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THE TRANSITION FROM EXHAUSTIBLE TO RENEWABLE OR INEXHAUSTIBLE RESOURCES

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THE TRANSITION FROM EXHAUSTIBLE TO RENEWABLE
OR INEXHAUSTIBLE RESOURCES*

by

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Allow me to begin with some simple and rather obvious remarks on the nature of the transition problem from exhaustible to renewable or inexhaustible resource use. First, a shift in resource use means also a shift in technology, because in this age resources go together with technologies that process them and put them to use. Secondly, while I have used the word "exhaustible," the term "depletion" is a more suitable word, in that it suggests a more gradual process. The later stages of depletion will then whenever possible call forth a substitute resource that allows society to meet the same or a similar need met by the resource being depleted. Finally, I will follow the model of price as a regulator that will touch off the substitution, smoothly if the degree and rate of depletion are foreseen sufficiently in advance.

This means that the transition problem is one of phasing out the technology associated with the resource being depleted and phasing in one or more technologies associated with possible substitutes. This process requires research and development for the new technology, if not already known, and a turn-over of the capital stock and retraining of the labour force as needed. Therefore the transition problem is a long-run problem,

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involving, I would say, something of the nature of 50 to 100 years. Examples of this substitution process abound in the field of energy, and the paper by Sassin and Häfele contains several of these.

Another important characteristic of the transition problem is its interdisciplinary nature. It involves technology and engineering; it involves geology whenever resource availability estimates are important; it involves ecology and environmental science to assess and estimate adverse impacts on the environment; and it involves economics to face up to the problem of best use of resources, whether in a market or a planning context or in a mixture of the two regimes. Also, where uncertainty about resource availabilities or future technologies is important, decision theory under uncertainty has an important role. Last but not least, the problem of transition involves ethical considerations in regard to the balancing of the interests of present and future generations. Thus the problem is by its very nature inter-disciplinary in character.

Moreover, with regard to the implementation of possible solutions, the problem has international as well as national aspects. As regards the possible effect of fossil fuel combustion on CO_2 in the atmosphere, which may in turn affect climates and crops in various regions—that is undoubtedly a world problem; as regards the transition from coal to nuclear energy (or conversely), that is in part national, in part international.

I tend to regard the communication difficulties arising from the inter-disciplinary character of the problem as deserving as much attention as the international aspects. Between the disciplines involved, there is need for more information exchange, translation of jargon, and actually debate, inter-disciplinary as well as intra-disciplinary, to remove the misunderstandings in one profession about the terminology and problem choices of the other. This difficulty is not one-way, but mutual and universal.

As a modest preparation for these interactions and debates, I will describe and comment on three approaches to the transition problem that are professionally somewhat different, and cite some examples in each without intending this to be regarded as a survey. My examples are illustrations, rarely statements of results, but where they are the latter they are results reached by others.

What was to have been my first example, Hotelling's seminal article on the theory of depletion of resources through competitive markets, under monopoly, and in optimal planning, has already been fully covered by other speakers.

My second example is a landmark paper by Dasgupta and Heal, "The Optimal Depletion of Exhaustible Resources." I want to comment on some parts of that paper to add substance to the foregoing general observations. The paper has two sections. In each section an optimal allocation problem is considered. In the first one, there is just one resource which is gradually being depleted, and the optimality criterion (or "objective function") is an integral of the utility of the flow of consumption of that resource over time, discounted with a fixed discount rate δ ,

$$(1) \qquad U = \int_0^\infty e^{-\delta t} U(G)\, dt \ , \text{ where } \ \delta > \theta \ .$$

The consumption flow is

(2) $$C_t = F(K_t, R_t) - \dot{K}_t ,$$

that is, the output flow of the single finished good minus the flow allocated to capital formation, as in the Ramsey model. Next, the production function $F(K, R)$ is a function of the capital stock and of the resource flow, i.e., the rate of resource depletion. Finally, the latter flow integrated over time cannot exceed the total available, S ,

(3) $$\int_0^{\infty} R_t dt \leqq S , \text{ where } S > 0 .$$

The problem thus is to maximize (1) subject to (2), (3), and a given initial capital stock K_0 .

