THE PROBLEM OF AGGREGATION IN MODELING PHYSICAL AND SOCIAL SYSTEMS AND PROCESSES*

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ABSTRACT: The design of complicated systems (nuclear reactors, bridges, advanced electronic systems, business organizations) usually proceeds on the assumptions of restricted interaction, local linearity, and similar simplifying approaches. Once such a system is designed it may be analyzed further by removing the simplifying assumptions, often one at a time. But "really to know" what goes on in a postulated nuclear-reactor accident; understanding the behavior of society following a major perturbation like the Arab OPEC embargo; judging in general the behavior of a complex system far from the design point; requires for efficient simulation some degree of aggregation in the treatment of the system. Insufficient aggregation poses problems of computer capacity; excessive aggregation may lose important aspects of behavior, as in some energy-related examples discussed. Furthermore, societal models must allow interaction with people motivated to act the roles of cartel operators, anarchists, law-breakers, and the like. To exclude from the model sectors of society which are much in demand, such as lawyers and lobbyists, is to neglect an important influence.

*Speech given in the Energy Short Course of the American Mathematical Society, San Antonio, Texas, January 21, 1976. To be published with the other Short Course Lectures in the Transactions of the AMS.

07/06/77 "The Problem of Aggregation in Modeling Physical and Social Systems and Processes," Proc. Symposia in Applied Mathematics 21, pp. 107-120. (070677AGMO)

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This talk prescribes no solution to the stated problem nor even provides well-formulated questions, but, I hope, rather indicates the importance and opportunity in this field.

How is it, with all the mathematical, scientific, and engineering talent in the United States; with our capital and productive resources; that we have an "energy problem"? Will whatever in the past limited our success in this field do so in the future? Can any finite set of reforms make a difference?

BACKGROUND:

I come to this question from some 25 years of contact with technical questions of increasing involvement with national policy. In the summer of 1950, I organized a group at the Los Alamos Scientific Laboratory and began an experiment to remeasure the reaction cross section of deuterium on tritium and of deuterium on deuterium to help decide whether it would be feasible to make thermonuclear weapons or fusion energy. From 1951 to 1954 I worked part time at Los Alamos on the hydrogen bomb and became acquainted with approaches to fusion energy, the problems of fallout and the use of computers in modeling man-made or natural systems.

From 1962 to 1965 and 1969 to 1972 I was a member of the President's Science Advisory Committee (PSAC). For the PSAC I was Chairman for a long time of the Antisubmarine Warfare and Military Aircraft Panels. That latter developed into an Aircraft Panel concerned with civil transportation, and even an Air Traffic Control Panel. These and the Defense Department activities led to acquaintance with operations research and with the political system whereby decisions were taken. One of the interests of the Aircraft Panel over some years was the Department of Transportation Study of Transportation in the Northeast Corridor. As a member of PSAC, I was also quite concerned with the mid-1960's massive energy study of the Office of Science and Technology, led by Ali Cambel.

From 1970 to 1974, following the Clean Air Amendments of 1970, I was a member of the National Academy of Sciences Committee on Motor Vehicle Emissions which was requested by the Congress to study the technological feasibility, economics, and possible necessity of delay in reaching Congressionally mandated emission standards from automobiles. However, our charter did not extend to a determination of the "best way" in our society (or a better way) to accomplish the Clean Air Amendment goals of air quality, even in the automobile sector, as by an emission tax instead of absolute limits on motor vehicle emissions. It was clear to some of us that there were alternative incentive structures which could accomplish the same goals more certainly and which would inherently provide better motivation for the automobile manufacturers.

In December 1973, I chaired a Task Force for the IBM Research Division to see what our division, our company, and the nation might do to mitigate the effects of the oil embargo and of higher fuel prices.

In 1974 to 1975, I participated in the American Physical Society Light Water Reactor Safety Study and became acquainted with the complicated conditions of flow which must be taken into account in the analysis of potential reactor accidents. In 1975 I chaired a National Academy of Sciences Study on the Establishment of a Solar Energy Research Institute by ERDA. At present, I am a member of the Federal Energy Administration Environmental Advisory Committee and of a Ford-Foundation-sponsored Nuclear Energy Policy Study.

In 1965 as a result of the Northeast Power Blackout I helped to begin IBM Research's study of large interconnected electric power systems.

