The Importance of Feedback in the Pacific Northwest Electric Conservation Planning Model

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ABSTRACT

This paper describes the importance of feedback loops included in a policy model constructed for the Office of Conservation of the Bonneville Power Administration (BPA). First there is a description of the region and the responsibilities for conservation planning at the BPA, and then a description of the purpose, structure, and use of the policy model. Several feedback loops involving customer response to higher electric rates are selected for our discussion of feedback. The system dynamics treatment of these feedback loops is contrasted with the treatment found in most electric utility planning models used in the USA. The paper concludes with an assessment of whether the inclusion of feedback has been important in BPA's application of the model.

INTRODUCTION

Electric utility companies in the USA have become increasingly interested in information and subsidy programs to encourage their customers to invest in conservation. Conservation programs are viewed as necessary to overcome market obstacles that limit customer investment to improve the efficiency of electricity use. Utility programs include general information such as advertising, specific information such as audits, and direct financial subsidies such as zero interest loans. Utility conservation programs are often viewed as a better use of company funds than investment in conventional coal or nuclear power plants (Bryson and Elliott 1981).

Nowhere is interest in conservation programs stronger than in the Pacific Northwest. This region is unique because of its vast hydro-electric resource which permits the lowest electric rates in the country. Because of historically low rates, the region's homes and businesses have not made the same level of investment in conservation as in other parts of the country. Thus, the potential conservation savings available at relatively attractive costs is quite large (Council Plan 1983). The Pacific Northwest is also uniquely organized to plan for the orderly development of the large conservation resource. With the passage of the Pacific Northwest Electric Power Planning and Conservation Act in 1980, this region organized itself to plan the development of all the region's electric resources in a co-ordinated manner. The Act created a Planning Council with members from different states and the responsibility for setting broad policies. The Act created and directed substantial new responsibilities for the BPA to help in the implementation of the Council's policy. The Act also called for the Council and the BPA to give highest priority to the acquisition of conservation savings in planning for the electricity needs of the region.

During the period from 1981 to 1983 BPA greatly expanded its conservation planning and program implementation capabilities. At the same time the Council launched a two-year planning process culminating in the adoption of the Regional Plan in early 1983. Due to the challenges involved in these new responsibilities, both entities spent considerable effort on developing resource assessments and tools to characterize the effect of conservation and other resources for power planning purposes. For conservation planning at BPA the work was concentrated in two primary areas of development: (1) building program offerings based on the experience of utilities in the region with residential retrofit programs; and (2) using preliminary assessment data to represent the regional conservation potential within the evolving corporate planning models. Conservation supply curves were developed based on existing end-use assessments and structured so they could be reconciled with both the end-use load forecasts and the resource acquisition model for system expansion planning.

These modeling efforts generated three difficulties for conservation planning. First, the conservation models were based on detailed end-use assessments and hence were very cumbersome to use. Also, existing corporate end-use demand forecasting models were not suited to retrieve the effects of alternative conservation programs and policies. Second, none of the initial conservation modeling had the capability to easily or practically model the effects of BPA conservation subsidy strategies or program timing decisions. Finally, the desk top analysis that was done for early program designs was inadequate to answer questions about the ultimate system impacts of programs, or potential tradeoffs among programs.

Therefore, in 1983 the BPA Office of Conservation initiated a study to improve its ability in modeling the effects of its conservation programs and consumer subsidy designs for the Pacific Northwest regional electric power system. The model was to provide ready access for program planners and analysts alike, build from the results of running existing models and databases, and provide quick analysis of many scenarios, while preserving general consistency with actual system planning and operations.

THE MODEL

The model is known as CPAM, the Conservation Policy Analysis Model. CPAM is a system dynamics model with around 2,400 variables, about a third of which must be specified by the user. BPA staff operate CPAM on the Dartmouth College computer with the help of a user interface program which provides English language prompts about the variety of policies that may be tested, scenarios that may be assumed, and outputs that may be requested. The first version of CPAM is known as the Regional Model because the loads and resources of the Pacific Northwest are treated as if they were under the control of a single utility. Further information on CPAM is given in the summary paper by Bull (1984), the working notebooks prepared for the Office of Conservation (Ford, Martinez, Naill, Geinzer, and Wood 1984) and in a recent analysis of conservation policy in the Pacific Northwest (Ford and Naill 1985).

