Tradition and common property management

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Abstract. Since management of a common property resource can be undertaken only by a government of finitely lived agents, studying the behaviour of such governments is a natural way to study common property management. I propose that we regard the choice of management objective by such a government as a 'move' in a game of sequential agents. Given this framework, it is shown that subgame perfect equilibria exist in which successive governments choose the same 'traditional' management objective. These strategies enable an economy to overcome any intergenerational externality. Thus, following a tradition of conservation may be a rational response to an intergenerational externality.

Tradition et gestion d'une ressource en propriété commune. Puisque la gestion d'une ressource en propriété commune peut seulement être faite par un gouvernement d'agents dont la vie a une valeur finie, l'étude du comportement de tels gouvernements est une manière naturelle d'étudier la gestion des ressources en propriété commune. Ce mémoire propose de considérer le choix d'un objectif de gestion par un gouvernement d'agents dont la vie a une valeur finie comme un 'mouvement' dans un jeu d'agents séquentiels. Ce cadre étant posé, on montre qu'il existe des équilibres parfaits de sous-jeux dans lesquels chaque gouvernement successif choisit le même objectif de gestion 'traditionnel.' Ces stratégies permettent à une économie de surmonter les problèmes causés par une externalité intergénérationnelle. Donc, suivre une tradition de conservation peut être une réponse rationnelle à une externalité intergénérationnelle.

1. Introduction

In this paper I consider the way that governments of finitely lived agents choose management objectives for common property resources. Since management of a

I would like to thank Vernon Henderson, Toby Page, Harl Ryder, Steve Kohlagen, Yehuda Kotowitz, Ralph Winter, along with two anonymous referees for many helpful comments. Remaining errors are entirely my own responsibility. This paper is based on chapter 2 of my dissertation, completed at Brown University in 1995. Some revisions were completed during a postdoctoral fellowship at the Woods Hole Oceanographic Institution.

Canadian Journal of Economics Revue canadienne d'Economique, Vol. 32, No. 3
May / mai 1999. Printed in Canada Imprimé au Canada

0008-4085 / 99 / 673–87 $1.50

common property resource can be undertaken only by a government of finitely lived agents, studying the behaviour of such governments is a natural way to study common property management.

First, I argue that the choice of management objective by the current government of finitely lived agents be regarded as a 'move' in a game of sequential agents. Given this framework, when decision makers do not condition their choice of management objective on the actions of earlier agents, only one sequence of management objectives is consistent with subgame perfection. Moreover, because of an intergenerational externality that distorts savings incentives, this sequence of management objectives does not result in a Pareto optimal allocation. On the other hand, when decision makers do condition their choice of management objective on the behaviour of prior agents, many subgame perfect allocations may be possible, including some that are Pareto optimal. While the strategies that support these Pareto optimal outcomes may be thought of as social contracts, we can also regard them as traditions. Taken together, these results imply that following a tradition of conservation may be a rational response to an intergenerational externality that distorts savings incentives.

The results in this paper complement the current debate on sustainability (e.g., Solow 1991, 1993) in important ways. First, the notion of sustainability may provide a way to implement the social contracts described here. Second, these contracts may provide an incentive to choose management objectives that are consistent with sustainability, apart from any sense of moral obligation to provide for the future.

2. A description of the regulation game

To investigate the behaviour of sequences of governments of finitely lived agents, consider the following simple economy. At $t = 1$ a single old agent, Agent Zero, gives birth to a single young agent, Agent One. At the end of period one, Agent Zero dies and Agent One gives birth to Agent Two. This cycle repeats for all natural numbers t. Let c_t^y denote consumption in period t by the young agent born at t, and c_t^o denote consumption in period t by the old agent born at $t-1$.

Agents derive utility from their own consumption in each period that they are alive. The following utility functions represent preferences:

$$V^0(c_1^o)$$

$$V^t(c_t^y, c_{t+1}^o), \qquad t = 1, 2, 3, \ldots.$$

We assume that consumption is a good, not a bad, so that all the V^t are increasing functions.

A natural resource stock, Y_t, provides consumption and also savings. Let $S_t = Y_t - (c_t^o + c_t^y)$ denote savings in period t. Any stock not consumed grows according to $Y_{t+1} = F(S_t)$, where $F(0) = 0$, $F'(0) > 0$. An *allocation* is an infinite sequence of consumption pairs, $\{(c_t^o, c_t^y)\}_{t=1}^{\infty}$. Say that an allocation is *feasible* if and only if

$Y_t \geqq c_t^o + c_t^y$ for all t. A *steady-state allocation* satisfies $(c_t^y, c_t^o) = (c_{t+1}^y, c_{t+1}^o)$ and $Y_t = F(S_t)$, for all t.

Suppose that the resource Y is common property. That is, agents in each period jointly decide on an allocation of the resource stock between consumption and savings, (c_t^o, c_t^y, S_t). Call such a triple a *management objective for period t*. Given that both young and old agents value only their own consumption, they disagree about the choice of management objective – each prefers that the other consume nothing. The role of government is, first, to provide a bargaining protocol allowing young and old to agree upon a management objective and second, to enforce the agreed-upon policy.