The first section of the paper describes the solution of this problem in rich detail. The second section constitutes, I presume, in the authors' intent the main purpose of the paper. It considers a case where an economy starts out in the circumstances of the first section, but in addition to that it may have the good luck of discovering and developing a substitute technology, to become available at some future date which is as yet uncertain. To my knowledge the second section contains the first theoretical model of this kind that expresses the idea of an uncertain ultimate transition to a durable solution. It assumes that at some moment in the future a constant resource flow becomes available. As an example, imagine that the solar flux can suddenly be tapped cheaply and on a large scale—the moment at which this happens being subject to a probability distribution.

I want to make two comments on the two parts of the paper. First, there is an interesting connection between the solution of the first problem and that of the second problem. To state that connection requires a long sentence: If the new technology in the second problem is so superior that, at the moment of its appearance it destroys the value of both the then existing capital stock and the then remaining resource stock, then the segment of the optimal path of the second problem, up to the appearance of the new technology, coincides with the corresponding segment in a suitably modified version of the first problem. The modification requires that the discount rate in the first problem vary over time in a particular way that depends on the probability distribution of the time of appearance of the new technology in the second problem. This is a case of a valid modification of a discount rate to allow for uncertainties—something that is often done with much less motivation.

My second remark concerns the first problem taken by itself. The tail end of the optimal path in that problem should not be taken, I submit, too seriously. In the case of a Cobb-Douglas production function, as T goes to infinite the optimal path has consumption going to zero, the capital stock going to zero, the resource flow going to zero. All of that is to be expected. However, the ratio of the capital stock to the resource flow goes to infinity. I want to make two comments on that. First, as all these variables go to zero, one puts a great deal of strain on the assumption of constant returns to scale if one uses that same Cobb-Douglas function deeply into that corner. Secondly, even if one were to be adamant about that and say "I believe that constant returns to scale holds at all scales," then one still has the difficulty that the ratio of capital to resource use goes to infinity. This places that ratio in an area in which we could not possibly have observations from which the validity of that Cobb-Douglas function in that area could have been tested econometrically. The authors point out that the difficulty I have referred to is even worse with the so-called CES (constant elasticity of substitution) function. For this type of production function, an inessential resource (i.e., a resource whose absence still allows positive production to take place) has as T tends to infinity a shadow price relative to capital that also becomes infinite. On the other hand an essential resource (one without which you cannot produce) has a shadow price that remains finite. As the authors point out, this is hard to accept as a trait of the real world.

I have mentioned both of these puzzles as examples of a difficulty that recurs in many modeling studies: One uses on the basis of econometric practice a constant elasticity of substitution, or a constant price elasticity of demand, or any other parameter of a behavior relationship. Then somehow the optimizing model carries you out of the area where the observations are found. I want to press a certain warning for the interpretation of these cases. They give theoretical insight, as long as they are not mistaken as being empirically validated by the econometric estimation of a function of that particular parametric form. Fortunately, in the case in hand, and due to the introduction of the second problem, the authors end up with the questionable tail end of the optimal path in the first problem being amputated by the occurrence of the new technology.

