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On the Intergenerational Allocation of Natural Resources

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Abstract

It is known (Hartwick and others) that, under standard assumptions, a society that invests in reproducible capital the competitive rents on its current extraction of exhaustible resources, will enjoy a consumption stream constant in time. It is shown here that this result can be interpreted as saying that an appropriately defined stock of capital —including the initial endowment of resources — is being maintained intact, and that consumption can be interpreted as the interest on that patrimony. This seems like a useful rule of thumb for policy.

I. Background

The first OPEC oil shock, which occurred just about ten years ago, had intellectual, as well as economic and geopolitical, consequences. It attracted attention forcibly to the finiteness of the world's useful stock of nonrenewable resources, of which oil is only one. The question of the appropriate intertemporal allocation of limited supplies inevitably came to the fore. And since the time-scale to be considered was very long, the intergenerational allocation of limited resource stocks was explicitly discussed. That is why this is an appropriate topic to be mentioned in a symposium in honor of Ragnar Bentzel.

At the popular level, the discussion of intergenerational equity usually takes a simple form. The basic question is: how much of the world's — or a country's — endowment of nonrenewable resources is it fair for the current generation to use up, and how much should be left for generations to come who have no active voice in contemporary decisions? One of the elementary, but nevertheless important,

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contributions made by professional economists to this debate is the warning that this is a damagingly narrow way to pose the question. The current generation does not especially owe to its successors a share of this or that particular resource. If it owes anything, it owes generalized productive capacity or, even more generally, access to a certain standard of living or level of consumption. Whether productive capacity should be transmitted across generations in the form of mineral deposits or capital equipment or technological knowledge is more a matter of efficiency than of equity. (The preservation of natural beauty is a different matter since that is more a question of direct consumption than of instrumental productive capacity.) As so often happens, recognition of the fact of substitutability or fungibility converts a matter of "simple justice" into a complicated question of resource-allocation.

This range of issues seemed to have died down lately, perhaps because the real price of oil had retreated. But I have noticed that the question has arisen again in Great Britain as part of controversy on macroeconomic policy. The discovery of North Sea oil brought to Britain an asset of great value but of apparently rather short life as these things go. Opponents of the government in power accuse it of having "wasted" this asset, at least so far. They mean that the revenues from North Sea oil have not been used to finance increased investment in productive capacity, but have instead been consumed, partly in the form of unemployment benefits during a long recession. The defenders of the government reply either that it had no choice, or that its actions were necessary to the more urgent goal of ending a destructive inflation, or that it was responding to the freely-expressed preferences of the current generation. I leave this summary deliberately vague because I have no intention of analyzing it further. My purpose is merely to illustrate the re-emergence of practical policy debate over intergenerational equity and the allocation of natural resources. I have heard that analogous debate has been encouraged in Norway; and I imagine that the intertemporal use of Dutch natural gas has been similarly discussed in the Netherlands.

The natural vehicle for an economic theorist concerned with the intertemporal allocation of resources is the standard sort of model of optimal growth and capital accumulation pioneered by Frank Ramsey and studied by many others. It is not hard to adapt that model to incorporate an initial stock of a non-renewable resource whose use is required for the production of consumable output. That

is in fact the form taken by nearly all of the discussion of the issue within professional economics.

Many interesting results were achieved this way; as an accidental by-product, however, the equity issues themselves have tended to be submerged. The Ramsey model takes as its measure of social performance the sum over time of instantaneous utilities of consumption. Intertemporal welfare economics, when it is organized that way, is utilitarian from the ground up. It simply assumes, without explicit justification, that equity between generations is adequately taken care of by adding one generation's utility-level to another's; and each generation's utility is assumed to depend only on its own consumption. The utilitarian ethic wants any generation to sacrifice a unit of utility whenever that permits more than one unit of utility to be provided for any other generation. Ramsey maintained that utility-discounting was ethically inappropriate: the intertemporal welfare criterion ought not to give earlier generations systematically greater weight than later ones simply by reason of position in time. Some modern authors have allowed for discounting more for convenience than as a result of reflection. (It is only fair to say that a justification for discounting can be provided by the observation that it is a way of allowing for uncertainty about the very existence of future generations.)