Given this stylized description of the regulatory process, how should we expect an old agent to behave? Since he derives no utility from his child's consumption or from savings, a rational old agent should always choose the bargaining strategy that maximizes his consumption, given his bargaining power.

The remainder of this section develops a framework in which the decision by each successive young agent about how aggressively he will bargain with his parent may be analysed. To begin, assume that in each period the young agent proposes a management objective which the old agent either accepts or rejects. If the old agent accepts the policy, then it is enforced. If the old agent rejects the proposal, then there is no regulation and the old agent receives consumption ηY_t, while the young agent divides $(1 - \eta)Y_t$ between consumption and savings. The parameter η is an exogenous description of the two agents' relative bargaining strengths.[1] This simple bargaining game captures the aspects of the bargaining problem in which we are interested: it explicitly models the choice of regulation as the outcome of bargaining, and it allows young agents to choose more or less aggressive bargaining strategies.

The young agent in each period may propose any feasible management objective (c_t^o, c_t^y, S_t). 'Accept any management objective such that $c_t^o \geqq \eta Y_t$' is the unique subgame perfect strategy for each old agent. Hence, without loss of generality, we can restrict the young agent's choices to those that the old agent will accept and disregard the old agent's move. Since $c_t^o + c_t^y + S_t = Y_t$, a management objective in period t is completely specified by the choice of (c_t^o, S_t). Thus, the set of possible proposals (or actions) for the young agent t is given by the set $A_t = \{(c_t^o, S_t) | \, c_t^o \geqq \eta Y_t, c_t^o + S_t \leqq Y_t\}$, where $Y_t = F(S_{t-1})$ for $t \geqq 2$. Since the old agent accepts any proposed management objective in this set, the old agent's moves can be ignored.

This simple characterization of the young agent's action sets is due to the simple bargaining process specified here. The reasonableness of ignoring the old agent's moves is not. Whatever the bargaining process, old agents always choose the bargaining strategy that maximizes their consumption. This strategy can be constructed for other bargaining games as well. This done, we can write down the young agent's

1 One can tell a number of stories about the origin of the bargaining strength parameter. For example, η could be the share of the resource stock that the old agent captures when bargaining breaks down and open access exploitation occurs. With this said, the source of this limit on the old agent's bargaining strength is irrelevant to the analysis.

strategy sets, contingent on consumption maximization by the old agent, just as is done for the ultimatum bargaining game above. In short, regardless of the particular bargaining game used and regardless of how much bargaining power the old agents have, all of the 'action' will be in the young players' strategy choices. The old agents always try to maximize their own consumption.

We can now regard the choice of management objective by each young agent as a 'move' in a game of sequential agents and the resulting allocation as an outcome of this game. In particular, the players are the young agents in each period $t = 1, 2, 3, \ldots$ An action, a_t, for young agent t is a pair $(c_t^o, S_t) \in A_t$. Player t's payoff function may be constructed from preferences over consumption by observing that $c_t^y = Y_t - c_t^o - S_t = Y_t - (1,1) \bullet a_t$, and $c_t^o = (1,0) \bullet a_t$. Preferences over actions can now be inferred from preferences over consumption. We abuse notation and denote preferences over actions with $V^t(a_t,\ a_{t+1})$, rather than use the correct but cumbersome, $V^t(Y_t - (1,1) \bullet a_t,\ (1,0) \bullet a_{t+1})$.

3. Equilibrium regulation without memory

Suppose that agents are aware of history and choose to ignore it, or that they cannot recall and interpret the historical record. In either case, if agents do not condition their choice of management objective on history, each agent t can affect his future consumption only through his choice of savings: Holding savings constant, the consumption level of agent t's parent does not affect agent t's old age consumption. Given this, player t is always better off driving a hard bargain and giving his parent the disagreement consumption level ηY_t. Moreover, since no other strategy is rational and credible for agent $t+1$, agent t should expect his successor to drive an equally hard bargain with him.

This means that player t should expect a return to savings of $\eta F'(S_t)$ in equilibrium. That is, in equilibrium, his return to savings is only as large as his bargaining powers allow. Since this is less than the social return to savings, $F'(S_t)$, each player t will undersave relative to the Pareto optimal level.[2]

Example 1. Consider the extreme case when $\eta = 0$ so that each period's young agent is able to dictate any feasible management objective to the old agent. Also suppose that agents do not condition their actions on the actions of their ancestors. The first young agent does not care about his parent and chooses not to give anything to him. Similarly, this agent expects that his child will not choose to give him any consumption in the future. It follows that the return to savings is zero and that in equilibrium, the first young agent saves nothing and consumes the whole stock. □

4. Equilibria with memory

If each agent could sign a binding contract with his unborn child requiring that the child permit the parent to consume relatively more of the stock in old age,

2 A more rigorous argument is available in Turner (1995).

provided the parent saved relatively more in his youth, then agents could overcome the incentive to undersave and be better off. The child has an incentive to break this contract, however, and there is no external agency to enforce it. Thus, we are led to ask whether self-enforcing contracts exist that can allow living agents and their unborn descendants to overcome the intergenerational externality.