My <u>third example</u> has to do with the young field of energy modeling. As far as participating professions are concerned, that field is still very much a concern of economists, but with equal participation by mathematical programmers, operations researchers and engineers. The professional basis widens as we proceed to this example. In particular, production possibilities are now best represented by the use of the process model and the techniques of mathematical programming. The empirical basis is the representation of production processes by fixed ratios of inputs to outputs for each process. That model is, I would say, squarely in the area of economic theory and of econometrics, but it has not penetrated as much as for instance the input-output model of Professor Leontief—which is that special case of the process model in which any one good can be produced only by itself alone, and that by only one process. In contrast, the energy sector has access to many alternative processes by which a given good or service can be produced, alone, or with one or more by-products. To generate electricity you can burn coal, burn oil, or have a nuclear plant, and hopefully in due course you will be able to catch the solar flux—there are several alternatives. To my belief, for the transition problem a model consisting of a set of alternative processes is a more appropriate way of expressing production possibilities than either the input/output model or the smooth production function of longer standing in the economic textbooks and in the teaching of Econ 100. In this connection I would like to relate a conversation I had with a friend of mine who is working in this field. I expressed to him some puzzlement over the fact that I find it much easier to communicate with engineers about the process model of production than with economists. He said "That is simple: engineers have never heard of a production function."

The basic idea is that you have the individual processes represented. Any production function should be constructable from these processes if there is a need to. The programming model allows several resources and technologies to compete side by side. The optimization suggests the best technology mix and its change over time. In a planning context, the planners would be customers for that type of analysis. In a market context, to the extent that the market process approximates a situation that in economic theory we label as perfect foresight and perfect competition, the model would simulate the market outcomes.

I will refer to three long-term models of the U. S. energy sector that apply optimization in this role of a simulation device. One is essentially a supply model, developed in stages at Brookhaven National Laboratory by Kenneth Hoffman, William Marcuse and their associates. Now called "DESOM," it treats final demand for energy services as an exogenously given vector path, and solves for the vector path of primary extraction, conversion and utilization of energy by minimization of the sum of discounted costs over time.

Two other models, "ETA" by Alan Manne and what I will call "Nordhaus" by William Nordhaus, while also treating the supply side by a process model, represent consumers' demand by a utility maximization. Here the utility function is derived by an integration from an estimated demand function.*
The optimization then maximizes the discounted sum of future utilities derived from consumption of energy services minus the cost of supplying them.

I will give one example of the application of these procedures to

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*An econometric basis of these estimates is provided in one case (WN) and claimed in another (AM).

a much debated problem in which different professions have had quite different expectations about the answer. This is the question of the feedback from constraints on the growth of energy use to the growth of GNP over a particular future period in the United States. Since I cannot take time to describe the models more fully, it is more the nature of the problem that I want to place before you rather than to claim that the information supplied here is sufficient to present the conclusion as fully established—although I, myself, think it is a significant finding.

Table 1 summarizes two sets of projections, in which the role of cause (shown in square brackets) and of effect (no brackets) is interchanged between the principal variables. Rows (0) and (1) report on "base case" projections in which the growth rate of GNP is assumed to be a driving variable (exogenous), that of energy use a dependent variable. The principal finding is that if GNP grows at an average of 3.2% p.a. over the period 1975-2010, then, depending on the model used, the energy use would grow somewhere between 1.7 and 2.9%. Here capital and operating cost and resource availability parameters are the same for the various models, but intermodel differences in price and income elasticities of demand could not be removed.

Rows (2), (3), (4) summarize a policy analysis in which policies constraining energy use are assumed to be imposed. In Row (3), various policies curtailing the growth rate of specific forms of energy supply are assumed to be imposed for reasons of environmental protection (coal, shale oil), or from a concern with the risks of various nuclear technologies. The cause of the departure from the base case now lies in the constraint on energy use over a 35-year period (represented in the table only by the percentage curtailment of the use figure for the year 2010). Note

TABLE 1

FEEDBACK FROM CURTAILED GROWTH OF ENERGY USE

TO GNP, 1975 - 2010, U. S.