In the mid-1960s I first had some contact with the US SST Program as Chairman of the Military Aircraft Panel and later in 1969 chaired a Special SST Review Panel of the Office of Science and Technology. A year or so later, I restudied the problem at the request of the relevant congressional committees and had a rerun this year in regard to the decision on landing rights for the Concorde aircraft. The problems now are those identified in 1969—airport noise, economics (especially fuel consumption), and technology, plus one more—the effect of exhaust gases in catalytically destroying the ozone layer.

We have problems. I think that if decision makers could see the future, they'd make better choices. And if the people who are watching the decision makers could see the future, then the decision makers would certainly make better choices. But where the future is murky, it's all too easy to choose one route or another because it sounds plausible or because it can be made to sound plausible. Even if the future cannot be seen in all detail, some candidate programs can be compared against others against some set of values. That would be useful. So we ask whether the future can be seen through computer modeling of the proposed systems. If not—if you say no—then how can we design systems with assurance? How can we choose a policy, whether a tax policy or military force structure, and have confidence in the outcome? If we can't model, how can we answer questions regarding reactor safety, worth of investment in fusion research, and so on?

People in the business have several approaches which are to some extent in competition. Some practitioners look down upon those who want just to simulate in fast time, using the computer as a kind of experimental prototype, which, started with assumed conditions and policies, will show more or less how things would be if these policies were in fact carried out. Many prefer to use some kind of automatic control algorithm in which one has not only some kind of model of the system, which might be a mathematical model in some closed form or a computer model, but in addition a procedure for restoring the system to some desirable state or for minimizing some loss function. But optimization without straight simulation seems quite inadequate, because of the need to show non-technical people—legislators, administrators, voters—how the *present* system is going to work or not work and how any alternative system will compare. So I think one is brought back to some kind of fast-time simulation even if one has a control algorithm, and one has to be able to handle people as well as machines in this simulation process.

EXAMPLES OF SYSTEMS PREDICTABLE BECAUSE CONSTRAINED:

Often in systems which are synthesized—artifically constructed—it is better to sacrifice some hypothetical efficiency in favor of assurance of costs of implementation, schedule, and reliability. For instance, take Personal Rapid Transit, defined here as having mostly four-passenger vehicles which traverse a city mostly on elevated guideways (this is all hypothetical—none of these exists). One has a problem in scheduling these vehicles, controlling them so that they don't collide, and in knowing and raising the saturation factor of the system (the fraction of the guideway that can be filled with vehicles moving at 40 or 60 miles an hour). In this case I think we ought to have initially a rather simple ("synchronous") control algorithm in which each of the vehicles normally follows a moving slot, a point in space which moves along at constant speed, and where the control restores the vehicle to that target slot. This is the analog of a lattice gas rather than a continuous mechanical system, and is obviously not an optimal control, but I think it's good enough. One needs bypass tracks for accelerating the vehicles and can bring them up to speed at an appropriate time to merge with an empty slot on the main track, and the same for transferring from one line to a line at right angles. I think one can get 60 or 70 percent occupancy by a quasi-synchronous control which limits long-range interactions by allowing limited transitions into adjacent slots. But what's more important, you could design and field such a system *now* so far as the control law is concerned, whereas experts in the field tell me there is no optimal control algorithm known. It will be several years before they can do what will satisfy them professionally, and I think that optimal control could be introduced later. So I think simulation of such a system (and of such an approach to system implementation) would show the merits of the approach I advocate, which is to constrain the design to make it controllable, to constrain the system to make it computable, and thereby sooner to realize the benefits of operation.

Similarly in air traffic control we published a report of the Air Traffic Control Panel of the President's Science Advisory Committee in 1971 (actually appeared in 1974) and proposed that one run the system with four-dimensional on-board navigation, where given a take-off time and a landing time each aircraft should follow a path in space as a function of time in order to show up to be handled routinely at its destination. So there would be very little real-time control required of the supervisory system; aircraft would handle their own navigation with respect to moving target points. In choosing such an approach one sacrifices. An aircraft cannot at all times make its maximum air speed because it has to track a point in space as a function of time, and so if adverse winds are felt the aircraft has to have some speed in reserve. Once again we sacrifice what might possibly be an improved system (slightly higher air speeds) for a system which is predictable and controllable. In this case the role of people (air traffic controllers and pilots) could be designed for efficiency and reliability. But overall social systems are different.