In this section a game of sequential agents is analyzed and sufficient conditions for a subgame perfect equilibrium are established. More intuitively, in this section a 'self-enforcing social contract' is described.

Consider a game played by an infinite sequence of players, $t = 1, 2, 3 \ldots$, such that each player t takes exactly one action, a_t, in period t. To develop some intuition about this game, suppose that each player t's strategy set does not depend on the history of past moves and is given by $A_t = \{E, P, D\}$. Let the sequence $h = (a_0, (E)_{t=1}^{\infty})$ denote a socially desirable outcome. Move P will denote a punishment move imposed by a player on his predecessor. Move D will be a move that is not the punishment move or the equilibrium move. In addition, imagine that there is a cultural norm or 'social contract' that requires each player to play E if his predecessor honours the social contract and to play P if his predecessor violates the social contract. Finally, suppose that this social contract requires that each player use the logic described below to determine whether his predecessor has 'honoured' or 'violated' the social contract.

If player t observes player $t-1$ to have played E, then player t concludes that $t-1$ honoured the contract.[3] If player t observes player $t-1$ to take action D, then player t concludes that player $t-1$ violated the contract. But what if player t observes that player $t-1$ played P? Is player $t-1$ punishing a transgressor, or wrongly punishing a player who honoured the contract? To answer this question, look at the action taken by player $t-2$. If player $t-2$ played D, then player $t-1$ honoured the contract by punishing a deviator. If $t-2$ played E, then player $t-1$ wrongly punished a player who honoured the social contract and thereby violated the contract. What if both $t-1$ and $t-2$ played P? Is $t-1$ punishing $t-2$ for imposing an illegitimate punishment, or is $t-1$ wrongly punishing $t-2$ for punishing a deviator? The answer depends on the moves made at and before $t-3$.

Column (A) of table 1 gives histories at time $t-1$ that should cause player t to conclude that player $t-1$ honoured the social contract. The histories that belong in this column are concluded by an even number (or zero) consecutive punishment moves preceded by action E, or by an odd number of consecutive punishment moves preceded by action D. Column (B) of table 1 gives histories that should cause player t to conclude that player $t-1$ violated the social contract. The histories that belong in this column are concluded by an even number (or zero) consecutive punishment moves preceded by action D, or an odd number of consecutive punishments preceded by action E. Except for the history where all players play P, every possible history belongs to exactly one column of table 1. If all earlier players played P, then player t should conclude that player $t-1$ honoured

3 The possibility that agent $t-1$ takes action E when he should be punishing a deviator by playing P will be taken up later.

TABLE 1

(A)						(B)					
X...X	X	X	X	X	E	X...X	X	X	X	X	D
X...X	X	X	X	D	P	X...X	X	X	X	E	P
X...X	X	X	E	P	P	X...X	X	X	D	P	P
X...X	X	D	P	P	P	X...X	X	E	P	P	P
X...X	E	P	P	P	P	X...X	D	P	P	P	P

the social contract if $t-1$ is even and that player $t-1$ violated the social contract if $t-1$ is odd.

Consider the following sequence of strategies. Player 1 plays E. Each subsequent player plays E if the history at $t-1$ is in column (A) of table 1 and plays P if the history at $t-1$ is in column (B) of table 1. In other words, the first agent plays E and subsequent agents follow the social contract: play E if the last player honoured the social contract, punish if the last player did not honour the social contract. Under what conditions is this strategy sequence an equilibrium?

Suppose player t observes a history that causes him to conclude that player $t-1$ honoured the social contract, that is, a history in column (A), and player $t+1$ is honouring the social contract. If player t chooses any move other than E, then player $t+1$ will observe a history in column (B) and conclude that player t violated the social contract and should be punished. Given a history in column (A), and that future players are playing the social contract, player t can choose move E and get payoff $V^t(E,E)$, or choose $a \in \{P,D\}$ and get payoff $V^t(a,P)$. Thus, player t's best response to a history in column (A), when other players follow the social contract, is move E if

$$V^t(E,E) \geqq V^t(a,P),: a \in \{P,D\}. \tag{1}$$

If the strategy profile where all players follow the social contract is to be a subgame perfect equilibrium, it is also necessary that the threat to punish be credible. Under what conditions does this occur? Suppose player t observes a history in column (B) and player $t+1$ follows the social contract. If player t plays P or E, then player $t+1$ will observe a history in column (A) and play E. If player t plays D, then player $t+1$ will observe a history in column (B) and play P. By (1), $V^t(E,E) \geqq V^t(D,P)$, so player t prefers action E to action D. Player t will prefer P to E only if

$$V^t(P,E) \geqq V^t(E,E). \tag{2}$$

Thus, the threat to punish non-cooperative behaviour is credible only if (2) holds.

In the preceding discussion I argued that if conditions (1) and (2) hold, then playing E after a predecessor has followed the social contract is the best response to the strategy profile where all agents follow the social contract. Similarly, playing P after a predecessor has violated the social contract is also a best response. This means that at all possible histories, following the social contract is the best response to the strategy profile where all other agents play the same strategy. Therefore, the strategy sequence where all agents follow the social contract is a subgame perfect equilibrium of the game of sequential agents. It follows that $(a_0, (E)_{t=1}^{\infty})$ is a subgame perfect equilibrium if conditions (1) and (2) hold. Alternatively, the social contract described above is self-enforcing if (1) and (2) hold.

