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## Property rights and resource allocation in an overlapping generations model

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Property Rights and Resource Allocation in an  
Overlapping Generations Model

by

Hans-Peter Weikard



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Paper presented at the  
Max-Planck-Institute for Research into Economic Systems,

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Oktober 1997

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# Property Rights and Resource Allocation in an Overlapping Generations Model

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*Abstract:* The paper is an enquiry into dynamic social contract theory. The social contract defines the rules of resource use. An intergenerational social contract in an economy with a single exhaustible resource is examined within a framework of an overlapping generations model. It is assumed that new generations do not accept the old social contract, and access to resources will be renegotiated between any incumbent generation and their successors. It turns out that later generations will be in an unfortunate position regardless of their bargaining power.

*Journal of Economic Literature classification:* D 90

## 1 Introduction

One of the key questions of resource economics is whether or not market allocation sufficiently provides for future generations' needs. In his famous paper on *The Economics of Exhaustible Resources* Harold Hotelling has given a positive answer. The equilibrium market allocation, where a supplier of an exhaustible resource is indifferent between selling now and selling later, maximises the social utility of resource use. A similar result is obtained when we consider an Arrow-Debreu economy. If a full range of markets exists – one market for each good at each point in time – then there exists a market equilibrium which is Pareto-efficient. However, it is clear that the importance of these results is limited. In the real world only a very limited set of futures markets exists. This leads to externalities and an inefficient market allocation. Furthermore, in an uncertain world the existence of contingent markets – one for each good in each state of the world – would be necessary to guarantee the efficiency of the market equilibrium.<sup>1</sup> However, this paper does not consider any of these problems.<sup>2</sup> The focus is, instead, on the underlying assumptions concerning the property rights of the Hotelling and Arrow-Debreu model, respectively. The functioning of markets presupposes well-defined property rights which can be enforced effectively and costlessly. In the Arrow-Debreu model,

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<sup>1</sup> Cf. Newbery (1990).

<sup>2</sup> Although some years old, Dasgupta/Heal (1979) is still the best book to consult on these matters.

for example, everyone is assigned a tradable initial endowment, without any enforcement being necessary. How rights are assigned to individuals, is beyond the scope of the model.

This paper takes up the ideas of social contract theory. Initial property rights, appropriate enforcement and trading rules are defined in a social contract which is negotiated by the members of society.<sup>3</sup> Social contract theory usually neglects the time dimension.<sup>4</sup> Here, we take time into account and, moreover, include the fact that in the course of time society consists of different individuals, some being contemporaries and some not. We assume that only contemporaries can sign a contract. In other words, we examine a generational contract.

The paper is organised as follows. Section 2 explains in somewhat greater detail how traditional models fail to capture relevant aspects of the time dimension. These can be taken into account by overlapping generations models. However, no attempt is made to survey results on overlapping generations economies. In section 3 an overlapping generations model with an exhaustible resource and fixed property rights is developed as a benchmark model. The main result of the paper is given in section 4 where it is assumed that succeeding generations bargain on the distribution of property rights. Finally, in section 5, the result is evaluated in the light of what intergenerational equity may require.

## 2 Future generations in market economies

Before stepping into formal analysis some remarks on how models of the market economy have treated future generations may be in order. These remarks will be confined to the Arrow-Debreu model, on which modern welfare economics is based, and to Hotelling's optimal resource extraction path.

The model of an Arrow-Debreu economy is rich enough to capture the time dimension and the uncertainty of the future. Time and uncertainty are dealt with by introducing a sufficiently rich set of markets. It is assumed that only private goods exist in the economy and that there is a market for each good at each time in every state of the world. Futures markets and contingent markets are important because a piece of cake today is different from a piece of cake tomorrow and a transport service to the railway station on a rainy day is different from a similar service, if it happens to be sunny. A full set of markets (no externalities) is one important condition for the efficiency of the market system.

Although the Arrow-Debreu economy can accommodate time and uncertainty, it does so in a very general way. This only allows for very general conclusions. The economy we want to

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<sup>3</sup> Cf. Nozick's (1974) and Buchanan's (1975) seminal contributions to modern social contract theory.