We reduce perhaps the ultimate efficiency of some social systems by reducing the information available, but may intervene less than in alternative societies. In the business sphere we properly forbid exchange of information among competitors. They set their prices independently, and that has been judged necessary if we are to maximize societal benefits and freedom. In other societies nominal competitors can exchange information and nobody cares because the price is set by the government. You have to choose one system or the other. You can't let suppliers pretend to have independent prices which are in fact not independent due to exchange of information.

The Northeast power blackout in 1965 involved an example of a large interconnected electrical power system. Such a system has tens of electrical generators, transmission systems, and thousands or hundreds of thousands of motors and other loads. Each of these generators or loads can be analyzed readily if it's working against some rigid fixed system, a given voltage at its terminals and near some design point. But how far this analysis, how far from stability the whole system was, was brought very clearly to our attention in 1965 when in New York City it was discovered experimentally that hospitals didn't have emergency lights; that La Guardia Airport carefully drew its power from three individual substations, all three of which were on the same electrical power grid and so the airport went black as airplanes were landing; that major generators in New York City had oil pumps for their bearings which were driven from the electric lines so that when the generator was coasting (grinding) to a halt because there was no electricity to run the pump, it couldn't resume operation for several months.

It's clear that a full analysis needs a lot of details, and that's really the subject of my talk—the degree of aggregation that one can use in describing the important aspects of a system. The level of detail goes to the moment of inertia of the rotating systems, the design of the governors and the steam throttles which drive the turbines. One might choose to require a "good citizen"—a kind of generator which is very stable and easily controllable when put into an electrical power net. And in doing this one sacrifices something overall—another example of increasing the margin of stability by sacrificing some potential efficiency. Since 1965 one has done other things; e.g., introduced load shedding and better communications in order to be able to keep systems from collapsing. What one needs to do first before one can *control* a system is to understand the consequences of the assumed systems. Then to improve the simulation and to improve the control really is inexpensive for these large systems relative to the benefits that can be obtained, but it may take time. For instance, if electric power systems run with about 20 percent spinning reserve, they have 20 percent more generating capacity on-line than is required to handle the load. If one has a load shedding system whereby there are customers who have agreed and who are not going to be damaged by shutting off their loads, then one can save spinning reserve and reduce capital investment in electric power system by a comparable amount, which could be worth tens of billions of dollars.

DETAILS ARE NECESSARY TO STRATEGIC PLANNING:

Take another and more current example which the Federal Energy Administration and its Environmental Advisory Committee have been assessing recently—to consider reducing the investment per unit energy consumed as electricity by spreading the use of electrical energy through the day. Several approaches include peak time of day pricing and peak load pricing. The task is to set a policy and create systems which will accomplish this result.

Let's look a bit more in detail what's involved with time-of-day pricing and spreading the energy load. This is a particularly interesting example, because it is likely to spread rapidly over the nation from those few locations where it has just begun to be practiced. Most important is to characterize the consumer. Hardly anybody knows what the householder or the commercial organization will do, even with present equipment, if there were a rate schedule such that electricity used in peak load periods costs much more than if off-peak. There *are* some loads with which we have experience, mostly electric water heating and those are usually run on timers. But in order to know how much benefit there is in this approach you have to characterize the consumer before and after education. If you just ask somebody on the street how much he would reduce his peak consumption if he were given a time-of-day meter he couldn't tell you. And probably wouldn't be able to tell you even after a short course in how good it is for society and how much it might reduce his costs. Having characterized the consumer, which requires some effort, one ought to assume a rate structure and then a tentative model should determine the consumption, the investment required, the profit, to see who benefits and how to apportion the benefit to the various sectors. And then one ought to recycle the rates, the kind of education, and decide whether this is a promising approach. Then one ought to do *experiments* with consumers to refine the structure and parameters of the model. How much would it cost for meters which will do peak-hour metering, provide remote operation of disposable load, and allow instantaneous pricing for optional loads? A customer who would like to use some equipment at a certain time of day could benefit from a meter telling him how much it's going to cost. And it might be much more expensive to dry the clothes at 4:00 p.m. than at 7:00 p.m. (or than at 4:00 p.m. on some particular and unpredictable day) especially if one is dealing with a nuclear power system where base load electrical energy comes reasonably cheaply but peak load is expensive because capital cost is high.