To generalize this intuition to allow for larger and possibly history-dependent action sets, let $h_\tau = (a_t)_{t=0}^{\tau}$ denote a possible history of the game at time τ,[4] and let H_τ denote the set of all possible histories at time τ. We also allow each agent's action set to depend upon the history of the game and denote these (possibly) non-stationary action sets by $A_t(h_{t-1})$. Next, we require two sequences of functions, $(E_t(h_{t-1}))_{t=1}^{\infty}$ and $(P_t(h_{t-1}))_{t=1}^{\infty}$, which correspond to the actions E and P of the example, and describe the feasible 'equilibrium' and 'punishment' actions that each player will take at each possible history. Denote the sequence that results when all agents choose the action $E_t(h_{t-1})$ by $(a_0, (a_t^*)_{t=1}^{\infty})$.

As in the stationary example above, a self-enforcing social contract can support the sequence of actions $(a_0, (a_t^*)_{t=1}^{\infty})$, provided that punishment is both sufficiently severe and credible. These conditions correspond to conditions (1) and (2), and may be stated more formally as

For all $t \geqq 1$ and all possible h_{t-1},

$$V^t(E_t(h_{t-1}), E_{t+1}(h_{t-1} + E_t(h_{t-1}))) \geqq V^t(a_t, P_{t+1}(h_{t-1} + a_t)),^5$$

$$\text{for all } a_t \in A_t(h_{t-1}). \qquad (3)$$

For all $t \geqq 1$ and all possible h_{t-1},

$$V^t(P_t(h_{t-1}), E_{t+1}(h_{t-1} + P_t(h_{t-1}))) \geqq V^t(E_t(h_{t-1}), E_{t+1}(h_{t-1} + E_t(h_{t-1}))). \qquad (4)$$

In addition, it must always be clear whether the preceding play 'honoured' or 'violated' the contract. Hence, the additional condition:

For all $t \geqq 1$ and all possible h_{t-1}, $E_t(h_{t-1}) \neq P_t(h_{t-1})$.

Provided that these three conditions are met, theorem 1 in the appendix shows that the outcome $(a_0, (a_t^*)_{t=1}^{\infty})$ is a subgame perfect equilibrium outcome of the regulation game when players follow the social contract described above.

Example 2. As in example 1, suppose that $\eta = 0$, so that each period's young agent can dictate any feasible management objective to the old agent. Suppose that the growth equation of the stock is $Y_{t+1} = 3S_t$, so that savings triples from one period to the next. Let player t's preferences over (c_t^y, c_{t+1}^o) be given by a utility function,

$$V^t(c_t^y, c_{t+1}^o) = \sqrt{c_t^y c_{t+1}^o},$$

so that player t's payoff function is

$$V^t(a_t, a_{t+1}) = \sqrt{(Y_t - (1,1) \bullet a_t)((1,0) \bullet a_{t+1})}.$$

4 An action a_0 at $\tau = 0$ is specified for notational convenience. Without it, h_0 is not defined.

5 $(h_{t-1} + a_t')$ denotes the history $(a_o, \ldots, a_{t-1}, a_t')$.

As above, the young agent at t chooses his action a_t from $A_t(h_{t-1}) = \{(c_t^o, s_t)|\ c_t^o + S_t \leqq Y_t\}$.

Since each unit of stock saved triples by the next time period, any agent may exchange one unit of consumption in youth for three units of consumption in old age without affecting the consumption of any other agent. It follows that any Pareto optimal allocation must satisfy, $\partial V^t/\partial c_t^y = 3\,\partial V^t/\partial c_{t+1}^o$ whenever $(c_t^y, c_{t+1}^o) \neq (0,0)$. The unique steady-state allocation satisfying this condition is $(c^y, c^o) = (\frac{1}{6} Y_1, \frac{1}{2} Y_1)$.

To support this Pareto optimal steady state, construct the following two sequences of functions:

$$E_t(h_{t-1}) = (\tfrac{1}{2} Y_t, \tfrac{1}{3} Y_t)$$

$$P_t(h_{t-1}) = (0, \tfrac{1}{3} Y_t).$$

These two functions satisfy conditions (3)–(5); hence, $(a_0, (a_t^*)_{t=1}^{\infty})$ is a subgame perfect equilibrium outcome. It follows that a self-enforcing social contract can sustain the Pareto optimal steady state allocation, $(c^y, c^o) = (\frac{1}{6} Y_1, \frac{1}{2} Y_1)$. □

This establishes the possibility of self-enforcing social contracts that allow the agents to overcome the incentive faced by selfish agents to overconsume to avoid sharing with their selfish children. Under such self-enforcing social contracts, each agent is offered more old age consumption by his child if and only if he offers his parent a more generous management objective than the parent's bargaining power requires.

Although example 2 supports a steady-state allocation, this is done entirely to lighten notation. The contracts work equally well to support non-steady-state outcomes (Turner 1995 provides an example).