<sup>4</sup> A notable exception is Brennan/Buchanan (1985). However, they do not consider overlapping generations and do not offer a formal analysis. A recent contribution is Voigt (1997).

analyse is more specific. Most importantly, consumers have finite lives and society has a particular demographic structure. Therefore, the relevant analysis requires the introduction of more specific assumptions. Formally, the finite life of a consumer can be modelled by assuming zero demand at times when a consumer is not alive. However, one implicit assumption of the Arrow-Debreu model is too demanding. According to the model individuals can engage in the market process at any time, in particular at the initial stage. Note that in the Arrow-Debreu economy all trade takes place at the initial stage. The Arrow-Debreu world is essentially static, although the time dimension is formally included in the model. Once equilibrium prices have been fixed, there is no scope for further trade.

With regard to the treatment of intergenerational allocation problems three shortcomings of the standard version the Arrow-Debreu model can be identified.<sup>5</sup> The model assumes (i) a given set of consumers (ii) who are characterised by their fixed preferences and (iii) endowed with a given bundle of tradable goods.

(i) Current choices can affect the size of population. Therefore, it is not adequate to fix the set of consumers in advance. An analysis requires models of resource allocation with endogenous population.<sup>6</sup>

(ii) Consumers' preferences are shaped by earlier consumption patterns. Models of endogenous changes of taste, developed in decision theory,<sup>7</sup> could be applied to the intergenerational case: The preferences of a new generation are to some extent shaped by the earlier generations' consumption pattern.

(iii) The property rights assignment cannot be arbitrary, but should reflect the limited life time of the individuals. Only when an individual is alive, she is able to protect her property rights. An arbitrary rights assignment, as supposed in the Arrow-Debreu model, can only make sense when enforcement of rights is costless and effective. In the real world future generations cannot enforce and, therefore, *de facto* they have no property rights. What future generations can acquire, will depend on what the current generation will leave for them.

In the remainder of this paper problems (i) and (ii) are ignored. It is assumed that the set of consumers and their preferences are exogenously given. Instead, the focus is on the assignment of property rights and resource use across generations. A further qualification which will be adopted is the following: Individuals who live for a limited time can only trade with their contemporaries. In this respect, too, the model developed in this paper is incompatible with the Arrow-Debreu model in which exchange between any two individuals is possible.

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<sup>5</sup> See for a similar criticism Dasgupta/Heal (1979) 108.

<sup>6</sup> Samuelson (1975).

<sup>7</sup> von Weizsäcker (1971), Yaari (1977).

Now let us consider Hotelling's (1931) argument for the efficiency of markets for exhaustible resources. According to Hotelling's rule the equilibrium price for an exhaustible resource – useable without extraction cost – must increase with the rate of interest  $i$  in the economy. In equilibrium resource suppliers are indifferent between selling a marginal unit of resource now