Figure 1 shows the Regional Model along with the special programs that have been constructed to facilitate the model's use at the BPA. These include the "user interface" which assists the user in setting up new simulations, the "LOTUS pre-processor" which translates cost and savings information on thousands of individual conservation measures into conservation cost curves for different end uses, and the "documentor" which generates a documented listing of the equations and variable definitions. CPAM is comprised of 5 sectors which represent different aspects of the region's electric system. Each of these sectors is designed to "mimic" on a very simplified basis the existing corporate models which BPA uses to do its overall resource acquisition planning and financial analysis. The most important sector is the conservation and electricity demand sector which is highlighted in Figure 1.

This sector simulates the utility customer's investments in conservation measures (and the electricity sales and conservation savings resulting from those investments) both with and without conservation programs. Here the model's forecasts have been calibrated to BPA's annual load forecast, using relatively gross assumptions about sectoral growth rates. Simulating projected electricity sales with and without a specified conservation program determines the net conservation savings from it, taking into account all the effects of the system's feedback loops on electricity demand and conservation. The demand sector has a great deal of structure that allows the testing of different types of program designs, and different subsidy levels, for 13 different end-use service categories.

The price of electricity needed in the conservation calculations is generated in the price regulation and construction financing sector. This sector mimics a simplified version of the ratemaking practices of the region. Rates are based on the annual costs of operating the hydro-thermal system and the return allowed on the utility company's investment. Operating costs are tracked in the hydro-thermal system operation sector which dispatches the region's thermal power plants and hydro-electric units, keeps track of the amount of interruptible load to be served, and keeps track of the secondary sales to utilities in California. The utility's assets are represented in the capacity and assets accumulation sector which performs most of the bookkeeping functions of the model. Decisions on the timing, magnitude, and type of generating capacity to add are represented in the capacity expansion sector. Investment in new generating units is determined endogenously, based on an internal forecast of demand growth and a comparison of the levelized bus-bar costs of the generating options available.

Figure 2 shows the model's base case projection of regional electric load used in a recent analysis of conservation policy in the region (Ford and Naill 1985). This projection combines the effects of the assumed growth in the region's economy, the customers' response to price changes, and the customers' additional response to BPA's current program to subsidize customer improvements in the efficiency of electric space heating. Figure 3 shows the model's base case projection of capacity additions needed to keep

