_{t+1} \) and \( S_t \) with lines labeled \((1 + h')\) and \(45^\circ\).
conservation objective by further impoverishing the economy.

Note that the drop in $h'$ may likely not be as severe as the decline in $r$, similar to solutions in the concave range in Figure 6.1 seeking a new steady-state. This implies $P_{t+1} > P_t$, consistent with lower opportunity costs of draws in identity (1). This offsetting effect to opportunity costs of draws completes the general equilibrium impact of the interest rate drop by accounting for diminished productive capacity left for the future following the reduced interest rate policy; and the event does not seem too unlikely.

The unravelling of conservation incentives from relatively severe income effects is consistent with the conservation question. In the previous chapter we discussed the impoverished environment that makes market protections from exhaustion erode. A policy that further impoverishes current agents is most unlikely to reverse the relative poverty induced problem of sufficient conservation. We do rely in our model on exchange of productive assets between overlapping generations to transfer input stocks from one generation to the next. It seems implausible that imposing a binding price constraint on that exchange would not generate non-trivial trade interruptions that impede the flow of productive assets to future generations, thus damaging sustainability rather than augmenting sustainability.

We hope our strong advocate is not a simple straw man. So before leaving this issue, let us explore the partial
equilibrium mistakes of the strong interest rate advocate posed here and the interest rate argument in the literature. Partial Equilibrium Pitfalls

If we think of first period income as the life-time production opportunities available, then the drop in interest prices reduces opportunities to acquire productive assets. Therefore the demand schedules retract by an income effect. This income effect extends to the future as well.

The hope by the advocate to stimulate a substitution of capital for LAND in production thereby increasing conservation ignores the continual compounding of wealth possible by reinvesting capital, represented by $\Pi_t^i(1+r_i)$ in the identity. Restrictions on current surplus by definition mean lower production opportunities for economic agents. This translates into less capital able to be transferred to the future. This systematic decline in production opportunities means poorer middle aged and young trading in the future. So as we reduce $\Pi_t^i(1+r_i)$ to increase the opportunity cost of a draw, we offset this gain by lowering $P_i$, the future price of Land leaving an ambiguous effect on current prices.

The partial equilibrium calculations regarding the interest rate get us into trouble in evaluating policy. Short and long run adjustments to the policy are not accounted. This specifically bypasses the long run production, therefore income, effects of the policy.

When we hope to increase the discount factor, $\Pi_t^i(1+r_i)$,
toward unity, we hope to place future benefits, $P_i \cdot \Pi_t^i (1+h'_i)$, on par with present benefits, $P_t$. By curbing our current appetites, market myopia is reversed so that we better consider the effects of future demands within our general economic structure. So as we draw a unit of Land, we deprive the future of $P_i \cdot \Pi_t^i (1+h'_i)$, leaving nothing in return.

This ignores the entire opportunity cost process by which future demands impact current prices within the general economic structure. Identity 1) is expressed entirely in future benefit terms. Given the prospect of transforming the marginal natural resource unit into capital today or transforming the same unit into capital in period $i$, the future optimizes to indifference between the two. Given the marginal rate of consumption of capital produced, given re-capitalized production possibilities for capital, given the marginal productivity of Land initially and at time $i$ and finally given the reproduction possibilities of natural capital, the future is indifferent between the immediate use of the Land unit and the conservation of that unit. Nothing is gained, in fact something is lost, by moving from equilibrium prices to a point that leaves the future more Land rich and capital poor despite anticipated demands that optimize at another stock bundle. We have not saved for the future but have in a very real fashion discounted the demands of the future by this artificial calculation.

This is exactly equivalent to assumptions that the supply
and particularly the demand schedules for Land expand with the onset of an interest rate reduction. Incomes prospects are ignored. The growth in future wealth implies the unlocking of incentives that had not existed and allow new wealth to be created, represented by total surplus gains in Figure 6.4. So our advocate, I argue, represents the position of those skeptical of interest rates as a form of theft from the future in the sustainability literature.

Unless the policy happens to induce conservation in an environment where exhaustion happens to be an outcome, the interest rate reduction policy will reduce future consumption prospects in our model. The conservation incentives in the reduced interest rate policy are not robust as illustrated above. Considering the income effects of a forced reduction in the price of long term loanable capital, the policy established with the objective to prevent the exhaustion of a natural resource input may indeed accelerate the exhaustion process.

**Property Rights Advocate**

A more intriguing proposal for securing future welfare advocates endowing the un-represented future agent with immediate tradable property rights over current assets. Bromley (Bromley, 1988) initiated the argument as a secure protection for the future. Bromley's suggestion is formally modelled in an OLG framework (Howarth & Norgaard, 1990) to
demonstrate the power of this mechanism.

We critique the claim by comparing steady-states under each property rights scheme. This tests whether a property right transfer to the next unborn generation can systematically circumvent reductions in consumption through time. Therefore a derivation of the Howarth and Norgaard entitlement scheme consistent with the exchange economy modelled herein follows.

**Howarth and Norgaard Model**

Howarth and Norgaard model an exchange economy without production inside a two-period OLG model. They show that utility differences between overlapping generations alter as we change the entitlement rights to the existing productive assets. Sole ownership of on-hand stocks by the young, sole ownership to the elderly and an application of the Rawlsian Difference principle over on-hand resources are all simulated to demonstrate the sensitivity of future consumption prospects to the assignment of property rights.

The authors conclude that intergenerational equity issues are largely a matter of a proper assignment of tradeable property rights. The authors then suggest that an iteration of this process by backward induction will resolve issues of multi-generational inequities. We emphasize tradeable rights as the authors rely on general equilibrium forces to implement the allocation of goods and services along the Pareto Frontier
following the determination of entitlements.

We translate a property rights structure that endows the immanent unborn generation with all tradeable property rights into our model. This implies the young must purchase resources at the end of each period just prior to their middle-age. At the same moment, the young are repaid any loaned capital with interest from the middle-aged, noting that capital had been borrowed from these young just prior to their birth the period before present time.

A Three Generation OLG

The ownership structure induces the following market process: The middle age endow the young with all economy-wide resources at birth, the young sell some of these resources back to the middle aged, they use some of these resources in production, consume some capital and defer some Land. They know however that any resources remaining at the conclusion of period one must be delivered to the next as yet unborn generation. Then of course stocks must be pre-purchased for the resources to be used through the rest of their life-cycle. At the end of period two, agents may keep remaining retirement savings for third period consumption as they have no option to trade with the emerging young.

Adapting this unusual property rights structure into our model is really straight forward.

The conditions for an equilibrium, given this market structure, are delineated from a modelled terminal condition.
The period conditions are induced backwards from the terminal period until a representative general equilibrium pattern emerges. Then a steady-state representing an interior solution is defined and compared to the steady-state in chapter four.

Consider the last period in which trade occurs. In this market the last period in which trade occurs corresponds to the period when the last agents are young. (Note that final trade would occur during middle-age in our model). The optimization conditions are outlined below.

Let Generation 'F' be the final generation, engaging in trade only in one period. The preceding Generation 'G' is the last generation to engage in intergenerational trade in both productive periods.

The objective problem for an agent in Generation F is:

\[
\text{MAX } L = U(C_{yf}) + U(C_{mf}) + U(K_{fr}) \]
\[
- \lambda_{yf} \{ K_{mf} - f(K_{mg} - C_{yf} - B_{yf} + P_t LAND_{yf} ; D_{yf}) - (1+r_t)B_{yf} \}
- \lambda_{mf} \{ K_{rf} - f(K_{mf} - C_{mf} ; LAND_{yf} - D_{yf} + h(LAND_{yf} - D_{yf})) \}
\]

The objective Life-plan for an agent in generation G is:

\[
\text{MAX } L = U(C_{yg}) + U(C_{mg}) + U(K_{rg}) \]
\[
- \lambda_{yg} \{ K_{mg} - f(K_{mk} - C_{yg} - B_{yg} + P_{t-1} LAND_{yg} ; D_{yg}) \]
- (1+r_{t-1})B_{yg} \}
- \lambda_{mg} \{ K_{rg} - f(B_{mg} - C_{mg} - P_t[DEF_{t-2k} + h(DEF_{t-2k}) - LAND_{yg} - Dyg + h(DEF_{t-2k} + h(DEF_{t-2k}) - LAND_{yg} - D_{yg}) - D_{yf} - DEF_{yf}] ; D_{mg}) + (1+r_t)B_{mg} \}
\]
Assumes generation 'K' precedes generation G.

The young are given, at birth, capital and Land from a previous generation entering period two. So $K_{mg}$ is the capital given to Generation F from G their initial endowment, or part of their initial endowment if bequests are preserved. Any deferred Land by Generation G plus net growth from deferred Land is delivered to F at birth. F sells $L_{yf}$ and loans $B_{yf}$ back to G. F then establishes its production plan for period two from returns to loaned capital and carry forward Land and capital.

The identity for the equation of motion of Land in G's second period constraint needs to be broken down. First we define the process. Generation G receives Land stock from the previous Generation K. It delivers to F this endowment minus Land sold back to K, $L_{yg}$, less resources employed to period one production, $D_{yg}$, plus any growth in the deferred Land stock.

The equation of motion of the natural resource stock by Generation G is introduced by substitution into the production function of the middle-aged. Period one substitution is a simpler expression but this form makes the life plan more immediately comparable to the equilibrium conditions delineated in chapter four where substitution of the equation of motion defined $LAND_m$, the amount of LAND sold by the middle aged.

Deferred Stock Identity
In any period the stocks of the natural resource delivered to the young have three uses by the young: sale, current production or deferred for growth. Or,

(i) $S_{ty} = LAND_{ty} + D_{ty} + Def_{ty}$

Since the middle-age in this new market only buy LAND for current production, next period stocks are generated by $Def_{iy}$. So,

(ii) $S_{ty} = D_{t-1,y}^{ef} + h(Def_{t-1,y})$.

For simplicity, assume that population levels are constant. Then,

$LAND_{ty} = LAND_{tm} = D_{tm}$

Therefore by induction,

(iii) $LAND_{tm} = Def_{t-1,y} + h(Def_{t-1,y}) - D_{ty} - Def_{ty}$.

$Def_{t-1,y}$ reflects the decision by the middle-age agent made upon entering period one. That is $Def_{t-1,y}$ define uses of Land by the middle-age agent during their first period.

From (i)

$Def_{t-1,y} = S_{t-1} - LAND_{t-1,y} - D_{t-1,y}$

and from (ii)

$Def_{t-1,y} = Def_{t-2,y} + h(Def_{t-2,y}) - LAND_{t-1,y} - D_{t-1,y}$

and finally,

(iv) $D_{tm} = LAND_{tm} = Def_{t-2,y} + h(Def_{t-2,y}) - LAND_{t-1,y} - D_{t-1,y}$

+ $h[Def_{t-2,y} + h(Def_{t-2,y}) - LAND_{t-1,y} - D_{t-1,y}]$

- $D_{ty} - Def_{ty}$

(iv) describes the decisions $LAND_{tm}$ or $D_{tm}$ in terms of variables fixed from the perspective of the individual agent.
and the first period decisions: \( \text{LAND}_{t-1} \) and \( D_{t-1} \). This makes the substitution comparable to the substitution in chapter four.

The first order necessary conditions for an interior solution to market clearing in each of the three periods (assuming constant population) can now be articulated.

First consider the identities that represent the sequence of ownership of the natural resource reported in the optimizations above.

Consider generation G's decision to purchase the Natural resource, all of which will be employed to period two production.

\[
[\text{DEF}_{t-2k} + h(\text{DEF}_{t-2k}) - \text{LAND}_{yg} - D_{yg} + h(\text{DEF}_{t-2k} + h(\text{DEF}_{t-2k}) - \text{LAND}_{yg} - D_{yg}) - D_{yf} - \text{DEF}_{yf}].
\]

Breaking this down:

\( \text{DEF}_{t-2k} + h(\text{DEF}_{t-2k}) - \text{LAND}_{yg} - D_{yg} \) is the amount of unused natural resource by an agent in generation G. This amount of unused resource by the young could be represented by \( \text{DEF}_{t-1g} \). \( \text{DEF}_{t-2k} \) is the amount of unused natural resource saved by the previous generation, K, delivered to generation G at birth.

Now

\( h (\text{DEF}_{t-2k} + h(\text{DEF}_{t-2k}) - \text{LAND}_{yg} - D_{yg}) \) is the additional stock of the resource added by growth to \( \text{DEF}_{t-1g} \).
$D_{yf} + DEF_{yf}$ is the amount of the natural resource employed to production by generation F in their first plus the amount of the resource saved by generation F.

So the amount of LAND bought by generation G in their second period still equals the unused amount of their natural resource endowment plus the growth of this endowment less the amount of the natural resource used and saved by generation F.