A reasoned defence can be given for the utilitarian ethic in this context. But it is not self-evidently valid, and it has been attacked at least as reasonably. My own first contribution to this literature went more or less to the opposite extreme in its definition of intergenerational equity. Partly because I had been reading Rawls, partly to acknowledge the direction and tone of popular argument, and partly because I wanted directly to oppose naive Club-of-Rome prejudices. I defined the welfare criterion to be the standard of consumption achieved by the least well-off generation. In other words, the current generation is always entitled to take as much out of the common intertemporal pool as it can, provided only that it leaves behind the possibility that each succeeding generation can be as well off as this one. According to this maximin criterion, a society starting from such an egalitarian reference path would not be justified in demanding any sacrifice, however small, from one generation in order to provide a benefit, however large, to any other generation. In a way, nothing could be less utilitarian. Whereas typical solutions to the standard Ramsey problem tended to recommend paths along

which the level of consumption increases steadily, mine took it for granted that the best path would show a constant level of consumption; the best such path was the one with the highest permanently maintainable consumption level. I pointed out that this criterion has its problems too (as Rawls had seen): a society starting out poor would find no justification for the initial accumulation that could provide a higher standard of consumption in the future. It is not so easy to find an ethical principle that will thread a path between Stalinism and stagnation. But that is not my objective here anyway.

In the next section, I briefly sketch some results about the achievement of constant-consumption paths. (These are due mainly to John Hartwick, with some help from others, including myself.) Then I want to propose a new growth-theoretic interpretation of Hartwick's finding. And finally I will conclude with a few reflections on the significance of these ideas for current policy issues.

II. Hartwick's Rule

In a series of papers written shortly after the first oil shock, John Hartwick proved an intriguing proposition under assumptions that are perfectly conventional in the theory of growth with exhaustible resources. Imagine a society that produces current output — which can be consumed or invested — under constant returns to scale, using as inputs a given supply of labor, the services of a stock of capital accumulated from previous investment, and withdrawals from an initially given stock of a non-renewable resource. (International trading possibilities have to be regarded as part of the "technology" as Lars Svensson reminds me.) To start with, assume that the supply of labour is constant, and there is no technological progress. Suppose the society governs its affairs according to the following rules. (1) It employs its capital and labor fully. (2) It obeys the usual conditions for intertemporal efficiency, which boil down in this case to the Hotelling rule that the shadow value of a unit of the unextracted natural resource should be increasing at each instant at a rate equal to the current marginal product of reproducible capital. (3) It follows a specific investment policy: at each instant it invests in reproducible capital goods the competitive rents on its current use of the wasting resource. (This is the Hartwick Rule.) Then this society will find that it is just able to maintain a constant stream of consumption. The

accumulation of reproducible capital exactly offsets the inevitable and efficient decline in the flow of resource inputs.

This is certainly a neat result. It can be extended straightforwardly to cover the case of several imperfectly substitutable resource pools, the presence of a renewable natural resource, and the existence of many capital goods. Dixit, Hammond and Hoel place the result in an appropriately general analytical framework. Dasgupta and Mitra extend Hartwick's ideas to a comparison of efficient equilibrium paths. They embed the model in discrete time, and this turns out to make a bigger difference than one might expect. Karl-Goran Mäler has pointed out that there is something anomalous in discussing intergenerational issues in terms of a continuous-time model that simply adds over infinitesimal instants of time. I have to agree. From this point of view a discrete-time formulation may be preferable; this would seem to be the natural habitat of an overlapping-generations model but, as far as I know, it has not been tried.