Who needs this kind of simulation? Utilities, Public Service Commissions, the Federal Energy Agency, manufacturers of all this equipment, the Congress. In fact, the people who make the policy and decide the investment structure need it most and earliest. But you don't have those answers until you do the detailed simulation, and a poor decision as to aggregation in this modeling may seriously impair the value of simulation.

SOME EXAMPLES OF CARE IN AGGREGATION:

There are simple examples of systems which are different if one aggregates supposedly identical elements of the system. One spring and one mass result in one resonant frequency. Two springs and two masses (identical), uncoupled, still have nominally one resonant frequency, but if there is any coupling there are two resonant frequencies. There is a splitting of the degeneracy into two eigenmodes which have different symmetry. This gives the possibility for instance of damping the antisymmetric mode without introducing damping of the symmetric mode and that's a way in which one could in fact in a *physical* system aggregate, that is put in more units of mass and spring without perhaps introducing instability. But there are different ways of stabilizing systems. For instance, if we take the example of two identical generators, which might have some instability of this kind when feeding a single load, one might introduce small signal stability with linear damping elements which are always in place, interconnecting the generators. If the generators get slightly out of phase currents flow. But these small signal elements, called upon to handle only rather small currents and voltages, might be overloaded if there were a large impulse. If one of the generators stopped one could burn out this damping element. The system could fail. So a problem in designing such a system is to understand the cost of this damping—of the thing which allows you to treat two generators as one, or two masses as one. As an alternative, one might allow the small signal instability, replacing this coupling at small signals by a threshold stabilizer which sees when the generators or the masses are sufficiently far out of phase and which can handle large currents easily because it's not doing anything most of the time. The dissipation of the two approaches is different; the cost is different.

This problem of aggregation arises even in simpler systems. Suppose you have a gas producer and a gas consumer, with consumption not perfectly matched to the production. Storage is indicated. So you put in a balloon. You can imagine a balloon which fills during the warm weather and contracts during the cold weather because of the gas being used to heat houses. The balloon is a perfectly reasonable thing. It may even save some money. Suppose now you have more producers and more consumers and want to double the storage capacity; it's a natural thing to put two balloons on that same pipe. But the result may not be what you expected. Two balloons next to one another do not grow and shrink at the same time. In fact when the two balloons are used one shrinks to nothing and the other has all the gas in it. That happens not only with rubber balloons but with soap bubbles, and there are several ways to avoid it. One could have a mechanism controlling inflow or efflux from the balloons so as to feed them equally; one could have mechanical coupling between them; or one could allow one balloon to fill and then use the other one, but means would be needed to keep that one balloon from overfilling. Thus although no problem is introduced by the aggregation of treatment of the gas molecules, balloon-type reservoirs cannot be treated in the same manner.

We want time-of-day pricing for electrical energy in order to have some social goal achieved by the individual actions of the consumers. If there were only one consumer, it would be easy for him to assess the consequences of his using electrical energy whenever he wanted it. He would see it was cheaper for him to spread his usage because he is the only one who pays for the investment in electrical generating capacity. He would make those adjustments to his consumption, in order to obtain the social benefit, because for a single consumer by definition the social benefit is all going to be his anyhow. Individual consumers of a public may see the facts. They may understand the theory. They may see the instantaneous load. But they may still reckon a short-term advantage over other consumers and even a relative long-term advantage by not doing what we would define as the socially desirable course. And that's why we need the signals that come from a price system which reflects total costs. Perhaps formerly religion in a rather homogeneous society induced individuals to behave in a way so as to maximize a particular overall social benefit. But Gresham's Law at times takes precedence over religious law, and people with identical interests sometimes see that their local interest, local in time and space, is more toward taking from their colleagues than in maximizing the overall social good.