Derivation of the General Equilibrium

The first order conditions of generation G, the last generation to trade in both periods, are listed below:

Period T-1 decisions

$L'_{Cyg} = 0$ implies $U'_{Cyg} = \lambda_{yg} f'_{xy}$

$L'_{Byg} = 0$ implies $B_{yg} = (1+r_{t-1})$

$L'_{Dyg} = 0$ implies $\lambda_{yg} f'_{Dyg} = \lambda_{ng} f'_{xy} P_T (1+h')$

$L'_{LANDyg} = 0$ implies $\lambda_{yg} P_{t-1} f'_{xy} = \lambda_{ng} f'_{Xm} P_T (1+h')$

Period T decisions

$L'_{Cmg} = 0$ implies $U'_{Cmg} = \lambda_{ng} f'_{xm}$

$L'_{Bmg} = 0$ implies $B_{mg} = (1+r_T)$

$L'_{Dmg} = 0$ implies $f'_{Dmg} = P_T f'_{xm}$

$L'_{Krg} = 0$ implies $U'_{Krg} = \lambda_{ng}$

If we compare these first order conditions to the optimization problem outlined originally, it is clear that the conditions are identical.
This last period in which trade appears allows us to articulate a general equilibrium.

GENERAL EQUILIBRIUM

Young Agent:

1. \( L'_{cy,t} = 0 \): \( U'_{cy,t} = \lambda_{y,t}f'_{xy,t} \)
2. \( L'_{by,t} = 0 \): \( f'_{xy,y} = (1 + r_t) \)
3. \( L'_{dy,t} = 0 \): \( \lambda_{y,t}f'_{dy,t} = \lambda_{m,t}f'_{xm,t}P_{t+1}*(1 + h') \)
4. \( L'_{landy,t} = 0 \): \( \lambda_{y,t}P_t f'_{xy,y} = \lambda_{m,t}f'_{xm,t}P_{t+1}*(1 + h') \)

Middle Aged Agent:

5. \( L'_{cm,t} = 0 \): \( U'_{cm,t} = \lambda_{y,t}f'_{xm,t} \)
6. \( L'_{kr,t+1} = 0 \): \( U'_{kr,t+1} = \lambda_{m,t} \)
7. \( L'_{bm,t} = 0 \): \( f'_{xm,t} = (1 + r_{t+1}) \)
8. \( L'_{dm,t} = 0 \): \( f'_{dm,t} = P_{t+1}f'_{xm,t} \)

Identities:

9. \( N_y B_y = N_mB_m \)
10. \( N_y Land_y = N_m LAND_m \)
11. \( K_m = f(K_{y,t-1} - C_{y,t-1} - B_{y,t-1} + P_{t-1} humming y, t-1; D_{y,t-1}) \)
    \( - (1 + r_{t-1})B_{y,t-1} \)
12. \( K_r = f[(B_{m,t-1} - C_{m,t-1} - P_{t-1} humming DEF_{t-3,p} + h(DEF_{t-3,p}) - LAND_{y,t-2} - D_y,t-2 + h(DEF_{t-3,p} + h(DEF_{t-3,p} - LAND_{y,t-2} - D_y,t-2) - D_{t-1,f} - DEF_{t-1,f}); D_{m,t-1} + (1 + r_{t-1})B_{m,t-1}) \)
13. \( Nm / Ny = \rho(C_{m,t-1}) \) given: \( C_{m,t-1} \) in t-1
14. \( K_y = N_{r,t-1} / N_y \cdot \mu \cdot K_{r,t-1} \) given: \( N_{r,t-1} ; K_{r,t-1} \) in t-1
15. \( P = (1 + r_{t-1})P_{t-1} L_y,h' \)
    given: \( r_{t-1} ; P_{t-1} ; Land_{y,t-1} ; D_{y,t-1} \)
The conditions are identical with the equilibrium outlined in chapter four, except that the equation of motion of capital and Land reflects a reversal of the period that an agent is an asset supplier and an asset demander. To determine if this generally implies a definably different nature of solution to the benefit of the future can be better illustrated through a steady-state to represent future prospects.

Steady-State

Young Agent:

1. \( L'_{cy} = 0 \): \( U'_{cy} = \lambda_y f'_{xy} \)
2. \( L'_{by} = 0 \): \( f'_{xy} = (1 + r) \)
3. \( L'_{dy} = 0 \): \( \lambda_y f'_{dy} = \lambda_m f'_{xm} P(1 + h') \)
4. \( L'_{LANDy} = 0 \): \( \lambda_y f'_{xy} = \lambda_m f'_{xm} (1 + h') \)

Middle Aged Agent:

5. \( L'_{cm} = 0 \): \( U'_{cm} = \lambda_m f'_{xm} \)
6. \( L'_{kr} = 0 \): \( U'_{kr} = \lambda_m \)
7. \( L'_{bm} = 0 \): \( f'_{xm} = (1 + r) \)
8. \( L'_{dm} = 0 \): \( f'_{dm} = P f'_{xm} \)

Identities:

9. \( N_y B_y = N_m B_m \)
10. \( N_y Land_y = N_m LAND_m \)
11. \( K_m = f (K_y - C_y - B_y + P*LAND_y; \ D_y) - (1+r)*B_y \)
12. \( K_r = f[(B_m - C_m - P*[DEF + h(DEF) - LAND_y - D_y) + h(DEF_y \)

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Identities
\[ + h(\text{DEF}_y - \text{LAND}_y - D_y) - D_y - \text{DEF}_y)D_m + (1+r)P_m \]

13. \( N_m / N_y = \rho(C_m) \)
14. \( K_y = K_m \)
15. \( 1+r = 1+h' \)
16. \( \lambda_y = \lambda_m \)

Again the conditions are identical with three exceptions. First initial capital endowment no longer models bequests for simplicity though we could retain this. The other two changes reflect only a reversal of the side of the market an agent is on in a given period of life. Identities 11 & 12 reveal these changes.

This steady-state continues to produce a supply and a demand curve for each of the two markets generated by the production/consumption decisions of life-cycle utility-maximizing agents.

The steady-state, and the general equilibrium from which it is articulated, engenders the identical set of features with this property rights structure as does the original model. The models differ only in reversing the periods in which agents are suppliers or demanders in their life-cycle.

Agents are still motivated to produce and to save in period one in order to provide enough capital and natural resources to the unborn so that there are sufficient supplies available for them to purchase upon entering middle-age. So rather than owning what they produce and save in period one,
period two agents still are able to purchase through borrowing some or most of what they saved depending upon the severity of income effects on the generation of the demand and supply schedules.

The most significant issue regarding the similarity of the two steady-state models is that the restructuring of property rights fails to alter the nature of solutions with respect to the trace of consumption through time. The conservation question posed in this work remains a valid critique. Consumption can still rise or fall, the reproducible resource can still be exhausted and population growth continues to frustrate sustained per capita income growth in the system.

The Howarth and Norgaard hope of a simple structural change to unambiguously protect the future cannot be designed within the general equilibrium framework with production. The reason that our model demonstrates no discernable conservation benefit is that it outlines the entire general equilibrium. The economic decisions affecting production, consumption, savings and trade are all directly derived. Failure to incorporate each side of the market and the incentives implied leads the property rights advocate to infer an otherwise untenable claim. The fundamental Coasian principles operating in our economy expose the modelling simplifications that enable the Howarth and Norgaard result.
Coasian Principles

We can extend the general equilibrium critique of the reduced interest rate policy to include what we have learned investigating the claim of the property rights advocate. The ineffectiveness of partial equilibrium models or so-called general equilibrium models that fail to fully endogenize production can be critiqued from a Coasian position (Coase, 1961).

The Coase theorem argues that the final output of economic goods and services is largely unrelated to initial assignments of tradable property rights. It follows that any re-assignment of property rights will alter the allocation of economic surplus among those trading but not the final output quantity by much at all.

The reason that the tradable property rights transfer succeeds in protecting future consumption in the Howarth and Norgaard model but fails to protect the future in our model reduces to modelling differences about the extent of trade. Our model endogenizes productive asset markets and prices. The Howarth and Norgaard model however presumes the existence of an exogenous return to labor and to savings (i.e. exogenous wages and interest rates). This assumption restricts agent trade between generations to a set of final goods, not productive assets.\(^5\)

\(^5\) It is not that agents are not productive. Agents in the Howarth and Norgaard model sell labor for a price and loan capital for a price. Therefore agents produce income (the
Howarth and Norgaard assume a predetermined level of final goods, cake, to be allocated among the generations. Therefore the transfer of property rights is directly a transfer of final welfare prospects among generations. The total level of economic activity is unaltered as Coase would predict but the distribution of utility between generations differs significantly with a change in property rights in this economy. *Ergo* future generations fare better under a new property rights regime if rights over property are limited to final goods and if agents cannot exchange the means of production.

If the assets transferred between generations are inputs, then prospects of future generations ultimately depend on trade to deliver the productive capacity that will exist in their lives; and this capacity is not pre-determined. Productive capacity for a generation depends on the amount of land and capital it purchases in period one. Further if productive assets themselves are produced (or if they regenerate), then the quantity of assets traded are linked to prior levels of production which are also not pre-determined. So if we allow the productivity of traded capital stocks, then

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The problem is that these prices are exogenously pre-determined for any time period and are separate from any trade between overlapping generations. So the opportunity to *generate* income (production) is exogenously given in their model, unaffected by the transfer of assets between generations. However if productive assets themselves are transferred via markets, what is now traded are the opportunities to generate income (production) themselves.
a limited appeal to Coasian arguments means that the level of production (final output) in any time period is relatively unchanged. It doesn't matter that the allocation of the economic surpluses among agents actually trading changes. With the long run sequence of output production relatively unaltered by a property rights re-assignment, future prospects that ultimately depend on the level of production are also effectively unaltered.

The inability of the property rights advocate to demonstrate any systemic change in the nature of solutions and to assure against a fall in future consumption emerges from an inability to demonstrate a long run increase in aggregate production following a change in property rights.

The only way to generate protection in our model is to restrict use rights to the tradable on hand productive stocks and directly pre-determine ownership rights to yet unproduced final goods. To make the system work, the manager must be prepared to force an agent at the margin to purchase an input used to produce an output that the agent can neither individually sell nor consume. By assigning ownership rights to final outputs rather than to immediate on hand productive stocks, future welfare is defended by a prior right to consume some level of output, independent of marginal production decisions. These rights of course will no longer be enforceable within a general equilibrium context, a stated benefit voiced by both Bromley (Bromley, 1988) and Howarth and
Norgaard. Enforcement of these claims on behalf of the future cannot be realized by unanimous consent within general equilibrium market transactions. Instead assuring rights to outcomes must be centrally managed. We will revisit this argument in the following sections critiquing a policy that we attribute to Bromley.

Strategic Policies

The policy advocates may be more strategic. The severity of economy-wide price controls of the interest rate advocate and the limited scope of property rights transfers to overlapping generations by property rights advocates may oversimplify some advocates' claims.

Interest rate advocates may simply aspire only to secure conservation on a case by case basis. Each resource under exhaustion threat will be managed by a benefit-cost analysis that merely calculates the opportunity costs of Land draws by using below market interest rates for analytic purposes. These advocates offer a less ambitious, more strategic conservation policy than a market-wide price ceiling.

Similarly the property rights policy suggested by Howarth and Norgaard also may not represent all property rights advocates. Yet the strategic property rights advocate may submit a much more comprehensive proposal than that suggested by Howarth and Norgaard. The trading rights to property could be transferred to a generation that does not overlap our own.
Bromley (1988) for instance does not insist upon a reassignment of property rights limited solely to adjacent generations. His missing markets certainly apply to distant non-overlapping generations as well.

**The Analytic Interest Rate Policy**

A sophisticated reduced interest rate advocate separates her argument from those discussed above by denying that she really intends to impose an actual capital price ceiling on the market. Rather the advocate operates in a policy environment that manages the rate of extraction of natural resources. So her interest reduction policy is analytical, designed explicitly for the purpose of calculating extraction levels that favor conservation only for threatened resources.

Suppose a benefit-cost analyst recognized the identity:

\[ P_1 = P_t \cdot \Pi_t^i (1+h_i'/1+r_i) \]

In calculating present value, the analyst locates \( P_t \) over some horizon, \( i \). However in calculating \( P_t \), subsets of \( r_t \) are evaluated at a lower level than indicated in the market.

Conservation is directly established. The higher \( P_t \) indicates some higher "social" value\(^6\) of current Land draws. Figure 6.10 demonstrates the regulated level of draws permitted by the manager, \( D^* \), calculated from the analytic policy. \( D^* \) represents original use and \( e \) represents the level

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\(^6\) \( P_t \) is the efficient market price. The social cost supposed represents an extra-efficiency value.
of draws that push deferred stocks beyond sustainable levels.\footnote{The resource is eventually pushed below $S_t^{\min}$. This may not occur for several periods but is inevitable at some future date given the sequence of market equilibria.}

The inferred $P_1$ signals a lower Land extraction level. To prevent exhaustion, the analyst must identify a sequence of capital prices consistent with the conservation target, $e$, for the resource in question. But the analyst is not free to choose any set of interest rates.

Resource exhaustion eventually imposes a hardship on the future. The moral consideration in preventing this hardship warrants some sacrifice; yet the sacrifice is not unlimited. At some point current sacrifices become too onerous and fail to justify the conservation benefits that accrue to the distant future. With no fully developed moral theory to guide our manager, this policy benefits by committing the analyst to an objective procedure for accepting efficiency losses in favor of conservation.

Several prior works suggest lower bounds on discount rates. Ramsey (1928) proposes using market rates for within generation projects and a zero interest rate for time periods beyond the current generation, a policy is echoed by Mishan (1971). Page (1978) classifies discounting \textit{per se} as dictatorship. He might well argue that a zero interest rate for all time periods is an equitable 'benevolently' dictated interest rate rule. Negative interest rate rules are not suggested as protections. An analytic interest rate of zero
Fig. 6.10
is presumed to constitute a bound to the level of sacrifice for a given good.