	(0)	(1)	(2)
(0)	[Driving][a] and Effect Variables	[GNP G_t]	Energy Use = E_t
(1)	Growth Rates in Base Case	[3.2% p.a.]	1.7 to 2.9% p.a.
(2)	Gauge of Effect and [Policy] Variable	$G = \sum_{t=0}^{35} \frac{G_{1975+t}}{1.06^t}$	[E_{2010}]
(3)	Curtailment Fraction [specific policies]	1 to 2 %	[up to 20%]
(4)	Curtailment Fraction [zero-energy-growth through conservation tax]	$\begin{cases} 1 \text{ to } 2\% & \text{if}^{b}\ \eta = -.5 \\ \text{Up to } 30\% & \text{if } \eta = -.25 \end{cases}$	[about 50%]

[a] In each set of projections causal or "driving" variables and their values are marked by square brackets. Effect variables are without marking.

[b] η = constant price elasticity of demand for energy

Source: Energy Modeling for an Uncertain Future: Report of the "Modeling Resource Group" of the Committee on Nuclear and Alternative Energy Systems, Tables III.0, III.22, Charts III.11, III.12, National Academy of Sciences, 1978.

that now the percentage figure does not stand for percent per annum, but for the fraction of curtailment out of the base case, in column (2) of the energy use in 2010 (representing the cause), in column (1) of the sum of discounted GNP over the 35-year period (a gauge for measuring the effect).

I want to emphasize the implicit assumptions that (a) the way in which the constraining policies are imposed is gradual as well as foreseeable, and that (b) there is a reasonably full employment policy consistently and successfully applied. Therefore we do not in this discussion deal with such matters as the effect of a sudden OPEC type embargo and the shooting up of the price of oil that might be connected with that. If such events occur, they are not covered or foreseen by this analysis. Then the up to 20% curtailment of energy use imposed by these particular policies or combinations thereof still affects aggregated discounted GNP by a moderate 1 or 2% . The basic reason for this outcome is that in time the technology mix can be shifted . If coal is curtailed because of the environmental effect of the dust and the sulphur it releases or because of the risk or damage from the mining, then, the constraint being foreseen and carried out gradually, nuclear fission can be called into a higher growth rate, and in that way the effect on GNP growth can be diminished. Actually, the feedback effect is due to the fact that the constraint of one technology (that is deemed harmful) to a value below the strictly economic "optimum" will be not quite compensated by the gain from shifting to another technology (that is deemed less objectionable), just because you are moving away from the economic "optimum," for noneconomic reasons.

In Row (4) a much more drastic curtailment is imposed on all energy use, merely for analytical purposes, and in no way implying that sensible policies might lead to such a measure. This is the imposition of a low or a zero energy use growth rate brought about by an imagined conservation tax on all primary energy, where the tax rate grows fast enough to hold the energy use down to a low or zero growth rate—still making the same assumption about gradualness of the imposition. Then two new things happen—the effect turns out to be more than proportional to the curtailment, and also depends strongly on the price-elasticity of demand for energy. If that price elasticity (the parameter η) is one half in absolute value then even the no-growth energy use policy still leaves GNP under these assumptions affected by not more than 1 or 2 % . But if the price elasticity of demand is only one fourth, then, in the ETA model in which this assumption is used, very remarkably the GNP is curtailed by up to 30%. So we also have a non-linearity here in the dependence of the effect of a severe policy on the price elasticity of demand for energy—assuming that elasticity to be a constant all along the demand curve.

Here is another case where our econometric practice leads us to work with a constant parameter, because we have not yet refined econometric methods to face up to a situation away from what the available data represent. However, on reflection, the price elasticity of demand cannot be a constant in the whole space. In fact, there is a theorem that has been in the folklore for some time, and of which the best proof known to me was given by Professor Hirofumi Uzawa in 1974 while at IIASA . I don't know whether he has published it, but I have a copy of his notes. Again, the theorem requires a long sentence. It says that if you consider the demand for a number of commodities as a vector function of the prices of all these commodities, and if for all prices the budget constraint is satisfied—total consumers' income is spent-- and finally if you assume that all the cross and own price elasticities are constant, even only in a small neighborhood of a point in the price space, then the only possible constant values of these elasticities are -1 for all own price elasticities, and zero for all cross elasticities. Any other set of values cannot stay constant. This theorem is rather upsetting for our econometric practice, but perhaps it does help us in further exploration of a situation in which a constant price elasticity is found to have so large an effect.