ENERGY POLICY AND THE NEED FOR SIMULATION:

To consider aggregation in reactor safety and how one might perhaps modify reactor design in some ways to make them easier to compute and therefore easier to certify as safe would exceed the time available. But I would like to discuss overall energy policy. In the middle sixties it was perfectly clear that one had options of quotas, tariffs, some choice of methods to limit or to increase US dependence on foreign oil or US consumption of foreign oil. The economic incentive was for this country to use low-cost oil from Saudi Arabia. It comes out of the ground at a cost of 15 cents a barrel, I understand, rather than the higher cost of US oil, which may cost \$2-\$4 per barrel to produce. In fact as one looked decade-by-decade into the future both the economic and the strategic incentive was to exhaust foreign oil first so that we would have our own oil left. On the other hand, also from a narrow US point of view, we wanted to avoid dependence on foreign oil so that in wartime or in case of other embargo we would have fuel to run factories, cars, and the like; so that we would have a current energy source. At that time my solution to this problem was to do more extensive drilling in this country, so that we would have enough production *capacity* to supply the instantaneous demand. These wells should then be produced at a low rate so that they would last for a very long time. My proposal was to have adequate refining capacity in the US to handle all US consumption. This would provide strategic reserve in the ground, would provide the production capacity, and thus would provide guarantee against arbitrary increase of price by the suppliers. The argument against this was that it would cost some billions of dollars to create this "excess" production capacity. And clearly from that point of view it should have been done rather than to get ourselves into the present pickle. But it wouldn't have helped of course at all in the long-term energy picture.

In the fall of 1973 came the Arab OPEC embargo followed by high prices, which have nothing to do with the embargo. The suppliers just see it in their interest to get more money for the goods which they have to sell. This brought into existence the Federal Energy Office and a lot of complicated regulations. Also initially long lines at gasoline stations. Unfortunately, my understanding is that we still have no policy in this country to deal with the energy problem, either short-term or long-term, except high price. High price is to my mind a tool and not an end, although for people who have oil to sell it may be an end.

What I want to do now is to look at some aspects of US national energy policy and show some of the hazards and perhaps indicate some means to improve what we're doing. The decision to restrict gas station operating hours in the fall of '73 rather than to ration gasoline didn't take into account the overall social costs involved. It did make consumers believe there was a problem. And there *is* a problem. There is a second problem of assurance of supply. There is a problem of long-range energy supply for this country. But this latter terrible problem I think isn't the one that people usually consider.

Let's look at one aspect of energy policy, at the regulations which set the price for old oil. This said that old oil (which is oil from fields which were in production before 1972) could be sold at not more than \$5.25 a barrel, and the same regulations decontrolled new oil, which sells for about \$11 a barrel.

Furthermore the regulation stipulated that for every barrel of new oil produced, the producer was entitled to release a barrel from control and to sell it at the uncontrolled market price. That's history. The Ford Administration wanted to decontrol the price of old oil as well as new oil, and argued that there would thus be a greater incentive to produce more oil. I'm discussing this specific question in the context of setting policy and I'm talking about understanding the consequences of different candidate policies. It is easy to show *without* a computer model that the consequences of the Administration policy are very different from what was claimed, and therefore we ought to do this kind of modeling in a serious and objective way in order to evaluate candidate proposals and to select one which works. But it's clear that under the old regulations to provide a barrel of new oil and sell it at $11 a barrel (and as a consequence be able to release a barrel of old oil and sell it too at $11 instead of $5 a barrel) amounted to an incentive of $17 per marginal barrel of new oil. Under the decontrol proposal the marginal incentive would have been just $11. (Less the same costs in both cases, of course.) You produce a barrel of new oil, you sell it at the market price; that's it. Under any reasonable model of behavior of producers, decontrol would have produced windfall profits on old oil. I'm not against profits; I'm not even necessarily against windfall profits. But that wasn't the stated purpose of the policy change. The purpose was said to be to create a greater incentive to produce new oil, and it would not do that. It would have *reduced* the incentive to produce new oil.

The point may be moot now because of recent legislation which mandates an average price for new and old-oil. I don't think anybody knows what the incentive is as a consequence of this legislation. I raised this point in a September 1975 discussion paper for the Environmental Advisory Committee. [This is a committee under the Federal Advisory Committee Act and so our meetings are attended by the press, by industry, by anybody who wants to come to observe the Federal Energy Administration Environmental Advisory Committee. The audience can send us propaganda or nasty letters, as the case may be. So I feel no reluctance in sharing with you the contents of this paper.] I raised these questions as to the incentive in the Administration decontrol proposal and found pretty general agreement among economists in this country and even among FEA staff. So the question is how we get a policy or a policy proposal from FEA and from the Administration which does what it is supposed to do.