Also note that the social contracts do not require that the young be dictators, as in the example. What is required is that punishment be sufficiently onerous. In particular, if the old agents have bargaining power η, then the worst utility that the social contract can impose on agent t is

$$\max_{S_t} V^t((1-\eta)Y_t - S_t, \eta F(S_t)).$$

That is, the social contract must guarantee each agent at least what he could obtain by violating it. This does not necessarily require that each young agent be a dictator, although this case is particularly easy to analyse.

5. Discussion

The possibility of self-enforcing social contracts depends upon the nature of the institution of 'government.' In particular, the set of possible equilibrium exploitation paths that may be sustained by self-enforcing social contracts shrinks as bargaining power shifts to the old. To see this, let $\{(c_t^y, c_{t+1}^o)\}_{t=1}^{\infty}$ be any allocation, and let $c_{\text{sup}}^o = \sup\{c_t^o/Y_t\}_{t=1}^{\infty}$. If $\eta > c_{\text{sup}}^o$, then for some t', the old agent's bargaining power allows him to consume more than $c_{t'}^o$. Since the only rational action for an old agent is to consume as much as possible, it follows that he consumes more than $c_{t'}^o$ in period t', and the allocation in question is not achieved. As η approaches 1 and bargaining power shifts to the old, the set of possible equilibrium allocation paths converges to the one where the first old agent, Agent Zero, consumes the entire stock. All else equal, as the institutions of government are more skewed toward the old, fewer exploitation paths can be supported by self-enforcing social contracts.

The possibility of self-enforcing social contracts does not depend in an obvious way on the rate at which population is growing. To apply the model to an economy where each successive cohort is larger than its predecessor, imagine that each cohort is able to act collectively and is represented at the bargaining table by any one of its members. Aside from requiring that the resource base be more productive to sustain constant consumption levels, population growth has two likely impacts. First, it may result in relatively more bargaining power for the young cohort. Second, all else equal, it results in lower per capita consumption for the young cohort. These two consequences of population growth have opposite effects on consumption by the young, and their effect on the set of allocations that may be sustained by a social contract is ambiguous.

The analysis does not allow for the possibility that parents care about their children. To see that this simplifying assumption does not qualitatively affect the analysis, suppose that parents value their childrens' welfare. Despite this, depending on the degree of altruism and the old agent's bargaining strength, children may still consume more of the resource stock than the parents want them to. If so, then (just as in the case where there is no altruism) parents have an incentive to undersave to avoid sharing with their children, and the threat to withdraw old age consumption can affect behaviour. Since parental altruism need not qualitatively change the incentive to overconsume in youth or the incentive effects of punishment in old age, the absence of altruism in the formal model should be regarded as a simplifying assumption, which does not qualitatively affect the analysis.[6]

Note that we can think of the regulation game as an infinitely long game tree. Each node of this game tree is a history, h_t, the set of possible nodes at time t is the set of possible histories at time t, and a path through the tree is an infinite sequence of moves $(a_t)_{t=0}^{\infty}$. The social contract described earlier allows certain infinite sequences of actions to be supported as subgame perfect equilibria of this game. By definition, this requires that the social contract specify Nash equilibrium actions at every possible subgame, no matter how far from the equilibrium sequence of actions in which we are interested. This requires that at every possible subgame, h_{t-1}, the threat of the punishment $P_t(h_{t-1})$ is sufficiently severe that an

6 The reader interested in a more exhaustive analysis of the role of parental altruism is directed to Turner (1997).

agent rationally prefers the equilibrium move $E_t(h_{t-1})$ to any actions that invite future punishment. This requires, in order to sustain a particular regulatory path, that the young have access to punishment that is either very severe or whose severity adjusts with the stock level. Hence, the analysis requires that the resource be 'big' in that utility depends upon having access to the resource in both periods – there are no substitutes or outside options.

The resource considered in example 2 is big in the required sense, and utility depends upon having access to the resource in both periods. The punishment response is to give the old agent zero in old age; for the utility functions in this example, receiving zero consumption in old age results in the worst possible utility level. Consequently, this punishment is sufficiently severe to enforce the equilibrium move, regardless of how far the preceding players have strayed from the desired path. These payoffs require that we interpret the resource stock as being big in the sense that access to the resource stock is essential to maintaining utility levels.

While one might try to list particular resources that are big in this sense (e.g., ozone or biodiversity), such a list will probably be contentious. It makes more sense to think of the common property resource stock Y as being an aggregate of many resource stocks. As we will see later, this nicely complements the literature on sustainability.

If a resource stock is 'small enough' that it makes sense to imagine the existence of a backstop technology, the self-enforcing social contracts described here cease to be rational equilibria. A backstop technology provides an investment that yields a constant exogenous rate of return $1 + R$. In the presence of such an investment, rational utility maximizing agents necessarily maximize the discounted present value of their income. Therefore, in order for Agent One to make a one unit gift to his parent in accordance with a social contract, he must expect a gift of at least $(1 + R)$ from Agent Two. Agent Two must in turn expect a gift of at least $(1 + R)^2$ from Agent Three, and so on. Hence, the social contracts discussed here require that the transfer from child to parent grow geometrically. An implausible necessary condition for this to occur would be that the resource stock also grow geometrically.