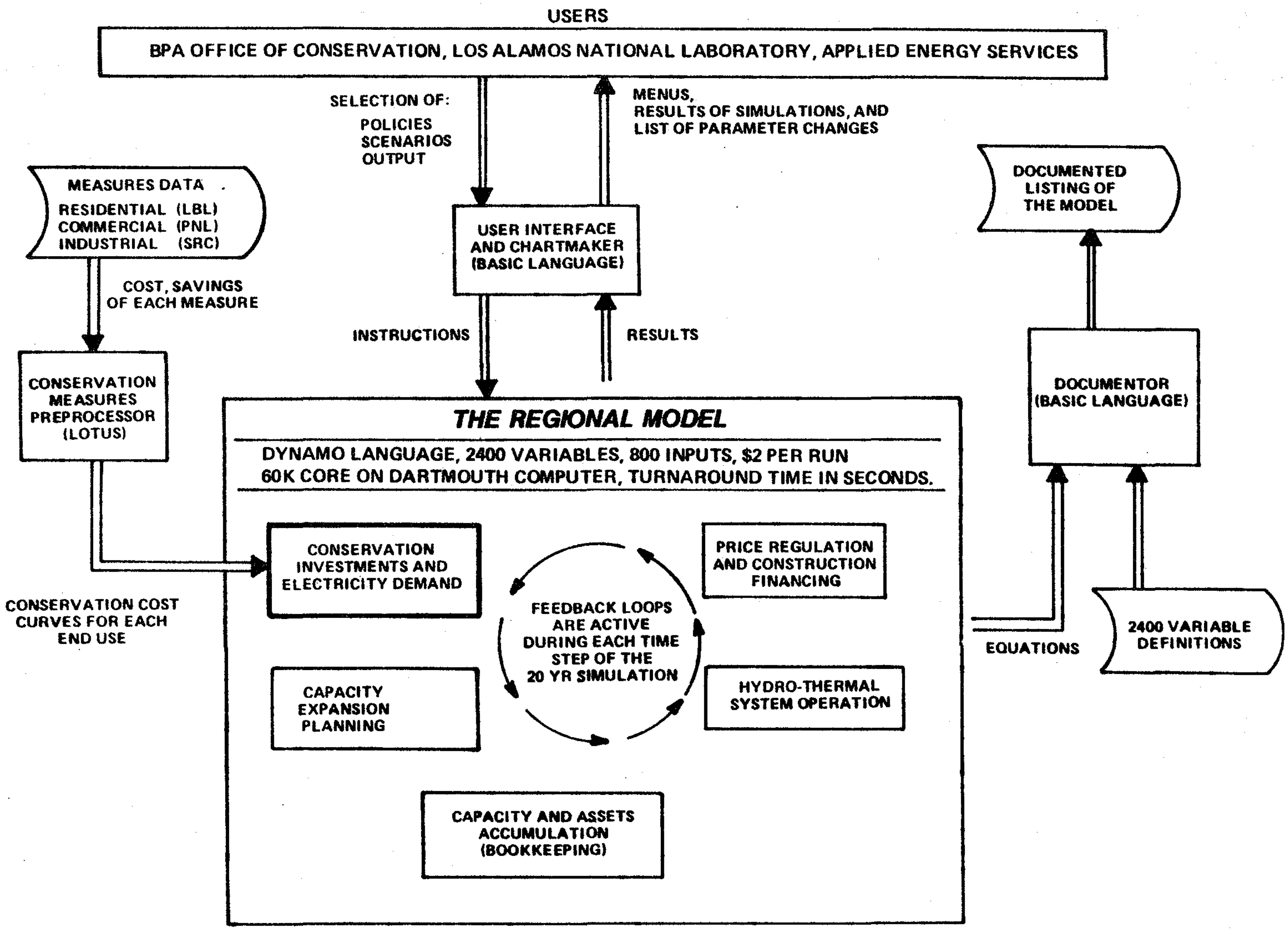

Figure 1. The Regional Modeling System.

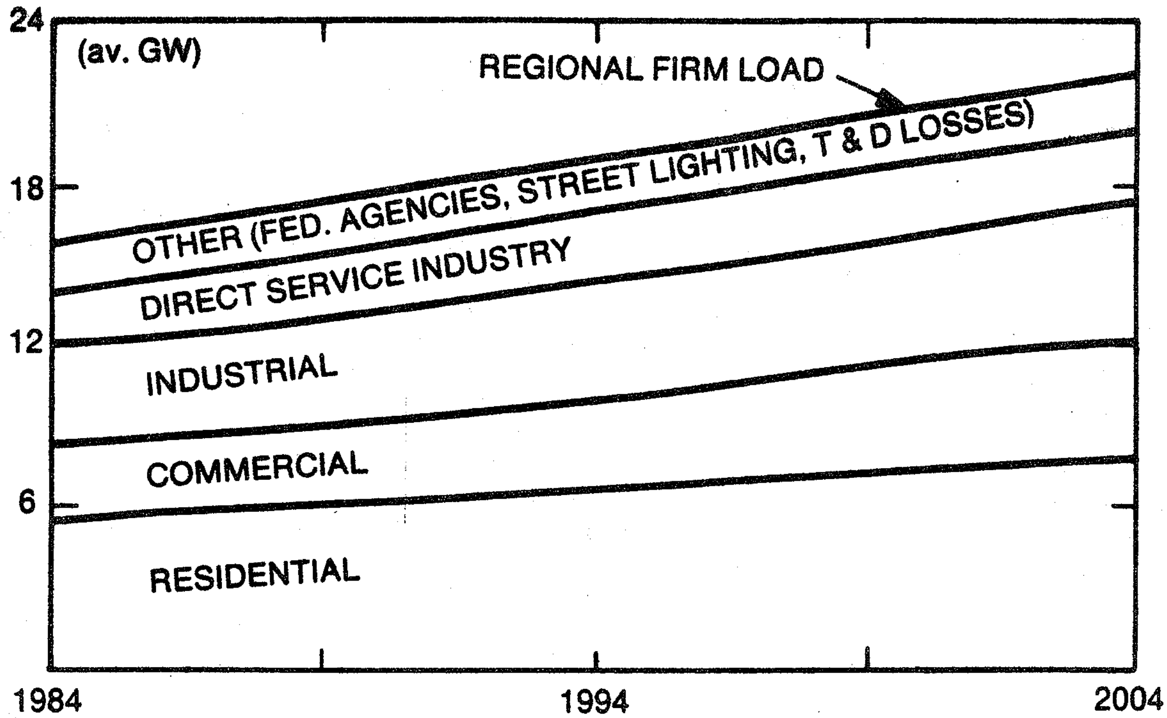

Figure 2. Base Case Projection of Regional Electric Load.