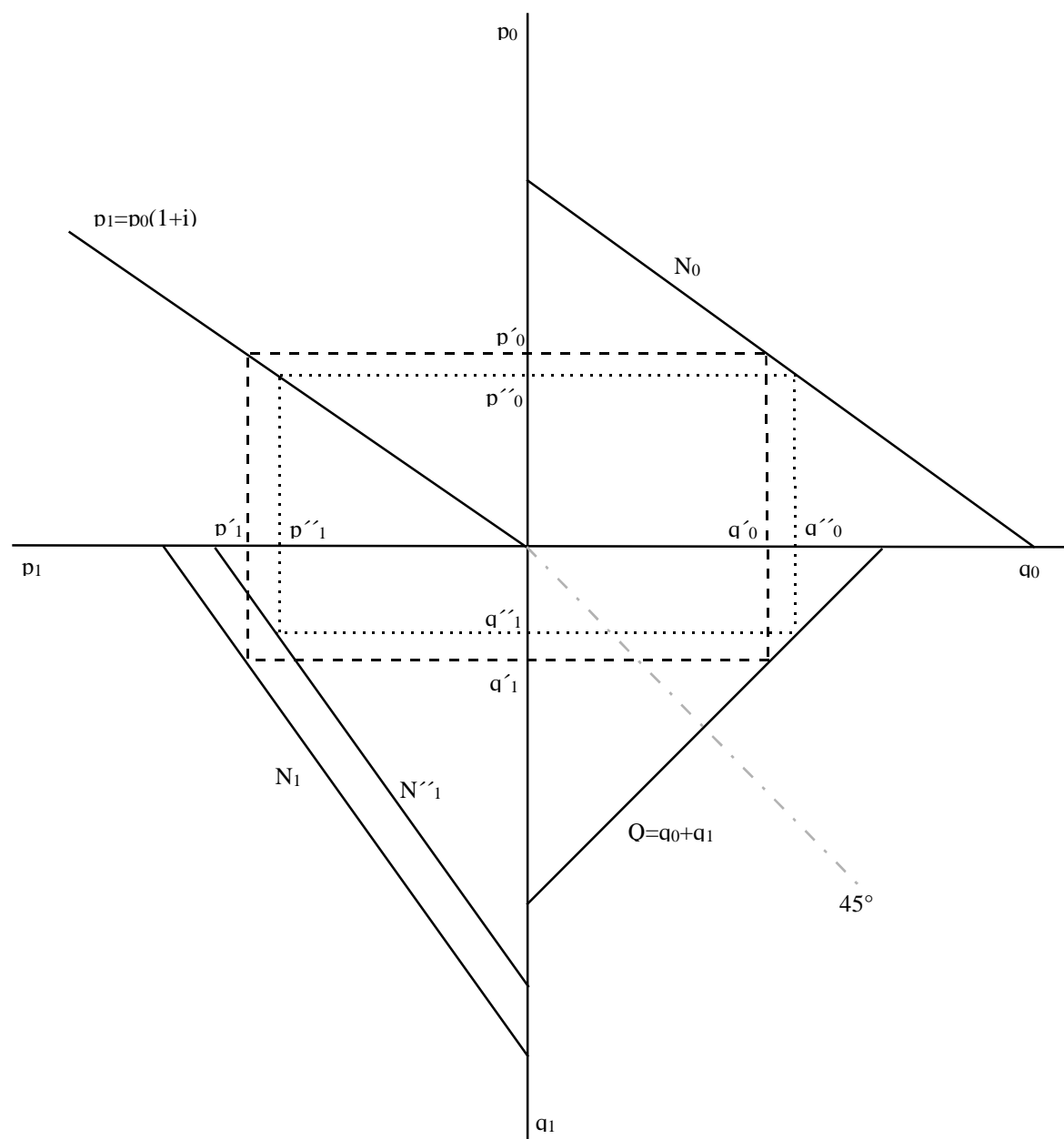


Figure 1: Resource allocation in a two-generations model

and selling later. Suppose, the price would increase at a lower rate than the interest rate. Then, it would be profitable to sell now and keep the proceeds in a bank account. Since the suppliers know this, current supply increases and the resource becomes scarcer at later times. The current price falls and later prices increase. Thus, the rate of price increase adjusts to the interest rate. Hotelling shows that the market result coincides with the utilitarian optimum:



Maximum utility (sum of consumers' rent) is obtained when the price rises with the rate of interest. Two crucial assumptions are necessary for this result. Firstly, Hotelling discounts future utility with the rate of interest. Secondly, the resource market's demand schedule is time invariant. Discounting utility can hardly be justified.<sup>8</sup> What, if anything, should be discounted is the monetary value of goods. Consider a simple two-generations model with identical consumers and, therefore, identical demand schedules,  $N_0, N_1$  (see figure 1). In the market equilibrium the resource, which is in fixed supply, is distributed unevenly between generations because the later generation faces a higher price. The market allocation is  $(q_0', q_1')$ , with  $q_0' > q_1'$ . However, with identical consumers and decreasing marginal utility of consumption, the allocation which equally divides the resource between generations is the utilitarian optimum. Hotelling's claim can only be accepted, if it is justified to discount future utility.