Therefore from project to project, sacrifices by the present are bounded by the product of the total re-capitalized value of man-made inputs, $\Pi_{t}^{1+r}$, from converting the marginal unit of the resource into capital today, $P_{t}$, and the magnitude of reduced resource use, $N_{y} + N_{m} (D^{*} - D^1)$. Or sacrifice costs have an upper bound of $[N_{y} + N_{m} (D^{*} - D^1) * P_{t} \Pi_{t}^{1+r}$, implied by a zero interest rate for any given resource.

A reformed benefit-cost decision rule emerges. Our resource manager directs resource use based on the greatest Potential Pareto Improvement (PPI) - the Kaldor Hicks efficiency in BCA - but exempts this criteria to discourage the exhaustion of a productive natural resource. Conservation, exempt from pure PPI criteria, is explicitly limited from imposing losses that are intolerably high. This rule sets an operational procedure to identify intolerably high costs on a case by case basis.

CRITIQUE:

The Benefit-Cost Analysis (BCA) constrained by the analytic reduced interest rate may manage a number of renewable resources aggregated into the modelled Land input. Even with weak separability, several resources may be unique enough so that exhaustion of any one resource remains a moral concern.

However, each natural resource can generate a different
renewal process, meaning different levels of resource vulnerability are likely present at any time for the different threatened resources. The analytic interest rate policy must then establish either a separate set of discount rates for every natural resource of concern or adopt a uniform analytic interest rate and accept various levels of conservation protection from vital resource to vital resource.

The inconsistency implied by various interest rates established to meet various strategic resource targets does not itself implicate the policy. After all this is a policy designed to implement a conservation target for threatened resources. But why not simply implement a given level of protection?

Presumably the reformed BCA policy rationalizes the additional analytics specifically to place a bound on the economic losses allowed by the conservation effort, not to search for a uniform social discount rate. In searching for a set of target friendly interest rates, certain very low rates are excluded. Negative interest rates might by forbidden in order to limit the social cost of the effort. So this check distinguishes the policy from a simple, direct conservation draw target. The inflexibility of the check is however problematic.

Take for example a zero interest rate bound. This precommits society to accept losses up to a prior pricing indicator for any resource market. This intolerable loss
however is not defined from social surplus measures, delineated in standard capital units in our model and therefore comparable from resource to resource.

The check on acceptable losses defined by this decision rule permits widely different real levels of 'unacceptable' loss from resource to resource. The procedure if seriously applied forbids the comparison of intolerable loss from resource to resource. Unacceptable losses implied by negative interest rate calculations for one resource may be strictly smaller than acceptable losses permitted for another resource with only positive interest rates. Even though no differences in protection for the future are provided by conservation efforts between both resources, the procedure bounds conservation sacrifices differently in each case.

We could establish a set magnitude of surplus loss which can be tolerated; but then the analytic interest rate policy becomes indistinguishable from a direct conservation target and the analytics become meaningless.

We recognize that our manager has no value theory to regulate all economic activity through time by a unique planning objective. So some irregularity may be necessary for a legitimate program. However the obligation to act positively even with an ambiguous objective does not rationalize this inconsistency. The strategic interest rate policy forces the admission of less effective conservation at higher costs when gains to both the present and to the future
could be identified by comparing levels of unacceptable loss. The unnecessary economic losses tolerated to adhere to the operating procedures of the policy may be required to eclipse the erosion of per capita income that creates the conservation crisis.

The policy does embody two useful concepts. First it introduces a specific standard that pre-empts strict economic efficiency based policy in the face of undo hardship on the future. The policy also considers this standard overridable and admits limits to the costs of meeting conservation targets. Yet the essential justification of the policy fails to be flexible enough to achieve its stated goal of providing a level of safety for the future at a minimum cost to the present.

The Alternative Property Rights Policy

The property rights policy suggested by Howarth and Norgaard also may not represent all advocates. The trading rights to property could be transferred to a generation that does not overlap our own.

Bromley (1988) does not insist upon a reassignment of property rights limited solely to adjacent generations. His missing markets thesis also applies to distant non-overlapping generations. By a re-assignment of property rights guided by moral principle, Bromley hopes to identify a strategic intervention into the market that will permit a new general
equilibrium to emerge.

We might conceive of an advocate that desires to assign immediate stocks to a generation two or more generations into the future. Therefore any potential state of the world that could actualize for this generation from an allocation of the on-hand assets may constitute an enforceable claim on the present. If the current young or middle-aged intend to use these stocks, they must design some payment method to assure that the future would be willing to accept that payment. That is, a particular generation entitled to current assets has the right to demand the highest utility opportunity to itself possible from the disposition of those assets. This right is only bounded by the right of another generation to demand a particular outcome, or state of the world, that may conditionally supersede these designated rights.

To implement the policy the advocate must establish a procedure to identify baseline conditions that entitle a generation to demand realization of a particular outcome. The Rawlsian Difference Principle, discussed in chapter two, probably best exemplifies such a procedure. The Difference Principle applied here identifies the expected worse off generation as conditionally entitled to a veto over economic activity. The veto however is not unlimited. The entitled generation can only enforce its veto up to the point that acting on this claim makes another generation the worst off (the contractarian process) or reduces the obliged generation
to consumption levels below subsistence (the Humian condition of Justice).

Like the strategic interest rate advocate, this advocate proposes a procedure to oversee conservation sacrifices by the present to circumvent the dramatic erosion in the welfare of future generations but simultaneously establishes a rule that limits the magnitude of sacrifice that can be imposed. Unlike the strategic interest rate advocate, the Rawlsian alternative property rights policy is much more intrusive than the policy that it modifies. The advocate also targets a different goal.

This property rights policy does not seek a particular conservation target directly, such as the prevention of resource exhaustion. Rather this policy seeks to secure a just process and protect procedural rights. It is in pursuing these rights to just process that our manager infers the disposition of on-hand assets. If the rights of the worst off generation dominate the decision process, then the resource exhaustion that devastates future society is surely unacceptable to the generations that succeed the exhaustion. Exhaustion brings about a future state of the world that could not be generated by the Difference Principle.

Armed with this objective the policy maker assigns ownership structures over all present and created assets to each ensuing generation. She must enlist the support of all intervening generations between the present and the worse off
generation to honor the allocation derived from this process.

The alternative property rights policy deduces a program target from just processes according to the Difference Principle. Unlike the Howarth and Norgaard program, the assignment of tradable property rights itself contributes nothing to the policy decision process in this alternative property rights scheme. The Difference Principle determines the target, determines who may trade with whom, and determines what must be produced and what must be saved.

Under the Difference Principle rights to property are conditional, contingent on the state of the world (i.e. veto of the worse off agent). So property rights are actively assigned in response to the state of the world. Rights are not assigned by the order of birth as in our model or the Howarth and Norgaard variation of our model. The rights of the future that must be regarded by the present are inviolable entitled outcomes, not merely the exercise of tradable property rights. We draw a distinction between tradable property rights and moral entitlements that arise from processes that we are duty bound to honor.

Critique

This alternative property rights policy is critiqued first by the moral arguments outlined in chapter two. The planning objective required to implement the Difference Principle simply exceeds the moral authority that we argue is open to our resource manager. The advocate must either
directly engage in the debate in professional ethics and outline a new value theory or justify the procedure on merely instrumental grounds.

Bromley (1988) and Howarth and Norgaard (1991) make a number of overtures to justify property rights policies on instrumental grounds. In both cases, the instrumental appeal is expressed as a specific desire to avoid the nuances of ethics while securing robust protections for the future with minimal on-going central control over agent actions.

Economic activity is presumed to operate without central direction once property rights are established. The resulting equilibrium, contingent on initial endowments, is self-enforced by the incentives of economic agents. Presumably the alternative property rights advocate hopes to strategically intervene to establish initial claims and open missing markets. After that the advocate relies on the marginality conditions of a general equilibrium to implement the desired production/savings decisions consistent with the objective. Specifically, the final outcome is incentive compatible. It does not require directing all economic activity (including reproduction decisions) by decree. If the manager can identify a set of initial endowments that will robustly protect the future realizable by a general equilibrium, the practical advantage of such a strategy may conceivably warrant its instrumental acceptability from a number of moral positions.
Even positions which do not accept the Difference Principle as a resolution to our complex obligations to the future may applaud the resulting consequences secured. Our manager may be secure in employing an objective to exercise her charge without committing her to resolve the epistemological intricacies of our obligations to the future and directly enter the embattled discipline of ethics.

However, we reject the feasibility of a general equilibrium consistent with the assignment of property rights to non-overlapping generations that can implement protections to the future - except by chance.

If the policy-maker desires a savings policy that runs for several generations to insure sufficient input stocks for some specific future generation, a sequence of tradable rights must be articulated to generate this target through the intervening generations.

The bargaining environment behind a Rawlsian veil for instance will almost surely require the production of output from a purchased input even though the final output can not be sold or consumed by the agent unless the present itself is the worst off generation. In order to justly secure the right to purchase other inputs that can be sold or consumed, we may require agents to produce some goods at the margin solely for the purpose of saving the output for another generation - a true set aside. Given Rawls' motivation structure and the veiling of individual identity, agents would freely agree to
the restriction; but a simple property rights vehicle to implement a Rawlsian contract is not flexible enough to realize the prior identified target if such 'bequest' production is required. That is, at the margin the solution is not incentive compatible and the instrumental reasons to accept the policy erode.

The failure in generating a self-enforcing general equilibrium emerges from the Coasian principles discussed previously. Distant future prospects are tied to increases or decreases in carry forward per capita stocks. This depends on the aggregate economic activity today and the incentives of today's agents. Once again the Coase theorem applies to relative invariance of economic output not the distribution of final welfare. The moral claims proposed impose stewardship restrictions on the means of disposing of on-hand resources - how we use resources. To unambiguously improve distant future prospects requires an extra-market savings program that will increase input stocks in the future - increasing future production.

This will be inconsistent with the agent marginality conditions. For instance a savings program setting aside output continuously recapitalized in trust for an identified generation would generate a strict inequality in equations:

\[ U'_{cy} / \lambda_y = f'_{xy} \quad \text{and} \quad U'_{cm} / \lambda_m = f'_{xm} \]

with the RHS > LHS. This is the result of the set aside. At the margin assets are committed to production even though the
agent cannot consume the value of that product through current consumption, $MUC_t$, or in the future through sale or direct consumption, represented by $\lambda_{jt}$. The agent produces more from purchased inputs than desired, contributing the marginal unit to the set aside. So the outcome cannot be implemented within a general equilibrium. Some additional management of economic activity is required, imposing duties on the present to act outside current marginality conditions.8

Both Bromley (1988) and Howarth and Norgaard (1990) offer the hope of separating protections for the future from 'moral duty' (which I take to mean relatively self-enforcing). There suggestion however relies on a highly central program committing society to a complete and coherent moral theory of value. To continue to rationalize the policy embroils the manager directly into the epistemological debate in ethics and likely exceeds our resource manager's legitimate authority.

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8 Rawlsian advocates of course do not insist on incentive compatibility outside the veil. But if our advocate fails to rely on the self enforcement of marginal equilibrium conditions, the advocate is committed to a justification of the moral position taken. In the case of the Difference Principle, the advocate is warned that Rawls considers the relevance of the veil to future generations and does not extend the veil to uncertainty regarding the period of birth. The inability of contracting agents to make direct claims on other contractors goes beyond the contractarian justifications that Rawls uses to generate his theory (Theory of Value, p147-51). This is exactly our concern that non-overlapping generations must press their claims through other agents, agents with whom they physically cannot trade, producing the disequilibrium detailed. As outlined in chapter two, such an advocate has a lot of philosophy homework to do before offering such a solution for anything other than generally acceptable instrumental reasons offered.
The alternative property rights policy is then critiqued from each of its two defenses. First one defense postulates an incomplete moral position that cannot be defended. A second defense inaccurately justifies the instrumental benefits of the policy as implementable within a general equilibrium and therefore marginally self-enforcing.

**Summary of Strategic Policies**

The analytic reduced interest rate advocate was critiqued because it needlessly wasted resources by over-restricting our manager's authority. The alternative property rights advocate, on the other hand, presents a policy that can only be implemented by over-stepping our manager's authority and defending the more aggressive intervention on moral grounds alone.

Unless some other instrumental case can be made that the public choice environment is uniquely structured so that either of these alternative policies define the best possible method to approximately implement the target, the policies do not distinguish themselves in any material way from direct conservation restriction on renewable resource use.

We are influenced by an important caveat recognized by each strategic policy in our pursuit of a robust conservation target. Conservation programs are costly. We might accept these costs if a devastatingly miserable future results from our current economic activity - particularly the exhaustion of a renewable resource highly valued in production. Yet our
sacrifice is not unbounded. The present is limited in its required commitment.

Our interventions designed to establish a safety-net for the future are themselves sensitive to safe levels of welfare assured for the present. Specifically, the safety target can be over-ridden if it imposes intolerable costs on the present. Intolerable costs were operationalized in the above policies by a zero bound on analytic interest rates used in a benefit-cost analysis or an expectation that the current generation becomes the worst off generation as a result of conservation efforts. We retain the general observation that positive obligations are required to prevent the exhaustion of a valued natural resource, but sacrifices can not be required if costs become intolerably high.