The situation is much more complicated when the labor force is growing and there is technological progress. At the simplest level, no path with constant consumption per person may be permanently maintainable, unless the rate of techological progress is large enough compared with the rate of population growth. Even if it is, the Hartwick rule may not achieve constant consumption. At a deeper level, it is not so clear that the maximin criterion retains its force when there is exogenous growth in the labor force and in productivity. One has to decide — whoever "one" is — whether later generations are entitled to a higher standard of living just because they come later in time, when productivity is higher. If they are, then a simple extension of the Hartwick rule is available. Let the technology be Cobb–Douglas, i.e., $y = e^{mt}k^a r^b$ where y, k and r are output, capital input and resource input, all per unit of labour, m is the Hicks-neutral rate of technological progress, the Cobb–Douglas elasticity for labor is $1 - a - b$, and the supply of labor is increasing like e^{nt}. The "natural" rate of growth for this model is $(1 - b)^{-1}(m - an)$. Then the Hartwick rule, investment of resource rents in reproducible capital, will cause consumption per head to grow at the natural rate.

If one is still after constant consumption per head, despite Nature's attempt to make the future richer than the past, then nothing so simple as the Hartwick rule will do the trick. I have not pursued this to the end, but it can be shown that consumption per head will

remain constant if the net saving ratio, s, satisfies the following differential equation:

$$\frac{ds}{dt} = \frac{1-s}{1-b}(m - an) + \frac{a}{1-b}(1-s)(s-b)\frac{y}{b}.$$

Here resource input into y has to be governed by the Hotelling rule, and the capital stock evolves according to the saving rate and y. It will be observed that if $m = an$, so the natural rate of growth is zero, then the Hartwick Rule ($s = b$ in this notation) will work. Otherwise the required investment policy is much more complicated. Obviously, however, the early generations will be entitled to consume more than in the previous case.

III. An Interpretation of Hartwick's Rule

The policy of investing resource rents in reproducible capital suggests irresistibly that some appropriately defined stock is being maintained intact, and that consumption can be regarded as the "interest" on that stock. This interpretation turns out to be quite right. I will get at it in a growth-theoretic way, using a neat result due to my colleague Martin Weitzman.

Imagine an economy that acts so as to maximize the present value of consumption

$$\int_0^\infty C(t)\,e^{-rt}\,dt,$$

subject to a well-behaved stationary technology involving any number of capital goods. (Weitzman remarks: "Strictly speaking, pools of exhaustible natural resources ought to qualify as capital...".) Then, if $p(t)$ is the vector of shadow prices (with consumption as numeraire) corresponding to the vector $K(t)$ of stocks of capital goods, competitive efficiency generates a net national product function $Y^*(t) = Y(K^*(t), \quad p(t)) = C^*(t) + p(t) \quad \dot{K}^*(t) = \text{Max}\{C(t) + p(t)\,\dot{K}(t)\}$ where the maximum is over technologically-feasible bundles of consumption and net investment, given the existing stocks of capital goods. In addition, the usual intertemporal arbitrage or efficiency conditions (e.g. of Dorfman, Samuelson and Solow) hold along an optimizing path. (In technical terms, $Y(K^*, p)$ is the Hamiltonian of the maximization problem.)

Weitzman shows that "the maximum welfare actually attainable from time t on along a competitive trajectory is exactly the same as what *would* be obtained from the *hypothetical* constant consumption level $C^*(t) + p(t)\,\dot{K}^*(t)$". In mathematical terms,

$$\int_t^\infty [C^*(t) + p(t)\,\dot{K}^*(t)]\,e^{-r(s-t)}\,ds = \int_t^\infty C^*(s)\,e^{-r(s-t)}\,ds$$

or

$$\frac{1}{r}\,Y^*(t) = \int_t^\infty C^*(s)\,e^{-r(s-t)}\,ds. \tag{1}$$

Notice that the integral on the left is the present value, from t on, of a *constant* consumption stream equal to the whole net national product *at time t*.