Now consider two generations of which the second receives a smaller initial endowment. Consumers are identical otherwise. The demand schedule of the poorer generation is  $N_1''$  (see figure 1). In this case resource use will be more uneven still. The corresponding allocation  $(q_0'', q_1'')$  can be Pareto efficient, given the unequal endowment, but it is hardly the utilitarian solution.

In the next section Hotelling's assumption of time invariant demand is dropped. We examine the case when endowments differ between generations, but are exogenously given. In section 4 endowments are endogenised.

### 3 A benchmark model

Overlapping generations models have been used to capture particular features of the time dimension of an economy, in particular, consumers have finite lives and trade takes place only among contemporaries.<sup>9</sup> In the simplest type of model individuals born in period  $t$  (they will be called "generation  $t$ ") live for two periods,  $t$  and  $t+1$ , and they can exchange goods with generation  $t-1$  in period  $t$ , and with generation  $t+1$  in period  $t+1$ . This type of model allows for endogenous population growth and endogenous changes of taste. Both issues will not be dealt with here. We assume that at the end of their lives generation  $t$  is replaced by a new generation  $t+2$  of the same size and the same preferences. The model presented in this section describes the market allocation when trade is restricted to contemporaries. Each generation's endowments (property rights) will be assumed to be given exogenously, just as in traditional market allocation models. In the model of section 4 the property rights assignment

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<sup>8</sup> For a detailed argument see Broome (1992) and (1994).

<sup>9</sup> The overlapping generations model has been developed by Samuelson (1958). For recent surveys see Geanakoplos (1987), Boadway (1990) and Lang (1996).

will be endogenised. What is presented in the remainder of this section provides a point of reference with which the model of section 4 is to be compared.

Since we have assumed identical individuals, the analysis can focus on a representative individual. To save words, I will use "generation  $t$ " as a short name for "the representative individual of generation  $t$ ". Generation  $t$  receives an endowment of an exhaustible resource  $Q_t$  in period  $t$ . The resource is transferable into the future (it can be stored). However, it cannot be consumed directly, but only after it is transformed into a non-storable consumption good  $x$ . Generation  $t$  can produce  $x$  only in period  $t$ . Consider a production technology

$$x_t = x_t(q_t), \quad (1)$$

where  $q_t$  denotes the resource input and  $x_t$  is continuous and twice differentiable with positive and decreasing marginal productivity. The initial endowment  $Q_t$  can be used for production ( $q_t$ ) or it can be stored and sold to the next generation. The quantity of resource bought and sold by generation  $t$  are denoted  $r_t$  and  $r_{t+1}$ , respectively. We obtain the following restriction.

$$Q_t + r_t = q_t + r_{t+1}. \quad (2)$$

We adopt an additively separable utility function.

$$u_t = u(c_t) + u(z_t), \quad (3)$$

where  $c_t$  and  $z_t$  are generation  $t$ 's consumption levels in period  $t$  and  $t+1$ , respectively.  $u_t$  is assumed to be continuous and twice differentiable with positive and decreasing marginal utility. Note that generation  $t$  cannot produce in period  $t+1$ . Their consumption in their second life period  $z_t$  must be obtained from generation  $t+1$  who receive  $p_{t+1}r_{t+1}$  in exchange. The resource price is denoted  $p_t$ . The consumption good  $x(z)$  is the numeraire good. Thus,

$$z_{t-1} = p_t r_t. \quad (4)$$

Furthermore, production  $x_t$  can only be consumed by the two living generations,

$$x_t = c_t + z_{t-1}, \text{ or equivalently, } z_t = x_{t+1} - c_{t+1}. \quad (5)$$

The task is now to determine the path of resource use and the utility path. To do this, we need to consider each generation's resource allocation decision.