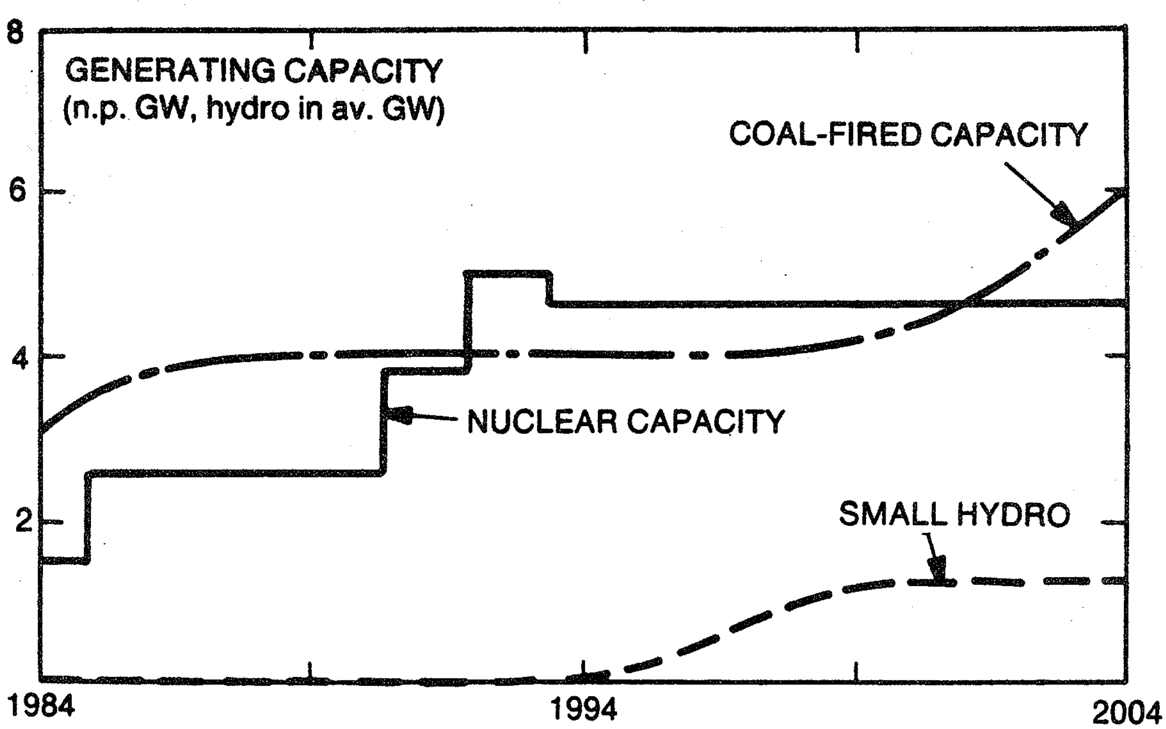

Figure 3. Base Case Projection of Capacity Additions.

pace with the load growth. The discrete changes in nuclear capacity occur at the user specified dates for completion and retirement of the region's nuclear units. Small hydro and coal capacity are determined endogenously, based on resource assessment data from BPA. The small hydro resource is developed first because the base case assumptions allow for about 1.3 GW of small hydro capacity that is more attractive than new coal plants.

In a hydro dominated system, such as that in the Northwest, the relative balance between the loads and resources is often summarized by showing the surplus that would exist under critical hydro-electric conditions. Figure 4 shows the model projections of a regional surplus to remain until around 1996 under the base case assumptions. The long duration of the surplus is responsible for the model's reflection of a long period of low avoided costs shown for the base case in Figure 5. During the first 8 years of the planning period, for example, the avoided cost is equal to the estimated secondary sales rate charged to utilities in California. (If electricity demand were to be reduced by 1 kwhr, it is expected that the region would continue to operate its hydro and nuclear units as before and sell the extra 1 kwhr to California. Total production costs would be unchanged; net production costs would decline by the secondary sales rate.) Figure 5 shows that the avoided cost would increase later in the simulation as growing loads force the region to first invest in small hydro facilities, and then in new coal-fired capacity.

The base case results shown in Figures 2-5 provide a point of departure for the analysis of conservation subsidy programs. Any one of a variety of proposed conservation strategies may be tested through direct simulation, and the overall effects are summarized in terms of simulated changes in the resource plan, electric rates, financial indicators, and the region's "total system cost." The most extensive analysis to date has shown that new programs are likely to be successful in reducing the "total system cost" (where the cost of the customer's investments in conservation measures are combined with the monthly bills from the electric utility). This is a key finding because of the importance placed on "total system cost" by the Act, the Regional Planning Council, and the BPA. A problem with introducing large new programs, however, is that they tend to increase the average electric rate over the planning period. Previous analysis has shown that conservation planning is made difficult by the conflict between two worthy goals--reducing total system costs and avoiding electric rate increases (Ford and Naill 1985). Depending on how the rate increases on different groups are weighted, one might adopt a variety of conservation strategies ranging from discontinuing current programs to the initiation of new programs which could acquire five times as much electricity savings as the current weatherization program.