Finally, note that the social contract considered here relies on the intuition that the current agent will alter its behaviour to secure the cooperation of the next generation. It is not obvious that this intuition requires that future cooperation be essential to the welfare of the current generation, only that it be valuable. Subgame perfection requires that the punishment action be 'sufficiently severe' (in the sense of equation (4)) at *all possible nodes*, no matter how many agents must make irrational decisions to reach the node. This requires the possibility of a very severe punishment, even though this punishment may be invoked only after long histories of irrational action. Hence, the requirement that the resource be essential seems to be, at least partly, an unintuitive artefact of the equilibrium concept. Unfortunately, there does not seem to be a weaker equilibrium concept that is useful for this problem.

6. Tradition and social contracts

The *Oxford English Dictionary* defines tradition as 'a long established and generally accepted custom or procedure, having almost the force of law; an immemorial usage ... handed down by predecessors and generally followed.' For any given generation of young agents, the social contract describes the behaviour that was followed by their parents and will be followed by their children through time immemorial. Because of the self-enforcing nature of this social contract, it has almost the force of law. As in example 2, this social contract may require young agents to behave in exactly the same customary way that their ancestors did. In other words, we can interpret the social contract as requiring that each successive young agent choose the traditional or customary management objective, or behave in the traditional way.

If we interpret a self-enforcing social contracts as traditions, then particular traditions of resource regulation may emerge because they allow rational agents to overcome an intergenerational externality. In short, traditions of conservation may be a *rational* response to an intergenerational externality.[7]

7. Sustainability and common property regulation

The debate about 'sustainability' is largely a moral debate that revolves around the question of how much of our resource base we should consume and how much we should conserve. While this debate has not yet settled on a definition of sustainability, Solow (1991) puts forward a promising candidate: 'The notion of sustainability is about our obligation to the future. It says something about a moral obligation that we are supposed to have for future generations ... it is an obligation to conduct ourselves so that we leave to the future the option or capacity to be as well off as we are.' This notion of sustainability requires that we consider a highly aggregated resource stock consisting of all natural and manmade capital that contributes to an economy's ability to satisfy its members' wants. We then say that an economy has selected a sustainable path if each subsequent generation has saved enough of this aggregate stock.

The social contracts considered here affect the management of a resource that is large in exactly the same way as resource upon which the judgment of sustainability is based. Sustainability is concerned with the management of a highly aggregated resource stock consisting of all natural and manmade capital that contributes to an economy's ability to satisfy its members' wants. The analysis conducted here is concerned with a similarly aggregated resource.

While measuring whether we have had the opportunity to be as well off as our predecessors is difficult, Solow (1993) argues that if national income accounts are augmented to reflect changes in natural resource stock levels, then these ac-

7 The stronger conclusion that traditions are the only way of solving the intergenerational externality is probably unwarranted. One can also construct trigger-type strategies that solve the externality problem but do not resemble traditions.

counts can be used to measure our welfare relative to our parents. In particular, given such augmented national income accounts, the test for whether our parents chose sustainable consumption and management objectives is simply whether or not an augmented measure of national net income is above or below a certain threshold.

This is also related to the present analysis. The social contracts described here are 'trigger' strategies. If the preceding generation does not save enough or fulfil its obligation to its parents, it is subject to sanctions. Similarly, if the preceding generation does not save enough, its actions are deemed 'not sustainable.' Hence, sustainability provides a natural punishment threshold and, given appropriately modified national income accounts, one that might even be practical. Thus, the debate over sustainability both provides a basis for interpreting this analysis and suggests a way that the social contracts described here might be implemented. Conversely, this analysis suggests that a rational regulatory process might select 'sustainable' exploitation policy, even in the absence of any sense of moral obligation or affection towards succeeding generations.

8. Related literature

The intuition behind the social contracts developed here is that children will take apparently altruistic actions towards their parents to avoid punishment by their children in the future. Although the application to the problem of common property management is new, the same intuition is used in other areas.

Kandori (1992) and Cremer (1986) describe games in which overlapping generations of agents play a stage game in each time period, extending the folk theorem of supergames to the case of overlapping generations of players. These authors require that agents play the same stage game in each period. In the analysis of common property, we must allow players' actions to change the size of the resource stock, and hence the stage game, from one period to the next. Thus, a game where overlapping generations repeatedly play the same stage game is not an adequate description of the problem of common property management.

Hammond (1975) considers a slightly more general game of sequential agents than is considered here. However, he is primarily concerned with developing an equilibrium concept. Kotlikoff, Persson, and Svenson (1980) consider a game of sequential agents, but they are interested in understanding a fiscal policy problem. In addition to considering a different application, this paper allows an analysis of how changes in the institution of government affect the set of equilibria, something that Kotlikoff, Persson, and Svenson (1980) do not do.

Finally, there is a large literature in which the exploitation of common property in a variety of different frameworks is analysed, for example, Olson and Knapp (1997) and Clemhout and Wan (1991). However, these papers are usually concerned with the way that a collection of agents exploits a resource under open access. This paper differs from the existing literature on common property in that regulatory behaviour, rather than competitive exploitation, is analysed.