Generation  $t$  solves the following maximisation problem:

$$\max_{r_t, q_t} [u_t = u(x_t(q_t) - p_t r_t) + u(p_{t+1} \cdot (Q_t + r_t - q_t))], \quad (6)$$

Examining the first order conditions of the maximisation problem (6) yields

$$p_t = \frac{dx}{dq} \quad (7)$$

and

$$\frac{p_{t+1}}{p_t} = \frac{\partial u / \partial c_t}{\partial u / \partial z_t}. \quad (8)$$

Equation (7) says that the price of the resource is equal to the marginal productivity of resource use. Equation (8) says that the ratio of marginal utility of current and future consumption is equal to the ratio of the current and the future price of the consumption good. Note, that the price of the consumption good is the inverse of the resource price.

For further analysis we consider a finite economy of  $T$  generations with a given resource distribution  $(Q_1, \dots, Q_T)$ . Furthermore, we adopt the following specifications for production

$$x_t = a q_t^\alpha, \quad a > 0, \quad 0 < \alpha < 1, \quad (9)$$

and utility

$$u_t = \log(c_t) + \log(z_t). \quad (10)$$

Generation  $t$ 's utility can be written as

$$u_t = \log\left(a(Q_t + r_t - r_{t+1})^\alpha - p_t r_t\right) + \log(p_{t+1} r_{t+1}). \quad (11)$$

The first order conditions of (11) yield:

$$p_t = a\alpha(Q_t + r_t - r_{t+1})^{\alpha-1} \quad (12)$$

and

$$r_{t+1} = \frac{Q_t + r_t(1-\alpha)}{1+\alpha}. \quad (13)$$

A special condition holds for the first generation, because they have no predecessors and cannot buy any resource, thus

$$r_2 = \frac{Q_1}{1+\alpha}. \quad (14)$$

The system of equations given by (12)-(14) can be solved for any initial distribution  $(Q_1, \dots, Q_T)$  and fully determines prices, resource use, and utility.

Let us consider two special cases.

(i) Suppose resources are divided equally between generations, i.e.  $(Q_1 = Q_2 = \dots = Q_T)$ . The index on "Q" can be dropped and equations (13) and (14) can be reduced to

$$r_t = \frac{Q}{1+\alpha} \sum_{k=0}^{t-2} \left( \frac{1-\alpha}{1+\alpha} \right)^k . \quad (15)$$

(15) gives the sales in the resource market. For a large number of generations (15) converges to  $Q/2\alpha$ . Prices, consumption and utility can easily be calculated. Figure 2 gives the amount of resource sold in the market and the utility for each generation. The utility of the last generation has not been included, because they do not have a second life period and, thus, their utility is not comparable.

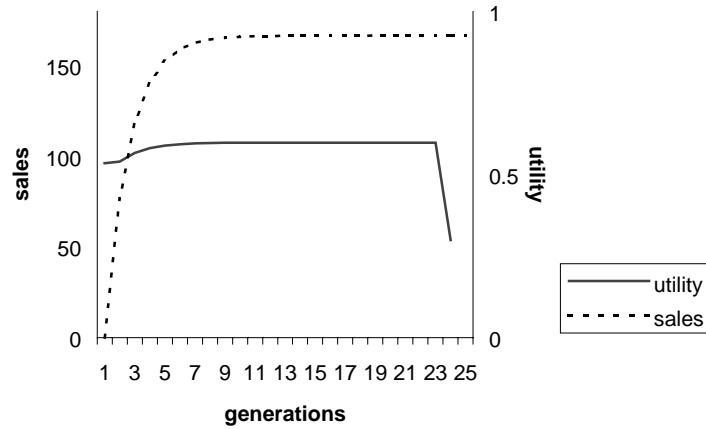


Figure 2: Equal access to resources<sup>10</sup>

(ii) Secondly, let us examine the endowment where generation 1 gets the entire stock of resources,  $(Q, 0, \dots, 0)$ ,  $Q > 0$ . (14) and iterative substitution into (13) yields

$$r_t = \frac{Q}{1+\alpha} \left( \frac{1-\alpha}{1+\alpha} \right)^{t-2} . \quad (16)$$

From the resource sales path (16) it is easy to calculate prices, consumption and utility. Figure 3 shows sales and utility. The graphs are based on the same parameters as used for figure 2.

<sup>10</sup> The following parameters have been used:  $a=1$ ;  $\alpha=0.3$ ;  $T=25$ ,  $Q=2500$ . A variation of parameters yields similar results.