ANALYSIS OF CONSERVATION PROGRAMS

The principal application of CPAM is to test the effectiveness of conservation programs in the region or utility service area.

Figure 6 shows how conservation is calculated in the Regional model. With no conservation programs, the model projects conservation induced by price effects alone; the addition of conservation programs enhances price-induced conservation. The model therefore can be used to project net conservation

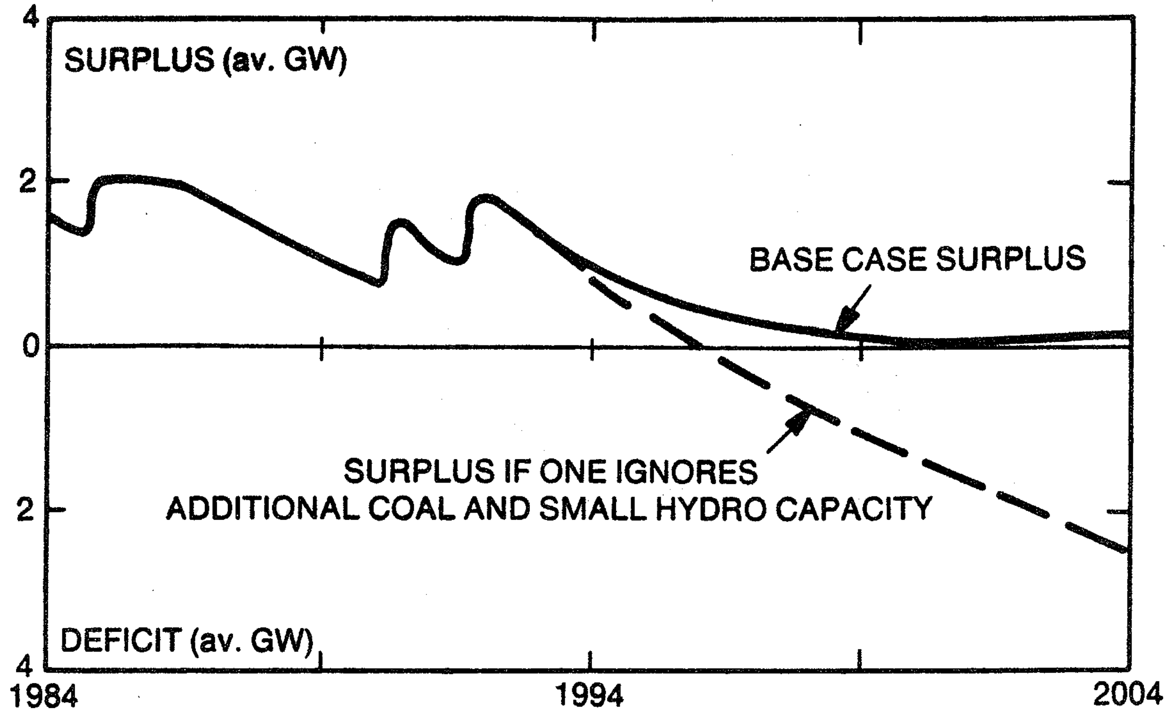

Figure 4. Base Case Projection of Capacity Surplus.