Conclusion

In this chapter two conservation policies and their indirect variations were reviewed. The direct policies were critiqued within our modelled economy and found to be ineffective or even dangerous to the sustainability concerns that justify the policies. The structure of the economy modelled and the reasons that generate the legitimate conservation question fail to admit plausible conservation efforts that either regulate prices or alter the distribution of current endowments. Coasian arguments reveal an oversight common to both policies.
Successful reductions of resource use can be assured by direct restrictions on use. In defining the conservation target the indirect policies proposed are more strategic. They attempt to preserve market advantages in assessing conservation targets by either modifying our efficiency analysis (BCA) or altering property entitlements. Each hopes to strategically intervene and allow economic incentives friendly to current and future welfare to proceed. These policies, however, are either too restrictive or too permissive of our manager's authority to act on conservation policies.

The indirect policies however realize certain important criteria for an effective conservation policy. Direct quantity restrictions on resource use of vital resources threaten with extinction assures the desired protection. This establishes a minimum safety target, preserving positive resource use through time, for the future. Yet the costs imposed on the present in accepting conservation restrictions is limited. A policy adopting these essential elements is considered consistent with the fundamental insights of the safe minimum standard (SMS) proposed nearly forty years ago in the resource economics literature.

In the next chapter, an SMS program is advocated. Arguments for SMS in the literature are extended. The SMS is explicitly identified a sensible response to the moral heuristics that burden our manager. In addition the
recognition that our conservation program not impose intolerably high costs on the present rationalizes a very forward looking SMS that begins to implement resource draw restrictions well before the resource is directly threatened with exhaustion. Given the importance of the resource to production and the poverty likely to coincide actual resource draws below their regenerative capacity, intolerable costs to conservation become more likely as we delay triggering the SMS until unsustainable draws are immanent.

Finally two programs that compliment our SMS efforts are presented to demonstrate how the model might be adapted to incorporate other concerns such as population reduction efforts or research and development programs.
In the previous chapter two conservation policies were investigated. Each rests upon partial equilibrium assumptions to press the claim that their policy achieves a conservation objective. Yet as we extend the economic models to allowed more responsiveness among our economic agents to react to the proposed policies, we found these policies were to implement the conservation objective.

Direct quantity restrictions on land use were then offered as an effective conservation strategy. Two indirect policies attempt to implement such a quantity target. However one policy unnecessarily restricts our resource manager's authority to implement a conservation target while the other policy oversteps the legitimate bounds of authority of our resource manager.

Although the indirect policies overstructure the implementation of the quantity target, those structures are motivated by a concern for capping the costs of meeting conservation targets. We retain this concern in defining an acceptable policy.

This chapter revisits our manager's moral dilemma in light of the economy modeled in this work, the conservation
question and the inadequacies of the policies critiqued. Given our modelled economy our moral heuristics can endorse direct Land use restrictions in the face of exhaustion of a renewable resource necessity; but our principles will also recognize that sacrifices required to meet the target are not unbounded. Such a conservation program is found to be similar to the original justifications for a Safe Minimum Standard (SMS) policy.

The SMS proposed here takes seriously the prospect of facing intolerable costs in conforming to the SMS. If the standard of safety is established at the moment of immanent exhaustion, the costs of preventing exhaustion are often exorbitant. The proposed outline for an effective SMS recommends a more anticipatory intervention by our resource manager.

Finally two complementary programs are identified, population control and research and development, to mitigate the costs of implementing an effective conservation policy. These programs are assumed to be options open to our manager who anticipates exhaustion that can only be avoided by intolerable costs at the moment of exhaustion. Examples of these programs illustrate the range of choices potentially available to our manager in the search for least cost options to meet a conservation target. In addition, these extensions of the model help to identify the micro-economic principles embedded in responses to public expenditures, particularly
research and development efforts and the role of technological change. The structure of the model itself has implications for current academic work incorporating technological change into growth models.

**Moral Obligations and the SMS**

S.V. Ciracy-Wantrup proposed an SMS program for the management of wildlife resources. His suggestion generally supports the benefit-cost approach to management of natural resources (Ciracy-Wantrup, 1968). The welfare gains attached to economic efficiency based management (benefit-cost analysis) are considerable. However at the point of extinction of a rare resource, or species, we want to check our standard benefit-cost procedures regulating resource management.

Exhaustion of a resource is permanent. Our manager pre-commits to a change in decision regime whenever in the normal course of operation the extinction of a species is indicated.

The SMS reveals the attitude of this new decision regime. At the point of exhaustion, a renewable resource is assumed to be due protection. This resource sustaining safety level becomes the default level of resource conservation even though our regular efficiency criteria would indicate deferring fewer land stocks and eventually exhausting the resource.

Consider three justifications for the policy. Richard Bishop suggests that the exhausting resource possesses assumed
value not reflected in the normal course of benefit-cost analysis. The SMS is established as a protection against state of the art limitations that will likely undervalue the resource. Bishop doesn't merely recommend a change in the decision process to assure that our manager perform the best state of the art expected value analysis, sensitive to option value, existence value et cetera. Rather the SMS assumes value beyond our best benefit measures, an assumption respecting the irreversibility of the consequence (Bishop, 1978).

Nonetheless, Bishop is not so pessimistic that our efficiency criteria are without merit. BCA guided policy up to exhaustion is still reasonable. Even though the efficiency measure is exempt from strict application in the case of resource exhaustion, our measure of economic losses accepted by respecting the SMS are relevant. Bishop argues that at some point these losses become intolerably too large to justify continued respect for the SMS target.

A second and third justification are more directly seen as moral justifications. A second justification sees the natural resource as intrinsically valued in itself. That is preservation is a moral concern directly. Our model really identifies the natural resource as instrumentally valuable in production for the purpose of augmenting present and future human consumption.

A third justification of the SMS considers directly the
intergenerational impact on future humans of a resource exhaustion. Current market transactions reflect the aggregate effect of existing utility optimizing agents, not future agents. So this justification accepts the conservation question posed in chapter five as relevant. Therefore our value considerations regarding obligations to the future recommend policy intervention to prevent the exhaustion of a resource highly valued in production. The SMS supported by this work assumes this third rationale though the general structure of the SMS proposed does not exclude appeals to the first two justifications.¹

The SMS recommended, regardless of the justification, recognizes the following value considerations. First our ability to manage resources by a unique objective is not promising given the difficult problems of defining a consistent coherent moral theory that will resolve the epistemological problems of defending our obligations to bring into existence and then provide for potential future persons. Our very general value concerns state only that future existence of humans is morally good and the level of welfare of those future persons is morally relevant.

Even so our manager may be justified in very intrusivc, central direction of economic activity in respect for these principles as long as the resulting management reflects an

¹ The three justification differ principally on their perspectives as to what constitutes an intolerable cost, not the definition of the Standard.
instrumental acceptance from a number of moral theories. However the power of markets to represent the demands of future generations provides considerable though imperfect protection. So a second consideration assumes that our manager seeks direct strategic interventions into the market that afford special protections against resource exhaustion. Rules such as the SMS do not inherently recommend aggressive managed intervention.

A quantity restriction that regulates harvest or use of renewable natural resource when economic dynamics imply movement toward eventual exhaustion is consistent with the two considerations above. A third principle of the SMS notes that losses result from a commitment to the quantity target established by the SMS when the SMS becomes binding on our economic agents. Our conservation program supposes that our commitment to accept these losses is bounded. This bound recognizes the moral concern for the welfare of living agents.

This general outline for a conservation program is consistent with the heuristic moral principles defined in chapter two, the characteristics of an SMS found in the literature, and the conservation question introduced in chapter five.

Finally we need to establish the broad acceptability of the SMS as at least instrumentally valuable to a number of moral theories of value. The proposed SMS is not only
consistent with the delineated heuristic moral principles; but it is unlikely to offend any specific, complete theory of value that might derive positive duties to the future.

The three justifications of the SMS offered above are consistent with very different moral theories; yet each can accept the SMS. Alan Randall demonstrates the broad acceptability of an SMS by a number of moral theories in the protection of biodiversity (Randall, 1991).

Duty-based theories, including contractarian moral theories, are friendly to rational rule derivation. The intolerable cost check embedded in the SMS is consistent with a hierarchy of duty-based principles. These theories set basic rules (i.e. don't extinguish a renewable resource); but they also establish rules that determine which principle trumps another principle when compliance to two principles directly conflict. As long as biodiversity, Randall notes, does not define a first or pre-eminent principle status that trumps all other valued concerns, a bounded SMS can be developed from duty-based theories. Similarly contractarians such as Rawls will recognize a limit to sacrifices by present agents since there are legitimate claims demanded by the present from the future (i.e. the present may become the worst off generation or its welfare may fall below a prerequisite basic needs level to enable a contract to take place).

In addition Randall notes that consequentialist theories, such as utilitarianism, could also adopt an SMS. The original
Bishop rationale that there may be costs associated with particular outcomes that are currently inestimable is a direct utilitarian appeal for the SMS. Randall considers this utilitarian based SMS more generally than Bishop. Randall conceives the consequentialist SMS as a rational safeguard against making mistakes in the regular process resource management, including Bishop's warning of over confidence in our evaluation techniques. Finally a consequentialist who holds that the welfare of the future is an objective value concern and accepts the conservation question could of course directly accept the SMS as a legitimate moral conservation policy. This consequentialist justification is consistent with the third justification of an SMS above.

So given our value concerns for the welfare and existence of the future along with the structure and function of the economy delineated, the articulated SMS emerges as a general decision rule consistent with moral principles that enjoy wide professional support.

The SMS and the Intolerable Cost

The SMS program envisioned by Ciracy Wantrup and embodied in the Endangered Species Act is a crisis response rule. The irreversible consequence is seen to come on us at an instant: the snail darter, the spotted owl, the previously uncatalogued tropical amphibian. However the SMS rule that evolves from this work is implemented with considerable awareness of the
dynamics of the economy.

Our agents are modelled with perfect foresight. The sequence of natural resource draws through time is known. So any resource exhaustion will be anticipated before an extinction is immanent.

Consider an exhaustion that emerges over several periods. Remembering our measure of resource tolerance:

\[ T_e = \frac{h_t - \rho_t \cdot D_{ty} - D_{tm}}{S_t - S_t^{\text{min}}} \]

exhaustion implies that tolerance to draws will identify negative values until tolerance eventually falls to or less than minus one - the point of extinction. The quantity of per capita stocks deferred declines from period to period until deferred stock levels fall below \( S_t^{\text{min}} \). This may take several periods.

Figure 7.1 illustrates an example of the decline in deferred stocks over three periods from \( \text{DEF}_t \) to \( \text{DEF}_{t+2} \). Approaching exhaustion \( h' \) increases over the three periods.

Land prices and interest rates may increase or decrease with the change in \( h' \).\(^2\) It is important to note that satisfying the modified Hotelling Rule does not necessitate a

\(^2\) If exhaustion coincides with increasing individual impoverization period to period, declining real life-time opportunities shifts demand inward though this is mitigated by population increases. Anticipation of lower willingness to pay schedules induce agents to plan to supply fewer assets for loan or sale in middle age, moving in the supply schedule period to period. The relative impacts allow prices to rise or fall.
dramatic rise in $r$, the marginal productivity of capital, as exhaustion approaches.

Price increases imply interest rate increases will lag equilibrium increases in marginal regeneration rates, $h_t'$. Possible price decreases on the other hand suggest a very rapid erosion in individual wealth. In this case Land price decreases are relatively larger than falling interest rates. So the increase in $h'$ does not necessitate approximate marginal productivity gains in capital, allowing exhaustion to evolve gradually over several periods without large gains to marginal productivity of capital.

In either case individual wealth falls as exhaustion approaches. Figure 7.2 in 'a' illustrates a production decision in Land and output space where prices increase and figure 7.2 in 'b' exemplifies a price decrease. In both cases per capita output falls and less of both inputs are employed to production.

The sacrifice by period $t+2$ agents required to accept the SMS is marked on Figure 7.2, a and b. The point $S_t^{\text{min}}$ on each indicates the level of draws permitted in period $t+2$ to assure the continuity of the resource. $Q_{\text{SMS}}$ is the quantity of output produced if the SMS is adopted. A fall in output from $Q_{t+2}$ to $Q_{\text{SMS}}$ indicates the sacrifice implied by adherence to the SMS.
\( Q_{\text{SMS}} \) however may fall below a required minimum draw of the resource necessary to maintain a minimum consumption level. An SMS that required a sacrifice to a production level below minimally required production, say \( Q_{\text{min}} \) in Figure 7.2a, is a target that requires an intolerable sacrifice.

Randall argued that a number of moral positions support an SMS established at the point of exhaustion to respect the continued existence of a species. However each of these moral systems might maintain a different view regarding intolerable costs. Much of the confusion by economists surrounding the SMS as a policy tool may emerge from confusion about the value theory concepts that underlie defining intolerable cost.