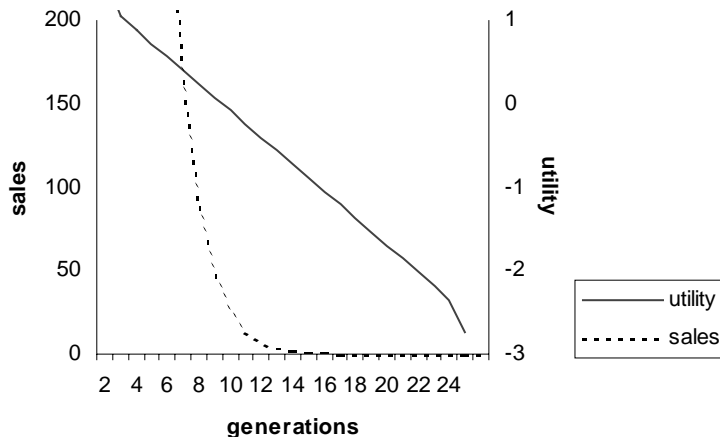


Figure 3: First-come-first-serve distribution

## 4 Intergenerational distribution of property rights

Section 3 provides some results on how the benefits from resources are divided between generations when property rights are secured. This assumption is now dropped in order to examine the case of an intergenerational Hobbesian anarchy. Every society has to negotiate their basic rules and property rights (the social contract) before they can use the market mechanism. If we assume, as economists often do, that individuals are self-concerned, we have to deal with the case that in period  $t$  resource rights are distributed only among those who are alive at  $t$ . Future generations cannot have any property rights because their rights cannot be enforced. However, when a new generation arrives they need not accept the existing property rights. The social contract is renegotiated at the beginning of each period. We assume that all individuals belonging to the same generation receive an equal share of the resource, that is, we restrict the analysis to the distribution of property rights between generations. Generation  $t-1$  and generation  $t$  bargain over the stock of resources remaining at time  $t$ , denoted  $R_t$ . Formally,

$$R_t \equiv Q - \sum_{k=1}^{t-1} q_k, \quad (17)$$

where  $Q$  is the initial total stock of resources. Since individuals are assumed to be self-concerned the use of a non-cooperative bargaining approach would be fitting. However, strategic models of bargaining require a more detailed time structure. The negotiation process must be modelled within any period  $t$ .<sup>11</sup> To avoid these complication, we simply assume that an efficient bargaining solution exists, in which the new generation receives a share  $s_t$  and the

<sup>11</sup> Cf. Rubinstein (1982) or Osborne/Rubinstein (1990) 29ff.

incumbent generation  $t-1$  receives a share  $1-s_t$  of the remaining stock  $R_t$ . The endowment that generation  $t$  can obtain is

$$Q_t = s_t R_t, 0 \leq s_t \leq 1. \quad (18)$$

In the framework of (17) and (18) the bargaining process is captured by the variable  $s$  in a very general way. This produces more general results than adopting a specific structure of a strategic bargaining game.<sup>12</sup>

The result of the bargain determines property rights which are valid for the current period only. Given these rights individuals can now decide on production and market exchange. This is modelled in the same way as in section 3. The notation and basic features are maintained. The remainder of this section describes resource use and market exchange in this model of endogenous property rights assignment. The results are compared to those of section 3 where all property rights were predetermined.

First, note that generation  $t-1$ 's share is sold to generation  $t$ .

$$(1-s_t)R_t = r_t, \text{ therefore by (4), } z_{t-1} = p_t R_t (1-s_t). \quad (19)$$

Furthermore,

$$R_{t+1} = R_t - q_t. \quad (20)$$

Using the utility function (10) generation  $t$ 's maximisation problem becomes

$$\max_{r_t, R_{t+1}} \left[ u_t = \log \left( a(Q_t + r_t - R_t)^\alpha - p_t r_t \right) + \log \left( p_{t+1} R_{t+1} (1-s_{t+1}) \right) \right]. \quad (21)$$