Now suppose that $p(t)\,\dot{K}^*(t) = 0$ from some date on. This is Hartwick's Rule. Those components of $\dot{K}(t)$ that represent reproducible capital goods add up to net investment in the conventional sense. For any component representing an exhaustible resource, $-\dot{K}_i$ is the current rate of depletion and $-p_i\dot{K}_i$ is the market rent (in the absence of extraction costs). Thus $p(t)\,\dot{K}^*(t) = 0$ does state that the sum of current resource rentals is always equal to current net investment in reproducible capital.

If $p(t)\,\dot{K}^*(t) = 0$, $Y^*(t) = C^*(t)$ for all t and thus

$$\frac{1}{r}\,C^*(t) = \int_t^\infty C^*(s)\,e^{-r(s-t)}\,ds$$

for every t. Differentiation with respect to t gives

$$\frac{1}{r}\,C^*(t) = -\dot{C}/C^*(t) + r\int_t^\infty C^*(s)\,e^{-r(s-t)}\,ds = -C^*(t) + C^*(t) = 0.$$

This is exactly Hartwick's result: investing resource rents along an efficient path generates a constant consumption stream.

Now $p(t)\,\dot{K}^*(t) = 0$ does not imply that $p(t)\,K^*(t)$ is constant, because $p(t)$ is changing. But differentiation of (1) gives us

$$\dot{Y}^*(t) = r(Y^*(t) - C^*(t)) = rp(t)\,\dot{K}^*(t)$$

and integration yields

$$Y^*(t) = Y^*(0) + r\int_0^t p(s)\,\dot{K}^*(s)\,ds.$$

Thus along any efficient path, the increment in NNP since $t = 0$ is representable as interest on the accumulation of capital value since $t = 0$, in an inclusive sense that records the decumulation of the stock of exhaustible resources. Under Hartwick's Rule net accumulation is zero all the time, and the stock that is being maintained intact can be thought of as

$$V(t) = \int_{-\infty}^t p(s)\,K^*(s)\,ds,$$

interpreted to include the initial endowment of resources and, if there is any, of capital. As Lars Svensson has pointed out, the assumption of a constant discount rate may be quite restrictive here, and the consequences of relaxing it ought to be studied.

IV. Conclusion

I have deliberately avoided explicit mathematical details in this paper because, like everyone else I know, I am tempted to take them too seriously. The temptation is greater the more remote from everyday life the subject. It is the essence of intergenerational equity that it is remote from us, more or less by definition. One's strongest impression is that we have very little to go on in the making of decisions with very long-run consequences. That is especially so when long-run and short-run factors interact, as they do in the specific case I have been discussing. The tendency is very great to allow short-run considerations to dominate, if only because we can grasp them better.

That being so, there is something to be said for rules of thumb, for shorthand ways of taking care of interests that might otherwise be neglected. The image that comes to mind is Ulysses lashing himself to the mast because he knows he will be tempted by the Sirens. From that point of view, Hartwick's rule is a better-than-average rule of thumb. No one could argue — at least I could not argue — that investing the rents from the national pool of exhaustible resources is the "right" policy. We do not know if the rule is robust against such obvious variations as endogenous population growth (and tech-

nological progress). The welfare economics of an endogenously changing population is altogether murky. But I could see the rule as a rebuttable presumption, as a way of constantly reminding ourselves that there are considerations other than immediate utility to be taken into account. The neat interpretation of allowable consumption as the interest on an initial patrimony or resource endowment seems quite appropriate. It is a reminder of the old-fashioned obligation to "maintain capital intact".

I was delighted to find in Gunnar Eliasson's lecture at the Bergen conference on oil and economics a discussion that ranges far beyond the limited point made here, but is completely compatible with it. Eliasson is concerned to argue that it matters a lot whether the rents from (Norwegian North Sea) oil are invested in paper assets on the world market or in improving the industrial base of the Scandinavian countries. It is healthy that such questions be discussed explicitly.

In fact, I have to admit that I do think the British government has been wasting the windfall of North Sea oil, and that these growth-theoretic considerationis are a help in understanding why. If that seems excessively philosophical for a hard-nosed economist, then a seminar in honour of a retiring scholar is the best possible occasion for a little philosophy.

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