Deontologists, including contractarians, are likely to define intolerable costs by a rule similar to \( Q_{\text{min}} \) exemplified in Figure 7.2 on 'a' as some basic minimum. Different deontologists among themselves are more likely to converge to the same standard of intolerance for sacrifice demanded of agents. The Humian condition of justice, recognized by nearly all Kantian derivatives, asserts that there is a legitimate precursor to duty. Some minimal standard of living is often required before we begin to ask agents to obligate themselves to the tasks of moral reason. This minimum level of subsistence is a deontological principle that emerges prior to contractarian obligations to others. While there may be
Fig. 7.2
duties that superceed assurance of basic living standards, the requirement to sacrifice living standards of existing agents below a Humian basic needs level for the principle of sustaining future consumption is unlikely to be such a principle by most deontological systems.\(^3\) So deontologists are likely to converge on a well defined intolerable cost.

The consequentialist standard of intolerance is certainly more conditional. It will be derived from the immediate circumstances that surround exhaustion and the relative status of all valued concerns. Simply if the costs of adhering to the standard are disproportionately large relative to the benefits of other valued (or expected valued) concerns, then costs are intolerably high. Depending on what is valued and how well those values are currently satisfied, the level intolerable costs may justify imposition of enormous sacrifice on the present to secure an almost infinitely large future utility benefit from avoiding exhaustion. Or the definition of the intolerable cost may imply almost no protection through the SMS if adherence offends some other highly valued consequence. Following an objective maximizing formula of

\(^3\) Deontologists often require individual agents to accept the ultimate sacrifice for highly valued principles. Pressing the present generation below basic needs to pre-empt condemning an infinite future from survival below basic needs may seem consistent. The regard for the Humian condition of justice however is typically strong enough to require a generation presented with such an apocalyptic choice set to not bring into existence future persons rather than fall below basic needs or impose existence below basic needs on the future.
value consequentialists are likely to disagree among themselves as well as with deontologists as to the definition of intolerable costs.

Working from largely consequentialist frames, economists may see the intolerable cost as a simple *ex ante* cost-benefit analysis, emasculating the SMS logic. So within a consequentialist frame the SMS argument of avoiding mistakes by prior binding behavior, the Randall and Bishop argument, or a direct utility value for future agents will have to stand as justification of the SMS target; but these arguments will certainly produce very different definitions of the intolerable cost.

For our purposes, we assume a $Q_{\text{min}}$ can be defined.

**Setting the SMS**

The existence of a minimum consumption level to bound costs of adhering to the SMS and the foresight of our modelled agents impacts the establishment of the SMS target.

If some minimum draw, $D_{\text{min}}$, of Land is required to secure a minimally acceptable level of consumption below which we cannot legitimately require agents to further sacrifice, then an SMS set at $S_t^{\text{min}}$ is wholly insufficient. In order to assure positive future draws and guarantee $Q_{\text{SMS}}$ beyond this period, something above $S_t^{\text{min}}$ must be deferred by the young.4

4 This of course bars the case of declining population.
For example if population is constant, an SMS that only assures existence at $S_{t}^{\text{min}}$ will imply that the following generation can take no resource draws. This of course assures that the following generation will face intolerable costs in adhering to the SMS and will be justified in exhausting the resource.

Figure 7.3 illustrates a feasible SMS for resource conservation. Rather than defer $S_{t}^{\text{min}}$ which simply returns the same level of Land stock, deferring larger amount, $S_{t}^{\text{SMS}}$, assures the return of $S_{t+1}^{\text{SMS}}$. This permits draws next period. The distance $S_{t+1}^{\text{SMS}} - S_{t+1}^{\text{min}}$ available in the next period is established to be sufficient to allow minimal draws both by next period young and next period middle age to meet $Q_{t}^{\text{SMS}}$ and enough additional deferred stocks to regenerate $S_{t+1}^{\text{SMS}}$, sustaining minimal draws through time.

So for the simple constant population example,

$$S_{t+1}^{\text{SMS}} - S_{t+1}^{\text{min}} = (S_{t+1}^{\text{SMS}} - S_{t}^{\text{SMS}}) + (S_{t}^{\text{SMS}} - S_{t+1}^{\text{min}}),$$

where $S_{t+1}^{\text{SMS}} - S_{t}^{\text{SMS}} = 2*D_{\text{min}}$

and $S_{t}^{\text{SMS}} - S_{t+1}^{\text{min}} = S_{t}^{\text{SMS}} - S_{t}^{\text{min}}$. 

This sustainable $S_{t}^{\text{SMS}}$ is equivalent to an assurance that $T_{e,t+1} = 0$. In other words the alternative, feasible SMS assures enough natural resource stocks are deferred to sustain $D_{\text{min}}$. 


draws through time provided that the delivery of this assurance does not require the present generation to reduce consumption below the legitimate minimum.

The distance in Figure 7.3 between $S_t^{\text{SMS}}$ and $S_t^{\text{min}}$ will vary with conditions. For instance, if population growth is anticipated, this distance must be larger. Also if there is uncertainty regarding the location of $S_t^{\text{min}}$, a more demanding SMS will be required. Both of these of course increase the likelihood that an intolerable cost associated with adherence will emerge.

The value of the natural resource in production separates this SMS program from those typically associated with the Endangered Species Act in setting the SMS; however the general components (a respect for economic efficiency, a change in decision regime and bound on tolerable costs) of the SMS received from the literature are maintained.

A Comprehensive Conservation Program

The more conservative SMS suggested will increase the costs of adhering to the SMS. So while the early SMS alarm establishes greater protection for the distant future, there is an increased risk that the SMS will require an intolerable cost, allowing the exhaustion. In our model our resource manager can anticipate this perfectly and will be motivated to avoid this Faustian choice.

If wealth falls toward a foreseen exhaustion,
conservation limits on resource use at the point of exhaustion may be intolerable. The reduction in current consumption necessary to meet the SMS when triggered may be so extreme that the demand for sacrifice is itself an immoral deprivation of the welfare to agents living in period t+2 in our example. Yet if conservation efforts were adopted earlier (say in period t), agents would be marginally more able to afford sacrifice. In addition the magnitude of sacrifice may be less severe.

Early intervention may prevent facing an SMS in the period in which Te falls below minus one from becoming an intolerable burden. At the same time the immediate urgency of using draw restriction as the lone conservation tool is lifted. Our manager has more latitude to implement a more comprehensive conservation program to prevent exhaustion if the program begins several periods prior to the moment of immanent exhaustion.

In addition to simple draw restrictions the manager can initiate policies that ease population pressures on resources or accelerate technological changes to pre-empt the wealth declines that make sufficient conservation unprofitable. The manager can head off a catastrophe with perhaps only modest sustainability efforts today and will be bound to do so.

The obligation to enforce an SMS at the moment of immanent exhaustion carries over to an obligation to pre-empt having the SMS overridden due to intolerable costs. If the
SMS is likely to be required in the future and we anticipate that the standard will be unenforceable because it imposes intolerable hardship on the generation that must decide between exhausting or conserving a minimal resource stock, then the derived justifications that establish the SMS dictate with equal moral force a required conservation effort today. This is not a general justification to impose any conservation program. The level of conservation effort required by our manager evolves from the terms that set the Standard and the definition of intolerable costs.

POPULATION CONTROL

Our manager hopes to head off a draconian sacrifice by future agents to prevent resource exhaustion by adopting policies today. If the foreseen disaster results from insufficient wealth, the manager will consider programs that enhance future wealth. Reversing population growth rates is one of the options likely to moderate wealth declines.

To evaluate the cost effectiveness of a population control effort, consider our population function and the agent budget constraint.

Recall the population growth function:

\[ \frac{N_u}{N_y} = p(C_m ; Q) \].

\( N_u \) is the average number of children born to a period two agent at time, \( t \).

For illustration we characterize \( p \) by the quadratic equation:
\[ N_n = \gamma C_{tm} - \delta C_{tm}^2, \quad \gamma > \delta. \]

Policies targeted directly at suppressing birth-rates are modelled very simply. The policy is revealed by an additional negative term added to the quadratic population growth function. The program technology is funded out of taxes on the young and middle-aged. Specifically:

\[ N_{A,i+1}/N_{Y,i+1} = \gamma C_{ih}^2 - \delta C_{ih}^2 - \eta [P_{ty}N_y + Y_{tm}N_m] \quad \gamma > \delta \]

where \( P_{ij} \) is the tax in period \( i \) assessed to agent in generation \( j \). \( \eta \) will be likely fairly small; but depending on the original equilibrium level of \( C_m \) and the curvature of \( p \) the policy may have a dramatic effect.

In this example program response is determined by the aggregate funds collected for the policy. The program embeds an assumption of positive returns to scale with respect to the number of agents in the economy, not a per capita financing effectiveness. A presumption of fixed costs, mass media and education efforts, is implied by this characterization. If effective control efforts are entirely individualized instead, the third term can be re-written as: \( \eta [P_{ty} + P_{tm}] \). Finally \( \gamma \) may be linear or non-linear.

The budget constraint for each agent is defined from the capital equation of motion. The new budgets are:

**Young (y):**

\[ K_{im} = f\{ (K_{iy} - C_{iy} - P*\text{Land}_{iy} + B_{iy})D_{iy} : \phi \} - (1+r)*B_{iy} - P_{ty}. \]

**Middle-aged (M):**

\[ K_{ir} = f\{ (K_{im} - C_{im} + P*\text{Land}_{im} - B_{im})D_{im} : \phi \} + \]
\[(1+r)B_{tm} - P_{tm}\]

The tax rates may differ between agents based on wealth differences.

If such an advanced warning effort is adopted, these two equations of motion and the amended population growth function will define a new equilibrium. The value of sacrifice from the tax of the population control effort can be estimated and compared to the cost of other efforts to head off an overridden SMS. Also our manager can identify an optimal mix of efforts to generate the least cost protection.

In addition to these two policies, the manager can also invest in R&D. She may 'over-invest' out of a conservation concern. However there are incentive reasons that will induce our manager to consider at least some R&D program for simple efficiency reasons within her primary charge of seeking fully efficient markets. These efficiency efforts may be sufficient in themselves to avoid the undesirable consequence and illustrate how technological change can be introduced into our model.

R&D / TECHNOLOGICAL CHANGE

The process of technological change is absent from the development of our economic model. This exclusion does not affect the theoretical conclusions of this work but technological change certainly affects the sustainability prospects of an economy. As such all growth models have at least considered adapting their models to include
technological change. Yet for reasons that these models fail to fully endogenize the incentives in capital and land markets, previous growth models do not fully specify the demand for R&D and the expectations of innovation emerging from R&D.

Solow employs a Cobb-Douglas production function using per capita capital as the sole input to estimate the stability of growth in the U.S. economy (Solow, 1957). The constant factor, \( A \), in the equation \( Y = A k^a \) (\( a < 1 \); \( y \) is GNP) was boldly presumed to measure aggregate technological progress and the variance of the regression assumed to report variation in the pace of technical innovation introduced into the economy. In this sense, technological progress is modeled as a random and exogenous factor affecting economic growth.

Exogenous technological change typifies the literature on economic growth. If interpreted literally these models often detail technological advancement that evolves at no cost. Technical progress is free. Jorgenson, D.W. and Grilliches, Z. (Jorgenson and Grilliches, 1967) were early critics of this implied position and sought to establish a link between deliberate expenditures and innovation. Their work associates aggregate expenditures on R&D with the rate of technical progress in an economy, applying more valid aggregation techniques for inputs, outputs and prices along the way. The results of their empirical estimates suggest that innovation is not free but is produced from deliberate investment.
Still the endogenization of research and development into growth models has been slow. An equation that records the supply of R&D investment into technical gain can be grafted onto most growth models; but an explicit incorporation of demand for R&D defined by the willingness to pay for research by a representative agent who anticipates productivity gains is scarcely considered within the context of long run macroeconomic growth models.

Over the last decade an exciting literature has evolved with respect to the role of technological innovation and aggregate growth. Paul Romer has estimated that returns to new physical capital exhibit increasing scale economies. This is due, he argues, to advances in human productivity via technological improvement (Romer, 1987). Over a series of articles Romer contends that the economy experiences positive externalities from individual capital investments that automatically induce additional technical advances to the economy at large.

This is not incongruous with two previous characterizations of technology. First that there is non-rivalry is consumption of the results of R&D, human knowledge, that leads to an underinvestment in R&D. Second, human knowledge grows automatically by human interaction in the workplace. The form of this automatic production of new technology is reminiscent of J.K. Arrow's learning by doing (Arrow, 1962). Arrow posits productivity growth through
simple experience with a new technology or production process - an automatic, exogenous gain.

We don't have to see in the Arrow position exogenous technological innovation. Nor do we have to view the Romer growth results as a capital externality whereby increased capital stock indirectly stimulates new technology. Rather we can reconcile the empirical results of Paul Romer, D.W. Jorgenson and Zvi Grilliches; the theoretical results of Learning by Doing, non-rival of technical innovation, rational expectations (or perfect foresight) by agents, and the ability of current agents to capitalize in current markets on the opportunities provided by demands of future agents for capital inputs.

We return to our model to incorporate these basic microeconomic principles directly.

Recall that the production function is described as:

\[ Y = f(X,D;\phi), \]

where \( X \) is the capital input, \( D \) is a natural resource input not aggregable into \( X \). \( \phi \) is the parameterization of the model, and \( Y \) is output expressed in units of \( X \).