9. Conclusion

In this paper I examine the problem of common property regulation and propose that the choice of management objective by the current government of finitely lived agents be regarded as a 'move' in a game of sequential agents. Given this framework, two results are established. First, absent the ability to condition the choice of management objective on the actions of earlier agents, only one sequence of management objectives is consistent with subgame perfection, and because of an intergenerational externality this sequence of management objectives does not result in a Pareto optimal allocation. Second, if current agents are able to condition the choice of management objective on the behaviour of prior agents, then many subgame perfect allocations may be possible, including some that are Pareto optimal. The strategies used to support these outcomes may be thought of as social contracts. It is also reasonable, however, to regard these strategies as traditions. Taken together, these results imply that following a tradition of conservation may be a rational response to an intergenerational externality.

Finally, the results in this paper complement the debate on sustainability in two ways. First, the notion of sustainability may provide a way to implement the social contracts described here. Second, these contracts may provide an incentive to choose management objectives that are consistent with sustainability, apart from any sense of moral obligation to provide for the future.

Appendix

In this appendix a 'self-enforcing social contract' is described and the outcomes that this contract can be used to enforce are characterized.

Consider a game played by an infinite sequence of players, $t = 1, 2, 3 \ldots$, such that each player t takes exactly one action, a_t, in period t. For notational convenience, an action a_0 at $t = 0$ is also specified. A sequence $h = (a_\tau)_{\tau=0}^{\infty}$ is an outcome of the game, and a sequence $h_t = (a_\tau)_{\tau=0}^{t}$ is a history at time t. Each h_t should be thought of as describing a node of an infinitely long game tree, while each h should be thought of as a path through this tree. Let $h_{t-1} + a_t' = (a_0, \ldots, a_{t-1}, a_t')$ denote the history that occurs when move a_t' is played after history h_{t-1}. In period t, player t chooses his action a_t from the an action set $A_t(h_{t-1})$. Let $H_t = \{(a_\tau)_{\tau=0}^{t} : a_\tau \in A_t(h_{t-1}), \tau \geqq t \geqq 1\}$ denote the set of all possible histories at time t, ($H_0 = \{h_0\}$). Let $H = H_\infty$ denote the set of possible outcomes for the game.

A strategy for player t is a function from the space of histories into the set of actions. More formally, let $A_t(H_{t-1}) = \bigcup_{h_{t-1} \in H_{t-1}} A_t(h_{t-1})$; then, a strategy for player t is a function

$$\sigma_t : H_{t-1} \longmapsto A_t(H_{t-1})$$

such that $\sigma_t(h_{t-1}) \in A_t(h_{t-1})$ for all $h_{t-1} \in H_{t-1}$. Player t's strategy set Σ_t is the set of all such functions. A strategy sequence is a sequence of strategy choices, one for each player, $\sigma = (\sigma_t)_{t=1}^{\infty}$. Let (σ_{-t}, σ'_t) denote the strategy sequence $(\sigma_1, \ldots, \sigma_{t-1}, \sigma'_t, \sigma_{t+1}, \ldots)$. Let $\Sigma = \Pi_{t=1}^{\infty}\Sigma_t$ denote the set of possible strategy sequences. Once selected, the strategy sequence is imagined to be known as common knowledge by all players.

THEOREM 1. *Let $h^* = (a_0, (a_\tau^*)_{\tau=1}^{\infty})$ denote a particular outcome of a game of sequential agents. h^* can be supported as a subgame perfect equilibrium if there exist two sequences of functions $(E_t(h_{t-1}))_{t=1}^{\infty}$ and $(P_t(h_{t-1}))_{t=1}^{\infty}$ such that*
(a) $E_t(h_{t-1}^*) = a_t^*$, for all $t \geqq 1$.
and for all $h_{t-1} \in H_{t-1}$ and $t \geqq 1$,
(b) $E_t(h_{t-1}),\ P_t(h_{t-1}) \in A_t(h_{t-1})$, and $E_t(h_{t-1}) \neq P_t(h_{t-1})$.
(c) $V^t(E_t(h_{t-1}), E_{t+1}(h_{t-1} + E_t(h_{t-1}))) \geqq V^t(a_t, P_{t+1}(h_{t-1} + a_t))$ for all $a_t \in A_t(h_{t-1})$.
(d) $V^t(P_t(h_{t-1}), E_{t+1}(h_{t-1} + P_t(h_{t-1}))) \geqq V^t(E_t(h_{t-1}), E_{t+1}(h_{t-1} + E_t(h_{t-1})))$.