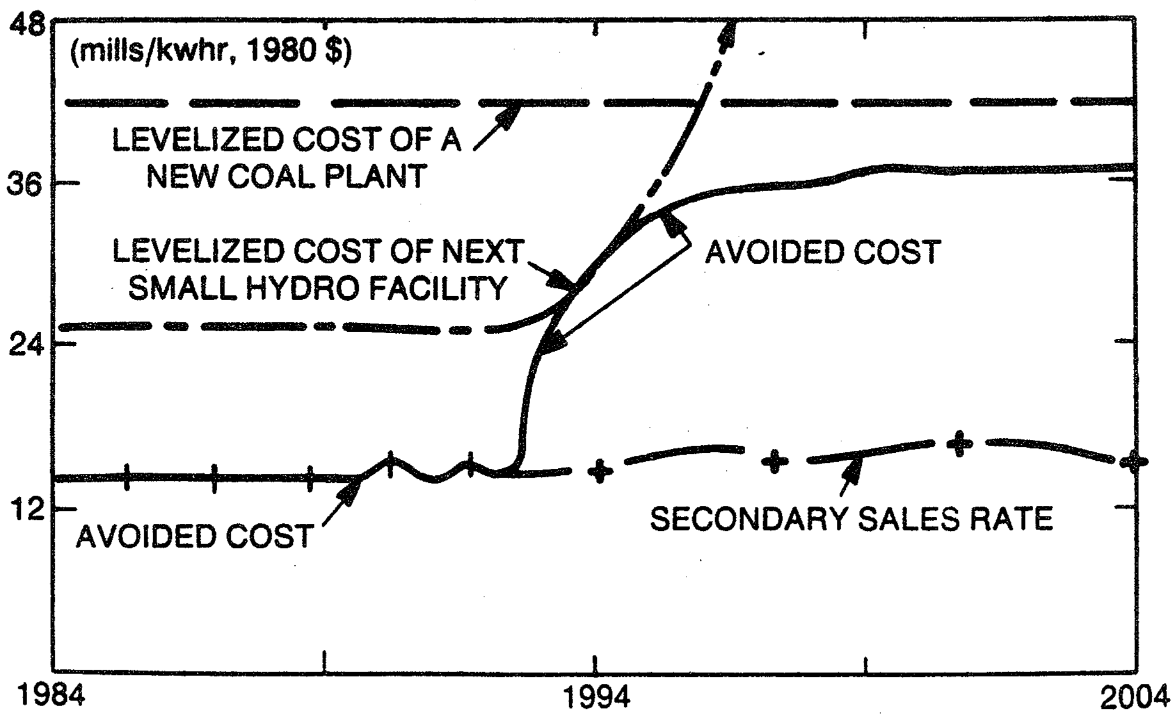

Figure 5. Base Case Projection of Avoided Cost
of Electricity Generation.

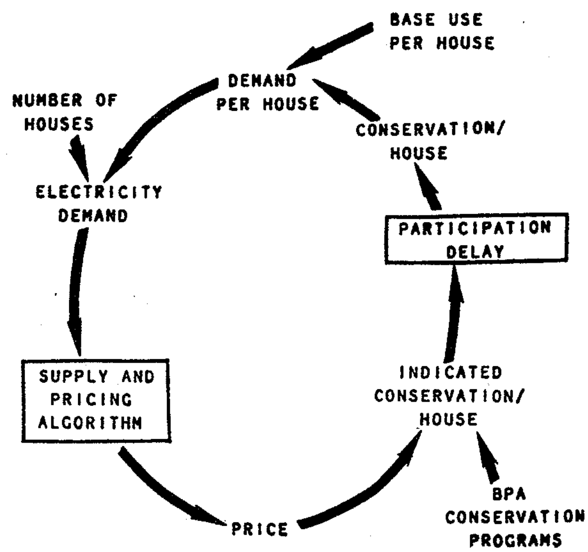

Figure 6. How Conservation Is Calculated in the Regional Model.

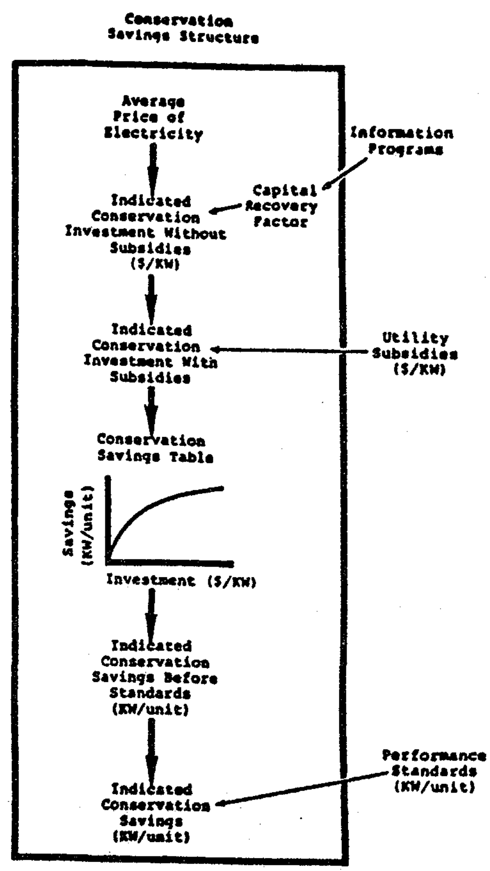

Figure 7. How Conservation Programs Are Included in the Model.

savings, measured by savings from conservation programs in addition to those savings that might occur without the programs (from price alone). For conservation programs, net conservation savings are an appropriate measure. This measure takes into account a program's redundancy: the fact that customers may purchase some conservation measures subsidized by a conservation program even if the program never existed.