Consistent with a technology that exhibits CRTS, substantive but imperfect complementarity (some substitution) we illustrate this discussion using the following production function:

\[ Y_t = a_0 + a_1 X_t + a_2 D_t + a_3 (X_t D_t)^{1/2}, \]

where \( X_t = (K_t - C_t\pm B_t) \). \( a_3 \) is presumed large enough so
that input specialization in X or D is undesirable.

Technological change in this model is not considered free or to emerge naturally from capital externalities. (Romer, 1986). Rather it emerges as a consequence of real resources devoted to R&D investments. (Jorgenson & Grilliches, 1967). So the parameters of the model \( \{a_0, a_1, a_2, a_3\} \) are directly affected by R&D expenditures.

Specifically a characterization of the research program technologies are listed as:

\[
\begin{align*}
    a_0^{t+1} &= a_0^t + b_0 \left[ N_y R_{ly} + N_m R_{lm} \right]_t + \Sigma_i \delta_{i,t-1} \left[ N_y R_{ly} + N_m R_{lm} \right]_{t-i} \\
    a_1^{t+1} &= a_1^t + b_1 \left[ N_y R_{xy} + N_m R_{xm} \right]_t + \Sigma_i \delta_{i,t-1} \left[ N_y R_{xy} + N_m R_{xm} \right]_{t-i} \\
    a_2^{t+1} &= a_2^t + b_2 \left[ N_y R_{py} + N_m R_{pm} \right]_t + \Sigma_i \delta_{i,t-1} \left[ N_y R_{py} + N_m R_{pm} \right]_{t-i} \\
    a_3^{t+1} &= a_3^t + b_3 \left[ N_y R_{cy} + N_m R_{cm} \right]_t + \Sigma_i \delta_{i,t-1} \left[ N_y R_{cy} + N_m R_{cm} \right]_{t-i}
\end{align*}
\]

\( R_{kj} \) is the period \( t \) investment by an agent in generation \( j \), \( j = \{Y,M\} \), into R&D efforts \( k \), \( k = \{1,D,X,C\} \), targeted to increase productivity of parameter \( a_i \). \( N_j \) are the number of agents in a particular generation.

Note that the research efforts are targeted. Funds directed to improvement in capital productivity, \( N_y R_{xy} + N_m R_{xm} \), affect \( a_1 \), investments in improving complementarity between inputs, \( N_y R_{cy} + N_m R_{cm} \), affect \( a_3 \). All we intend to capture for example, is that advances in micro-chip technology are more likely to emerge from grants to the electrical engineering department rather than from the agronomy department. The productivity of research results are uncertain but not wholly unpredictable nor entirely separate from strategic
investments. Spill over discoveries of course occur; and the individual parameter response functions above could be extended to include positive responses to R&D investment targeted primarily to other parameters.

Funds are again generated by assessments against the current generations. The payoff of R&D investment shift the production parameters \((a_0, a_1, a_2, a_3)\) commencing the next period. Each of the four parameters identifies a strategic research program: human capital research shifting \(a_0\), man-made capital research shifting \(a_1\), natural resource capital research shifting \(a_2\) and finally a compliment research program which shifts \(a_3\).

The parameter response is a function of total, not per capita, funds generated. This captures the non-rivalry of the payoff from research efforts. Every agent realizes a boost in productivity from any single agent's R&D investment, creating a divergence of private incentives and social gains. We can directly model this market failure without postulating generally exogenous capital externalities.

In addition, the Learning by Doing phenomenon can be reconsidered as a lagged parameter response to previous R&D expenditures. This simply implies that there is a gradual process of translating innovation into aggregate economic productivity. Productivity will continue at some modest, declining rate without new R&D investments: Learning by Doing. However, this addition to productivity is not exogenous or
automatic, but a fundamental aspect of the R&D investment process. For simplicity, no erosion of knowledge is modelled.

The new capital equations of motion that include a public sector which acquires funds to produce new technology become:

Young (Y):

$$K_{i+1,y} = \{ K_{iy} + a_0 + a_1[X_y] + a_2D_{iy} + a_3 ([X_y]D_{iy})^{1/2} - (1+r_1)B_{iy}$$

$$- P_1LAND_{iy} - R_{iy} - R_{ky} - R_{dy} - R_{cy}\} \quad \text{and}$$

and Middle-aged (M):

$$K_{ir} = \{ K_{im} + a_0 + a_1[X_i] + a_2D_{im} + a_3 ([X_i]D_{ih})^{1/2} + P*\text{Land}_{im} -$$

$$B_{im} + (1+r)*B_{im} - R_{im} - R_{km} - R_{om} - R_{cm}\}$$

where $R_{kj}$ is the tax earmarked for each specific research programs by agent $j$. Of course each $a_i$ depends on the accumulated effect of previous R&D expenditures and current R&D expenditures will further affect productivity next period and through the future.

The equilibrium result that incorporates these taxes and the impact of R&D on the production function will explicitly generate agent demands for the various R&D programs. The young of course will directly enjoy productivity gains in their next period. So their demand is non-negative. Similarly, R&D investments that increase productivity next period will increase prices for assets today, meaning the middle aged also have non-negative demand for R&D. So our manager will be able to identify the economic efficient level of R&D investment for each of the separate efforts which is assumed to be a public effort because of the market failure.
Since agents are forward looking and are modelled with rational expectations, this demand may be large.

Again the iterated effect of these technological gains through time means that R&D investment will assign a non-negative value to improvements in technology that emerge in the far distant future, beyond the lifespan of existing agents. Productivity benefits that accrue two periods hence, for instance, will increase the opportunity cost of consuming capital or using Land today. This increases interest rates and resource prices today.

Up to this point we have outlined the most basic and various microeconomic principles in the theory of innovation, agent expectations and the supply and demand aspects of R&D investment while offering a modelling frame that can rationalize the stylized facts about technological change. The salient elements to fully specify and endogenize technological change into a long run growth model have been incorporated into our model. Having demonstrated the adaptability of the model to this consideration, let's return to our manager's problem.

**Optimal Policy Mix and General Equilibrium**

Detailing the economic efficient level of expenditure on R&D (our manager's primary charge), the manager can still face a legitimate conservation question and a duty to act to prevent resource exhaustion several periods hence. She may
restrict resource draws, $D_{iy}$ and $D_{im}$, she may finance a population control effort, and she may exceed the efficient level of R&D expenditures on one or more of the specific R&D efforts.

If her immediate goal is to assure that an inevitable SMS alarm is not sounded in a period where adherence to the SMS requires an intolerably high cost on the then living generation, our manager can implement a set of conservation policies today that assure the sustainable use of natural resources in production through time. With the goal clearly specified, she can seek a least cost effort measured in units of capital among the three policy tools considered in this work.

Amending the population growth equation to:

$$\frac{N_t}{N_y} = p(C_m;\phi) - \eta [P_{tyN} + P_{tmN}] \quad \gamma > \delta,$$

the production function to:

$$Y = f(X, D; \phi),$$

where $\phi$ is itself a function:

$$\phi = \Upsilon(R_{kj})$$

with $R_{kj}$ the vector of specific research efforts, and altering the capital equations of motion to reveal the financing of these programs as:

**Young (y):** $K_{iy} = f\left( (K_{iy} - C_i + P*\text{Land}_{iy} + B_{iy}), D_{iy}; \phi \right) - (1+r)^*B_{iy} - P_{ty} - R_{iy} - R_{ky} - R_{py} - R_{cy}$.

**Middle-aged (M):** $K_{im} = f\left( (K_{im} - C_m + P*\text{Land}_{im} - B_{im}), D_{im}; \phi \right) + (1+r)^*B_{im} - P_{tm} - R_{im} - R_{km} - R_{pm} - R_{cm}$. 
our manager can identify an optimal mix of draw restrictions, population control and additional targeted R&D efforts to meet the requirement to pre-empt the intolerable cost of adhering to the SMS at minimal costs to existing agents. The optimal program mix is identifiable within the context of a long run dynamic general equilibrium economy built on fundamental microeconomic principles, principles considered relevant to a sustainability question an economist would consider reasonable.

The conservation program outlined is really part of the SMS generally. No obligations beyond assuring that resource draws remain positive through time is imposed on the present. Many moral theories may require more effort; but for the reasons developed throughout this work, this much effort appears a fairly robust minimum obligation on the part of the present. This program identifies a fairly broad scope to an SMS established to ensure basic needs well into the future. The SMS implies duties on the present well in advance of immanent exhaustion in order to soften the blow of the conservation sacrifice at the moment exhaustion is immanent. This duty is a direct extension of the principle that there are limits to sacrifice that one can morally require to adhere to an SMS.

CONCLUSION

In this chapter a general conservation approach is
outlined to address the conservation question developed in chapter five. The program evolves out of a set of policy objectives that are generally consistent with the definition of an SMS.

The refined SMS presented differs from existing defenses of the SMS. The proposed standard is set beyond a simple assurance of natural resource preservation to further insure on-going use of the resource. This amended concern reflects the considerable value of the resource used to produce basic human necessities, a value that motivates the sustainability question that we address in this work. This added protection however is not without cost.

The same basic and, arguably, widely held moral concerns that make us attend to future welfare commit us to value also the welfare of the living. This limits the required sacrifice that we can legitimately ask a generation to endure. The more protective SMS presented implies a greater chance that the SMS will bind the actions of the economic agent. It also increases the level of sacrifice likely to be attached to adherence.

If there is a limit to the sacrifice that we can demand of any generation and if the possibility of resource exhaustion is associated with declines in real wealth over time, then the potential for an SMS to be effective and to secure any real protections is diminished by an increased probability that the safety standard will be legitimately
overridden as too onerous. This imposes a burden on generations preceding the generation that enforces the SMS to ease the eventual sacrifice of adhering to the SMS. These preceding generations are by and large wealthier and they are afforded more policy options to implement a conservation strategy than the generation up against an SMS restraint. Early intervention prior to facing the critical choice to exploit the resource beyond its carrying capacity revitalizes the force of the SMS; and the obligation intervene early is justified by no more than the same principles that establish the SMS and define the intolerable costs of adherence in the first place.

Finally the additional latitude available to the present to implement a conservation program intended to forestall or to avoid facing intolerable costs when the SMS alarm goes off includes much more than restrictions on Land use. Today's resource manager can choose among several efforts and identify the least cost mix of policies to meet current obligations. Some efforts may include direct conservation of Land use of course but other efforts include policies that directly mitigate the erosion of wealth that makes self-selected conservation too expensive. Given the structure of our economy, plausible complimentary policies include population control programs to ease pressure on wealth and additional R&D investment to accelerate the productivity of resources.

To explore the benefits of R&D efforts we introduce
endogenous technological change which is literally produced by conscious R&D investments. This reinforces the adaptability of conceptualizing economic growth within a more fully specified general equilibrium system than frequently found in the literature. The process of technological change outlined can be more completely explained in our model since both the marginal cost of producing technical improvement and the imputed willingness to pay for R&D enter directly the modelling structure. The process of technical innovation modelled is consistent with a number of empirical studies such as Romer and Jorgenson and Grilliches and can be at least reconciled to the prominent theoretical issues surrounding technological change such as Learning by Doing and the failure of a market to provide sufficient private incentives to conduct R&D. So in outlining our manager's immediate conservation options driven by the SMS, we hope some order is added to the economic discussion of technological change.

If exhaustion of a resource necessity appears on the distant horizon as an outcome of a fully efficient, Pareto Optimal economy, we are under some obligation to prevent this dismal future prospect. The feasibility of this undesirable prospect and the general duty to pre-empt this outcome are derived in this work. Yet many of the conservation policies suggested fail to accomplish their objective, perhaps because the policies answer questions that evolve from models that have incompletely specified markets within an economy.
An SMS sensitive to preserving the sustained use of an input is offered as workable within the same modelling framework used to construct the conservation question of this work; yet the burden of adhering to the SMS when triggered may be intolerably expensive to impose on potentially quite immizerated future agents who must enforce the SMS conservation target. We defend that some immediate conservation action can be induced as both ethically obligatory and as economically reasonable to at least reduce the chance of emasculating the entire protective SMS net by waiting too long to intervene. It is important to remember that these immediate interventions are dictated by the SMS even though the critical stress to the resource is not immediately upon us. The justifying principles of an SMS program are consistent with peremptory actions that head off a resource scarcity crisis and can endorse a very large set of actual policy efforts other than curbing immediate resource use. Requiring inefficiently high R&D or population control efforts today can be defended directly from an SMS principle that bounds the level of sacrifice that can be legitimately imposed to secure the SMS.
CHAPTER VIII

Conclusions and Implications for Future Research

In this study we investigated the skeptic's concern that the structure of the market is incompatible with long run human welfare. We took seriously the skeptic's claim that the order of the natural world cannot be reconciled with human centered desires to satisfy preferences. We attempted to capture some important elements of this ecological skepticism about markets into an economic model that directly focusses on long run sustainability. We take an anthropocentric perspective on sustainability - sustained consumption levels for human population - whereas some ecologists might be more concerned with, say, preservation of particular ecosystems for its own sake. Yet in so far as we are interested in the ability to sustain human consumption through time, an arguably robust model of the economy has been developed to represent the use of the natural world to satisfy human preferences. This model respects generally both natural phenomenon and market dynamics.