Proof. Let $n(h_t)$ denote the number of consecutive moves immediately prior to and including t at which the punishment action P was taken. Let σ^* be the strategy profile such that

$$\sigma_1^* = E_1(h_0)$$

$$\sigma_2^* = \begin{cases} E_2(h_1) & \text{if } a_1 = E_1(h_0) \\ P_2(h_1) & \text{otherwise} \end{cases}$$

and for $t \geqq 3$,

$$\sigma_t^* = \begin{cases} E_t(h_{t-1}) & \text{if (i) } n(h_{t-1}) < t-1 \text{ is odd and} \\ & \qquad a_{t-1-n(h_{t-1})} \neq E_{t-1-n(h_{t-1})}(h_{t-1-n(h_{t-1})}), \\ & \text{or (ii) } n(h_{t-1}) < t-1 \text{ is even or zero and} \\ & \qquad a_{t-1-n(h_{t-1})} = E_{t-1-n(h_{t-1})}(h_{t-1-n(h_{t-1})}) \\ & \text{or (iii) } n(h_{t-1}) = t-1 \text{ is even.} \\ P_t(h_{t-1}) & \text{otherwise.} \end{cases}$$

It is sufficient to show that at every possible node, σ_t^* is a best response to σ_{-t}^*. More formally, σ^* is a subgame perfect equilibrium if and only if, for all t, $h_{t-1} \in H_{t-1}$, and $a_t \in A_t(h_{t-1})$,

$$V^t(\sigma_t^*(h_{t-1}), \sigma_{t+1}^*(h_{t-1} + \sigma_t^*(h_{t-1}))) \geqq V^t(a_t, \sigma_{t+1}^*(h_{t-1} + a_t)).$$

$[t = 1]$: $[\sigma_1^*(h_0), \sigma_2^*(h_0 + \sigma_1^*(h_0))] = [E_1(h_0), E_2(h_1)]$ and for all $a_1 \in A_1(h_0)/\{E_1(h_0)\}$, $[a_1, \sigma_2^*(h_0 + a_1)] = [a_1, P_2(h_0 + a_1)]$. Therefore, by (c), σ_1^* is a best response to σ_{-1}^* for all $h_0 \in H_0$.

$[t = 2]$: If $h_1 = (a_1^*)$, then $[\sigma_2^*(h_1), \sigma_3^*(h_1 + \sigma_2^*(h_1))] = [E_2(h_1), E_3(h_1 + E_2(h_1))]$ and for all $a_2 \in A_2(h_1)/\{E_2(h_1)\}$, $[a_2, \sigma_3^*(h_1 + a_2)] = [a_2, P_3(h_1 + a_2)]$. By (c), σ_2^* is a best response to σ_{-2}^* for $h_1 = (a_1^*)$. If $h_1 \neq (a_1^*)$, then $[\sigma_2^*(h_1), \sigma_3^*(h_1 + \sigma_2^*(h_1))] =$

$[P_2(h_1), E_3(h_1 + P_2(h_1))]$, $[E_2(h_1), \sigma_3^*(h_1 + E_2(h_1))] = [E_2(h_1), E_3(h_1 + E_2(h_1))]$, and for all $a_2 \in A_2(h_1)/\{E_2(h_1), P_2(h_1)\}$, $[a_2, \sigma_3^*(h_1 + a_2)] = [a_2, P_3(h_1 + a_2)]$. By (c) and (d) it follows that σ_2^* is a best response to σ_{-2}^* for $h_1 \neq (a_1^*)$. Therefore, for all $h_1 \in H_1$, σ_2^* is a best response to σ_{-2}^*.

$[t \geqq 3]$: If (i) or (ii) or (iii) holds, then $[\sigma_t^*(h_{t-1}), \sigma_{t+1}^*(h_{t-1} + \sigma_t^*(h_{t-1}))] = [E_t(h_{t-1}), E_{t+1}(h_{t-1} + E_t(h_{t-1}))]$, and for all $a_t \in A_t(h_{t-1})/\{E_t(h_{t-1})\}$, $[a_t, \sigma_{t+1}^*(h_{t-1} + a_t)] = [a_t, P_{t+1}(h_{t-1} + a_t)]$. By (c) it follows that σ_t^* is a best response to σ_{-t}^* when (i) or (ii) or (iii) holds.

If none of (i),(ii),(iii) holds, then $[\sigma_t^*(h_{t-1}), \sigma_{t+1}^*(h_{t-1} + \sigma_t^*(h_{t-1}))] = [P_t(h_{t-1}), E_{t+1}(h_{t-1} + P_t(h_{t-1}))]$, $[E_t(h_{t-1}), \sigma_{t+1}^*(h_{t-1} + E_t(h_{t-1}))] = [E_t(h_{t-1}), E_{t+1}(h_{t-1} + E_t(h_{t-1}))]$, and for all $a_t \in A_t(h_{t-1})/\{E_t(h_{t-1}), P_t(h_{t-1})\}$, $[a_t, \sigma_{t+1}^*(h_{t-1} + a_t)] = [a_t, P_{t+1}(h_{t-1} + a_t)]$. Therefore, by (c) and (d), σ_t^* is a best response to σ_{-t}^* at all possible nodes, so that σ^* is a subgame perfect equilibrium strategy sequence.

By (a) σ^* requires that $a_1 = a_1^*$ and that $a_{t+1} = a_{t+1}^*$ if $h_t = h_t^*$. It follows that $(a_0, (a_t^*)_{t=1}^{\tau})$ is a subgame perfect equilibrium outcome of the game of sequential agents. □

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