The findings summarized in Table 1 are the work of a modeling group that forms one of many parts of a joint study committee of the two U. S. National Academies, of Sciences and of Engineering, that is still continuing its work. I have been involved in the work of the modeling group as its chairman, but the work that has been drawn on in Table 1, while leaning mostly on DESOM, ETA and Nordhaus, cannot be attributed in detail because the specific findings have been combined in the aggregation and compression into one brief table.

My fourth and last example contemplates a still longer time horizon. It describes a contribution from the physical sciences, by Harold E. Goeller and Alvin M. Weinberg in an article entitled The Age of Substitutability. The approach is still more explicitly empirical than that in the previous models I have just discussed. This is not my field. I am impressed by the work the authors have done but I cannot say that I can evaluate it. They have gone through the entire periodic system examining all the elements plus some important compounds, to determine the flow of their extraction in 1968, and estimate for each the total resources potentially available according to a rather generous definition of potential sources—the atmosphere, the ocean and a mile-thick crust of the earth. That may be a little more justified if one takes a very long-run view, but I would have liked to see a discussion also of costs of extraction and processing, and of how these costs would evolve in the race between depletion and technical advances. In any case, the ratio of total resources to demand in that year is expressed in years to go until exhaustion at the constant 1968 rate of extraction—a simple signal of relative abundance or scarcity. In that list the most serious case, to worry about in the very long run, appears to be phosphate—1300 years supply at the 1968 rate of use. Next comes coal, oil and gas, taken together in the symbol CH_x , where x is zero for coal and positive for oil and gas. Because of the coal component this aggregate would still have 2500 years at constant use. Then manganese (13,000 years) and everything else comes out at more than a million years.

Through the entire list and in the cases where there is a clear indication of a finite life time, the authors trace the important uses and possible substitutes in these uses. Their proposal is akin to building up, for the entire list of resources, the type of process model that I have spoken of previously.

On the basis of their scrutiny of these geological and technological data, Goeller and Weinberg pronounce the principle of infinite substitutability: With the exception of phosphorus and some trace elements for agriculture, mainly cobalt, copper and zinc, and finally the CH_x (coal, oil and gas), society can exist on near-inexhaustible resources for an indefinite period. This extends into the future the thesis of Barnet and Morse that in the past a new substitute for a dwindling resource was always found. They do not say much more about the case of phosphorus except that at some point that element may have to be recycled, and emphasize its essentiality to sustaining life. Similarly with the trace elements, but on the hydrocarbons they have a very interesting observation. It is related to the doctrine of energy as the crucial resource, with which Weinberg has been strongly associated. The remark is that carbon and hydrogen are abundant, that both are tied to oxygen in nature, that it takes energy to detach the oxygen, and that there are a number of technical processes that do just that, putting in energy and obtaining the various hydrocarbons needed by industry or transport. For this to work, of course, the energy source has to be non-fossil and abundant. Among the various possibilities are solar, geothermal, the nuclear breeder reactor, and nuclear fusion. Each of those has difficulties associated with it. Solar on a central power station basis is expensive by present projections. Geothermal is still very much untried except in special situations. Perhaps the principal problem with the various nuclear breeder reactors is the difficulty that the by-products can, if so desired, be processed and diverted to become nuclear weapons-grade materials. And I understand that the technical feasibility and commercial viability of nuclear fusion reactors is still an open question. At least one of these options would have to work to make the doctrine of energy as the crucial resource a reality.

I have already said that I cannot evaluate these ideas, but I wanted you to be acquainted with this line of thought and be aware that when you look very far into the future quite a different type of information becomes important. Traditional econometrics doesn't help us here. There is a type of thinking here that draws on basic scientific notions and knowledge, and that economists should take note of.

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