We conclude that consumption can either rise or fall through time - a result consistent with a number of previous studies. What is disturbing is that our idealized economy admits the possibility of a devastating drop in consumption.
resulting from an overextraction to exhaustion of an essential renewable natural resource. This unsustainable overharvesting occurs even though our economic agents possess perfect foresight about future prices, understand perfectly the natural renewal process and can perfectly anticipate the output of a production plan.

This chapter summarizes our important findings and directions for future research on this topic. We review a theoretically reasonable conservation question and record our exploration of policies to mitigate the risk of an unwanted extinction of a valuable natural resource. We suggest that a lack of assurance that fully efficient markets can provide for future generations does not preclude economic input from the question of sustainability. On the contrary, we desire to retain many of the self-enforcing mechanisms to save and invest that contribute to conservation. We want our economic incentives to complement our policies as much as possible so we can reduce the scale (and therefore the costs) of required market interventions. This goal suggests a wider role for economists to respond strategically to a well defined sustainability crisis than the restrictive role of a resource manager charged with monitoring economic efficiency alone.

Summary of Findings

Critique of Ethics and Economics

This study begins with the trivial observation that
future generations are born to a preceding generation. The implications of this observation however are not trivial. The first two objectives of this work illustrate the fundamental theoretical challenges of addressing the dependency of the future on the present in both ethics and economics.

Chapter two argues that none of the prominent ethical value theories adequately consider our obligations to bring into existence future agents. The decision to bring about a future generation of a particular size and with particular consumption prospects is arguably the primary ethical question regarding our obligations to the future. Bringing a generation into existence is at least the first agent act with moral consequences affecting the future. Other moral contingencies that affect the future logically follow this decision.

Our duties to potential persons, even our typology of different kinds of potential persons, cannot be deduced directly from inside prominent value theories. We conclude that duties to the future are unlikely to be grafted onto existing moral theories. Instead these obligations must be derived as a fundamental principle during the initial exercise of listing the core value considerations of a moral theory.

We don't attempt to articulate an entirely new value theory. We also offer strong warnings to the economist who adopts a single value theory as a planning objective (i.e. maximize intertemporal utility, or maximize the minimal
consumption level of any generation). Rather we identify two very general moral principles that are likely to feature prominently in any plausible moral theory that derives a positive duty to the future. Our inability to confidently assert more directly from the moral perspective is important to the legitimacy of the rather pro-active SMS proposed in chapter seven which develops an argument for a rather strong contribution from economics.

We argue that the on-going existence of the human race is good and the quality of life of those future humans is also good. We conclude that if continued human existence and living well are conditioned on humans' ability to produce goods and services, then economics has a large role in determining policy options guided by these two heuristic moral principles.

In searching for an adequate model of the economy to capture the concerns of sustainability, we find that the dependence of future humans on the reproductive decisions by the present poses a unique modelling challenge for the economist as well. Both the Solow growth model and current forms of overlapping generations models (OLGs) cannot account for the demographic changes that can affect market prices and the quantity of productive assets that are finally transferred between generations. Designed for short-term business cycle theory, each model presumes an aggregate equilibrium by exogenously specifying either the supply or demand side of
long term asset markets. This simplification fixes actual prices or price trends and permits the economist to investigate the economic responses by agents of interest under various policy scenarios. Yet it is difficult to justify these modelling assumptions for analysis about time periods beyond the near future.

Trade evolves only from random variation among aggregably homogeneous agents in these models. Structural differences that arise between agents from different generations that have different relative population sizes and different relative levels of wealth cannot be incorporated into the market trade modelled by these theories. Attempts to graft these considerations onto the modelling framework results only in an exogenous specification of these dynamic economic processes. For instance, in the Solow growth model the quantity of savings is specified as a continuous function of aggregate wealth or capital, $s(k)$, rather than as the market interaction between credit suppliers and investment demanders. Similarly OLG models specify trade only between identical agents from the same, period one, generation. Asset and wage prices are also exogenously determined. If intergenerational changes determine the trend in consumption levels through time, then these trends comprise the core concern of an economic model addressing sustainability. An exogenous specification of these trends in the model will then impose the conclusion and mask the dynamic economic processes that determine
sustainability.

Just as philosophers need to reconstitute from core theory their approach to the moral obligations to the future, economists need to return to micro-economic fundamentals to specify a model that adequately describes the process of changing welfare opportunities over the generations. Shorthand adapted from models that address intra-generational concerns to concerns for future agents in either discipline is not adequate.

Review of the Model

Fortunately the design of an adequate economic model to describe sustainability prospects is much simpler than the creation of a coherent moral theory to prescribe our sustainability obligations. So our third research objective was to develop a relevant model to address sustainability.

We add a third, retirement, generation to a two period OLG model. This allows the entire life-cycle of an economic agent to be specified. Trade can now emerge between second period agents accumulating retirement capital and first period agents seeking capital to initiate productive life. The more asset rich middle-aged find it profitable to lend/sell some of their on-hand assets to the asset poor young since the marginal productivity of resources held by the middle aged are lower than the very first assets acquired by the young. So economic incentives induce the transfer of productive assets between generations.
More importantly the anticipation of a sequence of these trades between adjacent generations motivates speculative asset purchases by the young. The young acquire some productive assets with the hope of re-selling those same assets plus their marginal value in production to the next period young. From this expectation, a sustained level of savings could be induced in the economy.

In order for the model to be relevant to the sustainability question, however, the supply and demand schedules for productive assets must respond to the conditions of the natural world and its relation to our economy. How a general equilibrium economy accounts for these natural forces really outlines the conservation question.

The sequence of life and death motivates the fundamental structure of our model. Since so much of our discussion centers on demographic differences between agents and the pressures of population growth, a population growth function is introduced as a material balance condition to our general equilibrium. The decision by an agent to reproduce is modelled to respond to the level of consumption in the second period. The properties of the function reflect the economic content that has been hypothesized to rationalize the stylized facts about populations growth. Social security needs and infant mortality concerns explain the increase in population growth rates as consumption opportunities increase beyond basic necessity until some higher level of development is
realized and birth rates begin to decline. Inheritance is also admitted into the model, allowing our agents to enter life with some capital. However since our purpose is to investigate the non-altruistic prospects for sustainability, inheritance should be assumed to be small.

Most importantly the general equilibrium conditions must include a natural resource renewal function. Our modelled resource is also exchanged between generations and motivates the same speculative demand purchases by the young as does capital. If production discourages input specialization because Land and capital partly complement each other in production, then some speculative purchase of LAND will not be employed to production and re-sold as capital to next period's young. Rather some purchased Land will continue to be held as Land and carried forward for period two production and for re-sale as Land. Because the resource regenerates, some Land purchased will be withheld from production and reproduced. So the portfolio of Land and capital assets saved will specifically incorporate the marginal regeneration rate of natural capital and the unique value of the resource.

The expected future, even very distant future, productivity of the quantity of the resource available in any period affects the price of the resource today and indirectly the price of capital. The supply and demand schedules for Land specifically account for the simultaneous influence of each of these different factors. Preferences, production
technology, resource renewal rates, population growth and inheritance all simultaneously impact market trade and the amount of resources held in reserve from period to period.

**Toward a Conservation Question**

We then ask if incentives to save natural resources for future generations are sufficient to sustain long run production. We find that the same complementarities between Land and man-made capital that encourage self interested conservation of Land also make exhaustion of the resource a legitimate concern. If the inputs were perfect substitutes the conservation concern would be a meaningless concern to the sustainability issue that we posed. So the more serious are the consequences of a resource exhaustion, the stronger are the economic incentives encouraging conservation.

The relevance of the conservation question emerges out of the properties of the resource renewal function itself. If the function is sigmoid shaped rather than everywhere concave, non-convexities are introduced into the agent choice set. Under fairly robust conditions, this adds a vulnerability that exposes the future to an unwanted natural resource extinction even though all markets clear. Since natural resources will depreciate if stocks fall below the resource carrying capacity and since this range can be large, the opportunity costs of harvesting renewable resources may not be sufficiently large to prevent exhaustion of the resource.

Since the sigmoid shaped renewal function more accurately
reflects the biological process of resource renewal, we take seriously a conservation question generated from this biological property. Still the shape of the renewal function does not dictate resource exhaustion. The renewal process is only one dimension of a larger simultaneous equation system that characterizes the general equilibrium. We argued that economies identified by relatively high and stable levels of per capita wealth will tend to avoid the slide toward natural resource exhaustion if resource allocations are economically efficient.

Not surprisingly, poor economies burdened with relatively high birth rates tend to press resource stocks toward their carrying capacity. The opportunities anticipated from the speculative purchases begin to decline from period to period. Lower incomes mean that asset purchases are relatively more expensive, and this suppresses demand. This lowers the ability to pay for inputs by the young which in turn reduces their willingness to accept compensation for resources next period. The consequent loss of trade in assets reduces natural resource conservation. The greater relative payoffs associated with natural resource use could presage the eventual resource exhaustion. If the marginal rate of resource renewal near exhaustion is not large enough to dominate the opportunities associated with resource use, then exhaustion is consistent with market price signals. A concave renewal function with infinite slope at the origin assures
this high opportunity cost while a sigmoid curve does not.

Under conditions of rapid population growth that eclipse gains in per capita wealth, fully efficient markets cannot guarantee the existence of a renewable resource necessity into the future. The dependence on prices to regulate conservation may become unreliable. Under truly stressful conditions where incomes are rapidly declining, increased physical scarcity may actually accompany falling prices. The market incentives that transfer resources from generation to generation may not be sufficient to curtail the decline in wealth from period to period. This erosion of opportunities in the future can occur with or without a resource exhaustion given our model; but the entire elimination of a potentially essential input is assumed to escalate the potential crisis of declining welfare opportunities into the future and moves us toward an immediate conservation question.

Conservation Policies

The potential urgency of the conservation question motivates the exploration of policy interventions that discourage an unwanted resource exhaustion.

Two policy responses are criticized in this work. One proposal recommends reducing interest rates to increase the current value of future benefits (i.e. the opportunity cost of resource extraction). This proposal ignores the role of interest rates in encouraging savings and investment activity, therefore rewarding forward looking agent behavior. We note
that a reduced interest rate policy reduces economic surpluses and therefore reduces the aggregate wealth of current agents. Using our model we found that poverty tends to discourage conservation. From this we argue that a reduction of interest rates is unlikely to encourage conservation. Rather such a proposal likely aggravates the conservation crisis and accelerates the rate of natural resource use.

Another proposal seeks to increase the representation of future agents by assigning to the young ownership rights over all assets. The middle aged become input demanders and the young become input suppliers. A reconstruction of the general equilibrium under this property rights regime shows that no fundamental change in the nature of equilibrium solutions occurs from this change. The same vulnerability that admits the conservation question continues. The relative invariance of the risk of resource exhaustion from this shift in property rights is explained by an application of the Coase Theorem.

We then consider two variations of these policies. One policy is a less ambitious application of the reduced interest rate policy. The second is a much more ambitious application of a shift in the property rights regime.

We conceive of the first policy as a targeted conservation program that allocates natural resource use in benefit cost analysis by employing a below market interest rate in calculating the benefits of conservation. In evaluating the quantity of Land that can be used in any
period, the opportunity cost of future land use estimated by
the resource manager is therefore artificially increased. The
manager adopts lower future interest rates than will actually
exist in the market. The reduction of the analyzed interest
rate directly increases conservation by rationalizing a lower
quantity for resource harvests. The economic surplus losses
permitted by this market intervention are not unbounded. The
increase in the derived opportunity cost is restricted by
establishing an interest rate floor for the analysis. Suggestion
s from the literature commonly forbid negative
future interest rates for such an exercise. If the policy is
adopted for regulation over a disaggregated set of natural
resources or employed in different time periods, the magnitude
of the economic losses tolerated to assure conservation can
vary tremendously. This means that the same conservation
effort could be achieved at lower overall costs or that more
conservation could be realized with the same funds.

The variant property rights policy which we critiqued is
presumed to implement a contract among the generations. A
Rawlsian contract is the most relevant. If a legitimate
conservation concern appears on the horizon, we are duty bound
to alter our economic behavior in order to improve the
prospects of some assuredly worse off generation. Sacrifices
by the present are limited in this policy also. At the point
that the present becomes the worst off generation or
consumption falls below some level of basic human needs, no
further sacrifice is required.

The policy is defended in the literature by two arguments. First such contractarian duties represent a developed moral position. Second the program can be implemented with a credible legal enforcement of direct property claims by the future on the present. Having accomplished the proper trading position agents are left at the margin to exchange assets at the resulting general equilibrium price. So following a credible enforcement of this moral claim, agents are free to optimize without central direction making the policy self-enforcing from this point.

Our critique denies that our manager is legitimately free to presume this moral authority. We note that such a proposal exceeds the bounds of professional ethics and burdens the advocate to defend the proposal on moral grounds first. We also deny that the marginal self-enforcement of the policy through a new general equilibrium exists. Given that non-overlapping generations cannot directly trade with one another, the enforcement of the policy will require (except by chance) the centralized command of all economic activity by our manager to implement her program. We cannot extend the argument that property rights can be enforced by merely defining the ownership right to a good and then let the marginal incentives of the market implement our moral obligations. This more ambitious policy is discarded first because the objective cannot be currently justified and second
because the proponent fails to achieve her pragmatic promise of offering a policy that is relatively self-enforceable within a neoclassical market equilibrium.