$q_t$ , although also a choice variable of generation  $t$ , cannot be chosen independently of  $r_t$  and  $R_{t+1}$ . Thus we have substituted  $q_t = Q_t + r_t - R_t$  into the utility function. From the first order conditions we obtain

$$p_t = a\alpha(Q_t + r_t - R_t)^{\alpha-1} \quad (22)$$

and

$$R_{t+1} = \frac{Q_t}{1+\alpha} + r_t \frac{1-\alpha}{1+\alpha}. \quad (23)$$

Substituting (18) and (19) into (23) yields

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<sup>12</sup> A more specific structure of a social contract bargaining game is analysed in Houba/Weikard (1995).

$$R_{t+1} = R_t \frac{1-\alpha + \alpha s_t}{1+\alpha}. \quad (24)$$

Again, in a finite economy, the situation for the first and the last generation is special. Initially, at  $t = 1$ , the first generation can acquire the entire stock of resources  $Q$ . Thus  $Q_1=Q$ . Resources are used for the production of the consumption good or they can be stored and sold to the next generation, provided the property rights can be maintained. However, this will generally not be the case as  $s_t > 0$ .

Solving generation 1's maximisation problem yields

$$R_2 = \frac{Q}{1+\alpha}. \quad (25)$$

The path of resource transfers from one generation to the next can be calculated from (25) and iterated substitution of (24). Assuming  $s=s_2=s_3=\dots=s_T$ ,

$$R_t = \frac{Q}{1+\alpha} \left( \frac{1-\alpha + \alpha s}{1+\alpha} \right)^{t-2}, \quad t=2, 3, \dots, T. \quad (26)$$

Note that for  $s=0$  (26) is identical with (16). This is obvious because here we examine a generalisation of case (ii) of section 3.  $s=0$  means that the new generation has no bargaining power and, therefore, the existing property rights are fully secured. With  $s>0$  property rights are less than fully secured. The transfer of resources to the next generation is partly a result of the renegotiation of the social contract and partly a result of the market process. Figure 4 shows the endowment that can be obtained by each generation under conditions of Hobbesian anarchy and different values of  $s$ .

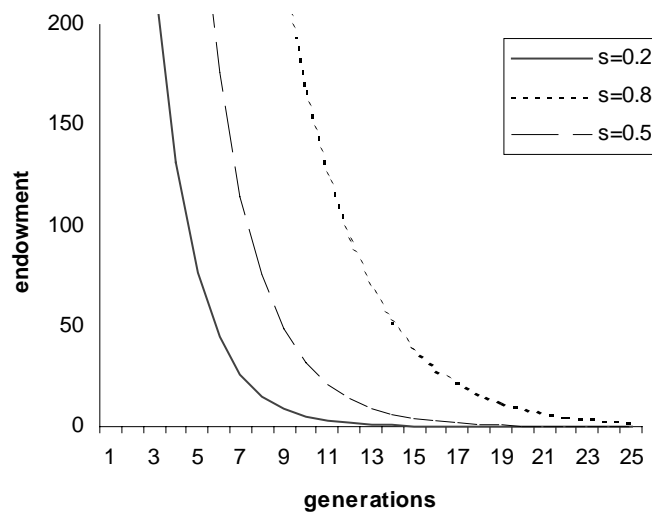


Figure 4: Distribution of endowment with intergenerational bargaining

Figure 4 shows that increasing bargaining power of the young generation leads to an increased endowment of later generations. However, a high value of  $s$ , is not always to the advantage of the new generation. From the resource transfer path (26) prices, consumption and utility can be calculated. The utility paths for different values of  $s$  are depicted in figure 5.