WHAT'S GOOD ABOUT HIGH PRICES?:

Let's look ourselves at the purpose of high prices. There are, so far as I can see, three benefits that have been ascribed to high oil prices. The first is that they would call forth alternative energy sources, for instance synthetic crude oil from coal, gasified coal, solar energy, and the like. The second is that they would provide capital formation to all the necessary investment to produce more oil or these alternative energy sources. And the third good is that they reduce demand.

But if you look at these three benefits, only the third is unambiguous. High prices really do reduce demand eventually; the short-term elasticity may be fairly small, but the long-term is I think pretty big. But this reduction of demand could be done equally well by a product tax, and so there is an alternative. Don't raise the price of oil to the producer necessarily; raise the price of oil to the consumer if you want to reduce demand. And the choice between these alternatives should have been made on an informed basis.

The second argument for capital formation is questionable in principle and in practice. In principle because that's not the way you get money to do something in this country. You have a prospect which looks good to investors, you sell stock to get equity capital, you borrow money, and you're in business. If only those who are already in the business can get capital to expand production or to go into alternative energy sources, that's in principle a bad thing and changes our entire system of operation in this country. In practice it doesn't work either, because Mobil in 1974 put almost a billion dollars of its money into the purchase of Montgomery Ward (MARCOR). If there's a big capital shortage in the oil companies, why didn't Mobil put that money into expanding production of oil or into alternative energy sources? So I say the second reason for high prices is at best questionable.

The first reason; namely, to call forth alternative sources of energy, would be available equally well under high product prices produced by a tax, but it is not available really under a decontrol system where the price of oil is set by an extralegal cartel—by OPEC. No US law that I know of keeps OPEC foreign countries from setting any price that they want. And there is no law or custom which keeps domestic producers from charging that same price. That's their option. They can't charge a higher price because Saudi Arabia has plenty more oil to sell and we wouldn't sell any here. They don't want to sell at a lower price. They can sell anything they can produce right now at the OPEC price, and that will be the case until potential domestic energy production could satisfy US needs. The problem with bringing forth alternative sources of energy like synthetic crude and coal gasification and solar energy is that there is no guarantee that energy in the future will sell at this high price, and in fact if the whole world goes over to solar energy (let's fantacize) at $5 per barrel equivalent, then the oil producers are not going to sit there and not sell their oil at all; they will lower the price. They may lower the price enough to put these alternative sources out of business. This is a major reason why you don't see much investment in these alternative sources. So whether or not there is twenty years or forty years of oil left, oil producers and other investors have much more incentive at present to put their money into more oil and to exhaust the supply faster than into coal-based gas or synthetic crude. The incentives are not there under this system (even if the money is) to call forth alternative sources of energy.

There are other problems with our policy and regulations. These problems are ones which were predictable and have not yet necessarily been observed, but I feel that they are there and will come to light. I raised some of them in December 1973, claiming that this two-price system for oil without vastly larger civil and criminal penalties would lead to various peculiar operations. For instance a tanker could load with old oil in Texas at $5 a barrel and it could arrive in New York, perhaps stopping at some intermediate port, with the manifest reading: Libyan oil at $11 a barrel. Instead of earning 50 cents a barrel for transporting the oil, a 50,000 ton tanker thereby earning $250,000 for the trip, it could make almost $6 a barrel and earn $3 million for the trip. Has this happened? I don't know. I don't think businessmen in general are dishonest, but the opportunities here are so high that honest businessmen will be bought out by fronts or by would-be criminals in view of the small fines that could be imposed for such activities.

HOW DETAILED THE MODEL?:

So in my opinion a model has to be sufficiently detailed (disaggregated) to make provision for such activities. Need we include all the 200 million people in this country in a fast-time computer model? We certainly don't have to include every barrel of oil, because the oil can be aggregated into tanker loads at least. People cannot be, because you don't know which person is going to be the entrepreneur who has the idea which is going to put the system on its ear. It is the possibility of exercise of free will which is the problem of modeling people.