In formulating our own policy we retain the basic notion that some economic sacrifice is warranted to avoid the exhaustion of a useful natural resource that will likely devastate future society. We also retain from the two variant policies the general acceptance that these obligatory sacrifices are bounded.

We reintroduce the Safe Minimum Standard (SMS) as a policy instrument present in the current literature that directly honors these two principles. The suggested SMS policy accomplishes the conservation goal of the alternative interest rate policy directly without the indirect analytic exercise. Most importantly the SMS does not bind our manager to a procedure that will impose unnecessary losses in controlling intolerable costs. Also the SMS simplifies the conservation procedure over the alternative property rights program. The general SMS procedure is widely acceptable to a number of different moral theories and is not likely to overstep the legitimate bounds of authority. Also the interventions into the market are likely to allow a constrained market to operate without the central control of all economic activity which may be practically and ethically valuable.

While the SMS standard preventing the exhaustion of the
valuable Land resource is robust, we accept that the definition of intolerable cost will vary from moral theory to moral theory. We do suggest however a general strategy to implement our policy that reduces the cost of adherence to the SMS. This offers the hope at least that costs are not intolerable to the moral agent who accepts positive obligations to safeguard future society from a devastating erosion of living standards.

The SMS protects sustained use of Land for future generations - not mere existence. If we accept the SMS standard and we foresee the eventual harvest of the resource to stock levels below carrying capacity several generations into the future, then we can also justify the immediate adoption of programs to interrupt this dangerous trend. These early interventions mitigate the costs associated with preserving some sustained minimal level of resource use and lowers the chance of facing an intolerable cost of adherence to the SMS. This of course strengthens the power of the SMS program. The continuous erosion of wealth that we typically associate with resource exhaustion in this work suggests immediate conservation efforts are relatively more affordable. Early sacrifice likely imposes a smaller marginal utility loss than a last minute moratorium on resource use. Also a gradual decline in physical stocks toward exhaustion may suggest that early interventions are absolutely less expensive as well.

Finally we note that the manager has more policy options
in pursuing her resource preservation goal. This freedom also mitigates the costs of adhering to the SMS. The manager may find it more effective for instance to prevent the deterioration of long run wealth than to directly pursue restrictions on resource use. With sufficient lead time, a research and development program that strategically targets technological advances or a directed population control effort may compliment or even replace immediate restrictions on resource use to guarantee that the resource is never exhausted. There may be other programs open to our resource manager that reduce the cost of an SMS protection and therefore the chances of facing an intolerably high cost of assuring a SMS for natural resource use through time.

We do not suggest that we have perfectly asked and answered the question: Can fully efficient markets provide for future generations?. Nor have we written the last word on policies to answer the more limited conservation question which is itself a subset of the larger sustainability question. We will consider some extensions of this work in the next section. Yet we have delineated a accessible approach to thinking about sustainability in the long run. We expose the ambiguity of moral approaches to the question. We extract the salient micro-economic principles that affect sustainability and build a model from them. We define a serious conservation question that captures many of the concerns of biologists and ecologists inside a macro-economic
model. We demonstrate the weaknesses of several conservation programs that were previously generated without the benefit of our modelling framework; and finally we offer some suggestions on how best to address sustainability concerns for the very long run.

**Implications for Future Research**

**The General Sustainability Question**

This work concludes that fully efficient markets may or may not sustain welfare for future generations. However the policies critiqued in this study focus on a subset of the larger sustainability discussion - our conservation question.

The three policies we considered: purposeful depression of the interest rate, reassignment of property rights and a safe minimum standard, I submit generalize well to the larger sustainability debate. Even the specific discussion of policy options available to our planner in implementing a SMS (intentional overinvestment in R&D and population control efforts) will likely feature prominently in a general sustainability program because these extra-efficiency efforts target the generation of future agent wealth.

Nonetheless the larger question is much more difficult. The SMS must now define a minimal level of income that must be secured. This level may be an absolute minimum or even a level relative to current income. The consensus claimed to support a safety standard that assures the on-going use of a
highly valued natural resource erodes with the larger question. Locating this SMS will take additional study. While the emerging standard may require a well specified moral theory, it seems that at least some consensus could be identified at least a the level of basic needs in concert with our conservation motivated SMS and may therefore remain a question for an economist.

The larger question demands more precision from the analyst in every way. The rather robust claim that exhaustion of a necessity of near necessity is to be avoided presumes that we can locate areas of vulnerability in the real world. The inherent real world uncertainties may not entirely eclipse the conclusions of this work. A sincere collaboration between ecologists, scientists, economists and other social scientists could highlight regions of serious vulnerability to a conservation crisis and some real potential responses. Simple rules that may only suggest specific R&D efforts targeting for instance new water purification technologies or backstop technology substitutes for strategic, eroding resources; or infant nutrition programs to curb population growth in particularly sensitive areas; or immediate conservation and pollution abatement efforts might be confidently identified without a detailed understanding of the specific dynamics of our economy through all time. This work certainly encourages these very applied studies and legitimizes or frees an economist to think about these potentially serious problems as
possibly more than a concern for economically efficient allocation when facing the conservation question. Resolution of uncertainty about the actual dynamics of the economy becomes much more important when we consider the larger sustainability question.

**UNCERTAINTY**

An obvious simplification of the model developed in this work is the assumption of perfect foresight. The idealization is intended to strengthen the impact of the conservation question. However a systematic investigation of the impacts of agent uncertainty will better detail the prospects that efficient markets will generate a conservation crisis. At the same time this investigation makes the model easier to translate to other questions, including the larger sustainability question and other outstanding macro-economic issues such as social security policy.

The legitimate admission of a conservation question continues with the introduction of uncertainty. Yet we really cannot determine whether a conservation crisis becomes more or less likely with the introduction of various forms of uncertainty. Do agents save more or less, do speculative purchases increase or decrease, do agents produce more or less when faced with uncertainty? These are certainly relevant questions with implications well beyond our conservation question.

Introducing uncertainty into this work is probably most
effective placed in two positions in our model: uncertainty about the parameters of a resource renewal function and a random error on the effectiveness investments in R&D. Production uncertainty particularly with respect to degrees of local substitutability and uncertain life expectancy could be considered; but I suspect the magnitude of these uncertainties are less serious in aggregate. The two uncertainties mentioned directly impact the speculative purchase and accumulation of assets in this model. These two uncertainties directly determines the magnitude of assets transferred between generations and both functions are arguably subject to considerable uncertainty relative to other functions in the model.

The directional impact of these uncertain outcomes on speculative asset acquisition and saving will probably depend on the paramterization of all the functions in the entire model. Without analytic solutions to our model, an extension of the discoveries in this work to address uncertainty will require simulation of various parameterizations of the model.

With the introduction of uncertainty into selected functions in the model, various functional forms and parameter values can be simulated to test the response of agent consumption, production and savings decisions. Different functional forms under certainty for the utility function, the production function, the population growth function and inheritance can be introduced along with a
probabalistic set of outcomes for resource regeneration and introductions of new technologies. The technical demand of each simulation is no less than the solution to a computable general equilibrium problem. Given the complexity of solving many CGEs, this extension could easily require another dissertation.

AGGREGATION OF D

A more immediate extension of this work is the relaxation of our modelled definition of D. There are in reality not one but many renewable resources; and there is no special reason to assume that they are aggregable into a single D. In the real world some renewable resources may be aggregable into capital, subsets of resources may be aggregable into a different resource goods and some of course may be entirely inaggregable with any other input. Finally some resources may be consumption goods themselves. The concern about habitat protection for instance as it relates to long run production can be viewed as uncertainty regarding complementarities between resource stock levels affecting regeneration..

Substitutes may already exist or backstop technologies might be developed for many or most of real world renewable resources. A conservation crisis then may involve only a few natural resources. These vulnerable resources of course must be identified and an appropriate SMS program must be initiated to respond to each crisis. A first glance we may be relieved that a conservation question does not arise for all resources
in general; but this is little solace. In reality the demands on a pro-active government that takes seriously our conservation question requires a fairly sophisticated constant vigilance on the performance of our economy with respect to an entire set of critical resources.

An even more sobering implication of a disaggregated set of Land resources that must be managed, many of which may be subject to market failure, is that the simultaneous implementation of many different resource management plans complicates our efforts to monitor the performance of our economy for the long run. Our resource management policy recommends efficiency-based management subject to a safe minimum standard that targets the preservation of highly valued renewable resources. We argued strongly that benefits and costs should be defined within a general equilibrium framework and that analyses account for all relevant simultaneous impacts of a policy initiative.

An independent peicewise estimation of economic efficiency (benefit cost analysis) and identification of vulnerable resources that should be managed by a SMS will introduce specific simultaneity biases into the resource management program.

We worry that ignoring the substitutability and complementarity between individual policies simultaneously adopted will overlook (or create) a conservation crisis in allocating a critical resource. This crisis will likely
remain systematically undetectable until the undesirable consequences are upon us unless our managers can establish a procedural check on the most likely biases from neglecting total program valuation. The reallocation of resources may alter the baseline prices and quantities presumed in the analysis sufficiently to invalidate their conclusions. A serious problem can arise if many natural resources are managed according to benefit cost estimations of the demand for resource use in production and are allocated accordingly. As the number of resources in the economy managed by BCA subject to SMS rules grows and these harvests are estimated independently, then resource use will be systematically overallocated. Speculations lead us to worry that a resource crisis that warrants triggering the SMS alarm will go unnoticed. Even worse, independent policy evaluation may cause a resource crisis. Certainly this question which is motivated by our model deserves further investigation.

The Challenge of General Equilibrium Driven Policy

A second pitfall of BCA led resource policy is suggested directly by the basic insights of our model. Our model specifically eschews the practice of assigning constant prices over long time horizons to conduct economic efficiency analyses for long run projects. We need some indicator of the trace of prices through time. For the same reason policies that reverse overuse of non-rival or non-exclusive goods and prevent a dramatic erosion in the standard of living in the
future cannot rely on the trace of prices implied by the current state of the world before the policy.

In the strictest sense we find ourselves in an environment of comparing noncomparable states of the world from one production possibilities frontier to another. The more dramatic the implications of the policy for the future, the more current prices will change in response to the introduction of the policy from a change in the expectations of future asset demands. To really estimate the efficiency gains of the policy, the entire general equilibrium trace should be re-estimated. The total economic surplus change then will define the true measure of net benefits.

This observation helps to end some of the nonsense that economic theory can only value a project that may save future civilization only one or two generations hence from disastrous consequences at a truly trivial cost. The normal mode of partial equilibrium estimation in a BCA really obscures the economy wide changes likely to result from a policy that dramatically alters the state of the world - even if it is a distant future world. We have found that efficient markets can admit a conservation crisis; but to best assess the strength of the market incentives in preventing a crisis resource economists have to be aware of the general equilibrium implications of programs that result in non-marginal changes. This is not a new argument, but the argument is somewhat rehabilitated in the context of our
model.

The research implications of this extended question are immediate. Our main tool for assessing efficiency is arguably inappropriate if employed to issues that really count in the social decision process. An extreme view cites that any efficiency correction is burdened with this incomparability of partial versus general equilibrium differences. In considering future welfare implications of resource policy, the discipline needs to consider conventions that guide the use of traditional BCA as a tool to inform policy. How much of a change is too much for our techniques to be valid? What are the theoretical properties that signal a change in the state of the world is too strong to accept the current trace of expected prices? Combining this with the aggregation concerns above, how likely are we to realize too strong a change to validate standard BCA when we adopt a general BCA subject to SMS strategy employed to a large number of small social decisions previously exempt from this management practice?. The general theoretical concerns are available in the literature but need to be extended to this model specifically. Eventually, however, the issue should be explored by simulating the model under various assumptions of functional form and parameter value for the critical functions in the model. In this way, the discussant can relate assumptions regarding production, utility, and resource renewal to the sensitivity of aggregate prices in the economy.
We may also identify alternative analytic conventions when traditional BCA becomes untenable through such an exercise.

Conclusion

The basic goal of this study was to reconstruct an economic view of long run sustainability from the fundamentals of micro-economic theory. A serious attempt was made to comprehend the extra-disciplinary concerns of ecologists and biologists about sustainability and reformulate these concerns into our economic view. Ecologists and biologists will justifiably respond that many of their important concerns were lost in the interdisciplinary translation. Yet the effectiveness of a response in moving society forward on this issue is likely improved.

As a result of this study normative versus positive arguments by economists and ecologists can be better distinguished from each other - and, we hope, better argued. The interrelationship between natural phenomenon and economic processes moves beyond the resource economics literature addressing materials balance additions to input-output models or current attempts at adjusting national income accounts for reductions in natural resource capital.

Most importantly, we have a better way to think about the economic relationship between generations; and this relationship is entirely consistent with separate neoclassical explanations of credit and Land markets.
Our hypothesized structure of the movement of assets between generations seems to correspond to the real world structure of institutional retirement savings and the significance of these institutions in financing new business enterprises, new homes and current government programs. If we are to understand the implications of our actions on future generations, we need to seriously investigate these institutions as well as our standard operating procedures for monitoring the use of essential natural resources.

We only hope that the framework we have delineated can help us to better explore these social structures and institutions. Such explorations can only underscore the gravity of our actions on the ability of our successors to lead their lives, pursue their goals, and realize their human potential.
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