The rest of the structure in Figure 6 accounts for the dynamics of conservation savings -- how conservation savings change through time. For retrofit programs in existing buildings, there is a delay or lag between indicated conservation savings (which is determined by price and conservation programs) and actual conservation per house. This delay represents the rate at which customers participate in the proposed programs (it takes time to achieve significant participation rates for any program). With no programs, it is assumed that consumers participate in purchasing conservation measures by replacing old equipment with new equipment as the old equipment wears out. The model calculates total demand and conservation by multiplying conservation and electricity use per house by the total number of houses in the region.

Figure 7 shows in more detail how indicated conservation is determined, and how conservation policies and programs are accounted for in the Regional Model. Consumers are assumed to move toward an indicated level of conservation investment, measured in first-cost dollars per average kilowatt saved, according to the current price of electricity and their financial criteria for such investments (as determined by the capital recovery factor based on their presumed discount rate). Consumers are assumed to make investments until the annual cost of these savings (the cost/kWh of the savings from the conservation measure) equals the price of electricity. Data on costs and savings for conservation measures are used to calculate the amount of savings that can be purchased from a given amount of conservation investment.

Figure 7 also shows how conservation programs affect savings in the Regional Model. Three generic types of programs can be represented in the model: information programs (audits for example), subsidies, or performance standards. Information programs affect the decision criteria consumers use to make their investments, but not the costs of the investments. For example, a good information program might lower the risk and uncertainty associated with conservation investments, thereby lowering the hurdle rate for such investments. Subsidies add directly to consumer investments (or subtract from the purchase price of conservation measures), increasing the amount each consumer is willing to invest. Performance standards determine a minimum level of conservation measures that must be purchased by consumers.

The Regional Planning Council's 1983 Northwest Conservation and Electric Power Plan estimated the economic potential for conservation savings in the Northwest region, based on conservation savings costing less than 4 cents/kWh (in 1980 dollars according to utility cost accounting). For residential space heating in existing houses, this economic potential was estimated at 615 average Megawatts (Mw) at 4 cents/kWh. Newer data on the potential amount of conservation in the Region indicates that this economic potential may be larger than originally thought in 1983--as much as 1,220 average Mw, almost twice the Regional Plan's initial estimate of 615 Mw.

	2004 CONSERVATION SAVINGS
INDICATED SAVINGS (Base Case; 3.6 cents/kWh)	1075 Mw
REDUCTION IN SAVINGS DUE TO:	
PARTICIPATION DELAY	-340 Mw
REDUNDANT SAVINGS (SAVING WITH NO PROGRAMS)	-336 Mw
SECONDARY EFFECTS	
Rebound Effect	*
Price Feedback	-6 Mw
Cost Escalation	*
Interfuel Substitution	*
Worn-Out Measures	--
NET CONSERVATION	393 Mw

(* these effects are not included in the Base Case projection.)

Figure 8: Summary of Conservation Savings in the Base Case (Residential Space Heating in Existing Homes)

The Regional Model starts with the costs and savings of individual conservation measures that add up to this 1.2 Gigawatts as input data, and attempts to calculate how much of this conservation potential will be realized with the different conservation programs. Figure 8 summarizes the Regional Model's projection of conservation from the Base Case conservation programs (a projection of conservation from the Base Case program, i.e., a residential weatherization program paying 75 percent of the cost of qualifying measures). With Base Case programs, conservation measures costing up to about 3.6 cents/kWh might be purchased, according to the model's calculations. These measures would result in 1,075 Megawatts of conservation savings by 2004 (88 percent of the economic potential at 4 cents/kWh).

Yet not all of these indicated savings are realized as conservation by 2004. First of all, the program is not projected to result in full participation by 2004--not all homes are expected to participate in the program and install the measures. The model projects about a 70 percent participation rate for the Base Case program by 2004, resulting in a reduction of 340 Megawatts from potential or indicated savings. Second, some of these savings--the Regional Model says about one-third of indicated savings (336 Mw)--might occur anyway even without the conservation program. These 336 Mw are referred to as redundant savings in Figure 8 (savings that might occur with no programs). Finally, secondary effects--for example, the rebound effect, price feedback, cost escalation of conservation measures, interfuel substitution or the effect of worn-out measures--can further reduce net savings from a conservation program. These secondary effects are reactions caused by the savings themselves that work to erase some of the savings. For example, conservation programs might cause customers to turn their thermostats up because they can now afford more comfort. This reaction offsets some of the program's conservation savings.

Figure 8 shows that these secondary effects are either small or excluded in the Base Case projection. For example, price feedback reduced net savings by only 6 Mw (1 percent) in the Base Case, because the price effects of the conservation program were small (about 2 percent at most). The potential impacts of the other secondary effects were either purposely turned off (the rebound effect was turned off; it was assumed that worn-out measures were replaced) or ignored (cost escalation, interfuel substitution). Later versions of the Regional Model will explore the importance of these secondary effects more completely.