Let's first look at the producing sector and ask to what extent that could be aggregated in a model which would be suitable for testing candidate national energy policies. We would have to be careful not to mask by aggregation qualitatively or quantitatively important effects. If I have two balloons and I say they are equivalent to one balloon, without making sure that they *are* equivalent by stabilizing the system, I would get a very wrong answer. And if I put all of the production together into one producing sector, I think I will get a very wrong answer. So I'll have to consider separate producing sectors. I'll have to consider first major domestic oil producers with large oil supplies abroad. Their behavior is likely to be different from a second group of major domestic oil producers with little foreign oil but maybe with large coal holdings. And a third group: coal producers. And a fourth group: potential coal producers—organizations with money, credit, and management talent. It may be that this last group is most important to the goals of Project Independence. But I don't know because such detailed modeling has not been done.

It's rather a big thing to specify such a model and to write such a model. The Federal Energy Administration has a model called the Project Independence Evaluation System (abbreviated "PIES"), formed by bringing together sub-models from all over the government and academic institutions. The results of the model are available and have been criticized by a number of groups. My September paper was a partial criticism for unwarranted aggregation and for inconsistent assumptions. For instance, arguing that the decontrol of old-oil prices will have very little effect on overall energy costs (because natural gas is price controlled and the coal is mostly under long-term contracts) is inconsistent because it was the policy of the Administration at the same time that it was pushing for decontrol of oil prices to push decontrol of gas prices. And so you have to assume some coherence. If you succeed in one decontrol, you are likely to succeed in the other. Inconsistency in regard to the coal long-term contract, because for instance it was just at that time that Westinghouse told utility customers that had firm contracts to buy uranium from Westinghouse at about $10 per pound that it would no longer supply uranium at this price because the overall exposure to Westinghouse would be about $2.5 billion if it had to fulfill those contracts over the next several decades. For the FEA, knowing this, to rely on the sanctity of the long-term coal contracts seem to me to be disingenuous. Maybe ingenuous.

IMPORTANT SECTORS IGNORED:

There are some other sectors of society which have to be included in any model. These sectors exist; they're important because they get paid lots of money; they're visible in the newspapers, and yet they don't show up in the model. For instance, lawyers. If it's important to pay lawyers, it's important to model lawyers. What is the influence of the legal profession and the courts in energy policy? Criminals—some grain inspectors in Baton Rouge have been indicted recently and charged with taking $67,000 in bribes, which reduces the value of shipments by many millions of dollars because of the loading of imperfect grain. Such actions have a big effect on the system, like termites boring invisibly at the foundations. And the model ought to include them.

Now it's very hard for the systems analyst to be as clever in all the same ways as lawyers on the one hand or criminals on the other. And so you can't rely exclusively on the model designer. Economists don't really have the necessary bent of mind. It seems to me what one has to do is to have a model such that there is room for human initiative. There could be some terminals operated by people who are motivated. Perhaps college students, undergraduates, are the best ones to be paid (in fact you don't probably have to pay, they'll pay you) to act the role of an imaginative criminal. Law students can be asked to show how by delay they can postpone the imposition of penalties until they make no difference. It is very important for the people section of models to be disaggregated to the point where these important sectors can be included.

Now how about people in general? Maybe some people are going to not pay their income tax and other people are going to have great ideas for founding companies. Do we have to model every person in this country, N of them where N is 200+ million with a Monte Carlo probability of P (where P is very small so that PN is a few) in order that we be able to catch these few important events? Of course not! So long as the interest is in a few rare events and not in a coincidence of rare talents, a different sector can be included in the model, (a criminal sector or an ingenious sector or the like) where the number of individuals N is reduced by a factor F and the Monte Carlo probability P increased by a factor F, so that the event rate of the extraordinary events remains the same.

CONCLUDING REMARKS:

I've touched on the problems of aggregation in modeling electrical power systems; on balloons and gas storage; on time-of-day charging, and the details which have to be considered before you can be sure what that's going to do; on national energy policy. The same detailed modeling is probably necessary to the setting of tax policy, of educational policy. Having listened to simulation proponents and to automatic control proponents and to those who think that if everybody is just better educated we will automatically arrive at a better country, I think that among our realistic choices it would be very useful to have more simulation, more understanding of what happens, more testing of candidate proposals and policies against the discipline of computer simulation. These simulations ought to be a lot less aggregated than they are and should make provision for real-time interaction with ingenious people who don't know anything about computers but who have good ideas how to manipulate the system eventually to their own advantage. Finally, a simulation should be presumed defective which does not model the behavior of a sector of society which figures importantly in the real world.

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