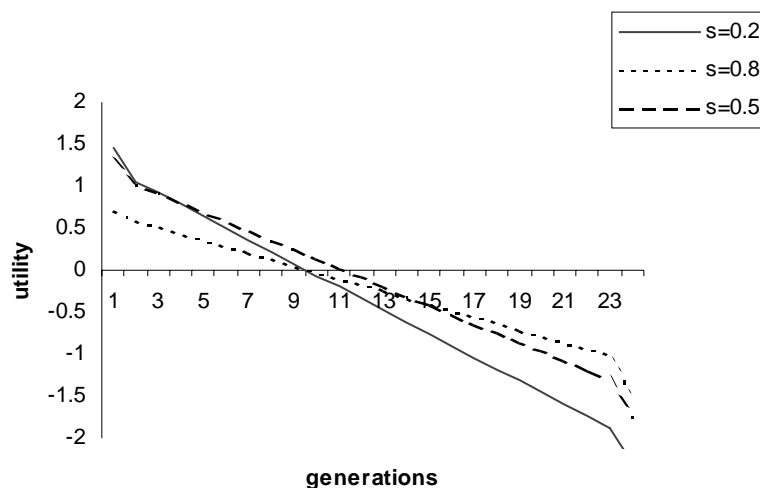


Figure 5: Distribution of utility with intergenerational bargaining

For higher values of  $s$ , earlier generations are worse off. Each generation gets a greater endowment, but this positive effect is offset by higher prices in the resource market.<sup>13</sup>

Finally, let us briefly consider the case of technical progress. There are many ways to introduce technical progress into the model. A simple way is to let parameter  $a$  of the production function (9) increase over time. In the specific model considered here, the intergenerational resource transfer is not affected. This is clear from (26). Higher productivity of the next generation will drive up prices. For utility function (10) the income effect just compensates for the substitution effect. Higher prices in the second life period will put the incumbent generation in a better position. They can increase their consumption. But increasing productivity also causes a change of relative prices of current and future consumption. Current consumption has become more expensive. Therefore, the path of resource use (production) is not changed. But contrary to what one would expect, technical progress is more to the benefit of earlier generations.

<sup>13</sup> Results obtained from a model examined by Konrad et al. (1994) suggest that resource extraction accelerates as property rights become more insecure.



## 5 Conclusion

Resource economics has focused on the efficiency of resource use and markets are – under certain conditions – an appropriate mechanism to achieve efficiency. The market mechanism presupposes well-defined property rights. In many areas of economic research it is suitable to assume that property rights are indeed well-defined. In resource economics, however, two difficulties need to be resolved before markets can work. In the course of economic growth resources, which were free goods in former times, have become scarce. The introduction of tradable private property rights may be the best possible solution to the problem of scarcity – at least when scarce goods are private goods. The question is, however, how the property rights will be distributed initially. Perhaps the economists' recommendations to use the market mechanism has not been successful and other types of environmental regulation are still predominant, because distributional issues do not get sufficient attention.

Resource economics investigates allocations with many generations involved. Again, the distribution of property rights is an important issue. Opposition against certain uses of resources may be interpreted as a claim of the young to renegotiate the property rights held by the older generation. On average demonstrators against nuclear energy, new motorways, high speed trains cutting through nature reserve areas, etc. are twenty or thirty years younger than the average member of parliament. The resource use of the generation in power is challenged by the young generation. But some doubts remain whether this will lead to a sustainable world.

Liberal theories of the state in the spirit of Buchanan's *Limits of Liberty* adopt the view that the initial distribution of property rights may well reflect differences in power between individuals of society. However, in the intergenerational case future generations who are not our contemporaries can only indirectly influence the social contract of the current society. Future generations' influence via the overlap of generations is too weak to guarantee them a sufficient endowment of clean air, clear water and other essential resources. This is the result of section 4.

A stronger normative view like Nozick's in *Anarchy, State and Utopia* will assign everyone in society a set of equal basic rights on which a theory of acquisition of property rights must be based. My final conclusion is, that traditional resource economics must be combined with a normative theory of legitimate resource acquisition. Some work has been done by philosophers in recent years.<sup>14</sup> But, until today this work has not had much impact on resource economics.<sup>15</sup>

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<sup>14</sup> See e.g. Becker (1977), Waldron (1988), Schmidtz (1990) and Simmons (1994). Weikard (forthcoming) examines the rights of future generations under three different versions of liberalism.

<sup>15</sup> With the notable exception of some authors of the "ecological economics" heterodoxy.

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