Of the 1075 Megawatts of potential conservation savings from the weatherization programs in the Base Case, Figure 8 shows that only about 40 percent--or about 400 Megawatts--is realized as net conservation savings by the year 2004. The Regional Model helps sort out the effects of a complex number of factors on net costs and savings of utility conservation programs.

FEEDBACK

We now turn our attention to information feedback in the Pacific Northwest electric system and in the CPAM representation of that system. As noted in Figure 1, the different sectors of CPAM are tied together through feedback loops which are active during each and every time step of a simulation. Although this may appear as standard practice to participants in the Keystone Conference, it is not the approach typically taken by electric utility modelers in general.

To present an application of the model that may be of general interest to the participants in the Keystone Conference, we illustrate the contrasting approaches by focusing on the so-called "spiral of impossibility" in which higher electric rates lead to lower sales, lower sales force the utility to request further rate increases to cover fixed costs, and the new rate increases lead to still further reductions in sales. We emphasize that this application is presented merely for illustrative purposes because the focus of the CPAM project is conservation programs and not the analysis of the "spiral of impossibility."

The "spiral of impossibility," sometimes called the "death spiral," has been studied for utilities with widely different characteristics by Ford and Youngblood (1983) and for utilities in the Pacific Northwest by Moorlan (1984). These and other studies indicate that the "spiral" could be particularly bothersome when the utility customers react strongly and quickly to changes in the price of electricity. Since the region's large aluminum industry fits this description, it is natural that there should be so much concern about the "death spiral" in the Pacific Northwest (Northwest Energy News 1985).

In CPAM the "spiral" is represented as the first of 5 feedback loops in the causal loop diagram given in Figure 9. To understand the effect of this positive feedback loop, consider the likely effect of an outside disturbance like a drop in the market price of aluminum. This change would lead to less profitability, closures of some aluminum plants, less regional sales, an increase in the average electric rate, an increase in the rate charged the aluminum companies, an increase in the variable costs of aluminum production, and a further decline in profitability. Loop #2 in Figure 9 provides some negative feedback to counter the effect of the "spiral." Here, we assume that the least efficient aluminum plants will be the first to close down in a depressed market. The improved efficiency of electricity use of the plants remaining in operation reduces the importance of the rate increases from the "spiral."

The first two loops tell only part of the story, however. A more complete picture is provided by considering the effect of three additional loops, each of which involve the estimated effects on revenues earned from the sale of secondary power to California. We call loop #3 the "more secondary sales" loop because it leads to greater sales of secondary energy over the intertie to California when there is a loss of aluminum load in the region. The third loop provides negative feedback which partially offsets the severity of the "spiral" and is often cited by analysts who feel that the "death spiral" is not a serious problem for the region. More secondary sales are only possible, however, if there is room on the intertie to California. As the intertie becomes more congested, the California utilities are more effective in reducing the secondary rate. The effect of intertie congestion is represented by the fourth loop in Figure 9.

A similar effect is represented by the fifth loop which involves the calculation of secondary rates based on the cost of the generating resources used to produce the secondary power for California. This loop leads to lower secondary rates when there is a loss of aluminum load in the region. With lower regional load, the fraction of low cost generation (mostly hydro) that is available for secondary generation is greater, and "cost-based" secondary rates would decline. The effect of both the fourth and fifth loops is to lead to lower secondary rates with reductions in the aluminum industry load. If the intertie happens to be full, the reductions in secondary rates will lead to lower secondary revenues, higher revenue requirements, higher electric rates, higher variable costs of aluminum production, less profitability, and still further closures of aluminum plants. Thus, the fourth and fifth loops in Figure 9 are similar to the "spiral" -- they act to amplify the effects of disturbances introduced from outside the Pacific Northwest electric system.

To show the relative importance of the internal forces (the 5 loops in Figure 9) and the external forces of the world wide aluminum market, we use CPAM to simulate the likely closures in aluminum plants under different assumptions on the aluminum marketplace. As a simple example, we assume a 4 cents/lb downward movement in the world price of aluminum. If this outside disturbance is superimposed on a base case projection of aluminum prices, we project temporary closures of almost all the region's aluminum plants followed by a return to operation of roughly half the region's capacity. We obtain a rough indication of the importance of the internal forces by examining the rate increases during the years of greatest closures. These rate increases, when multiplied by the average electricity requirement per pound of aluminum, amount to a 1 cent/lb additional movement against the

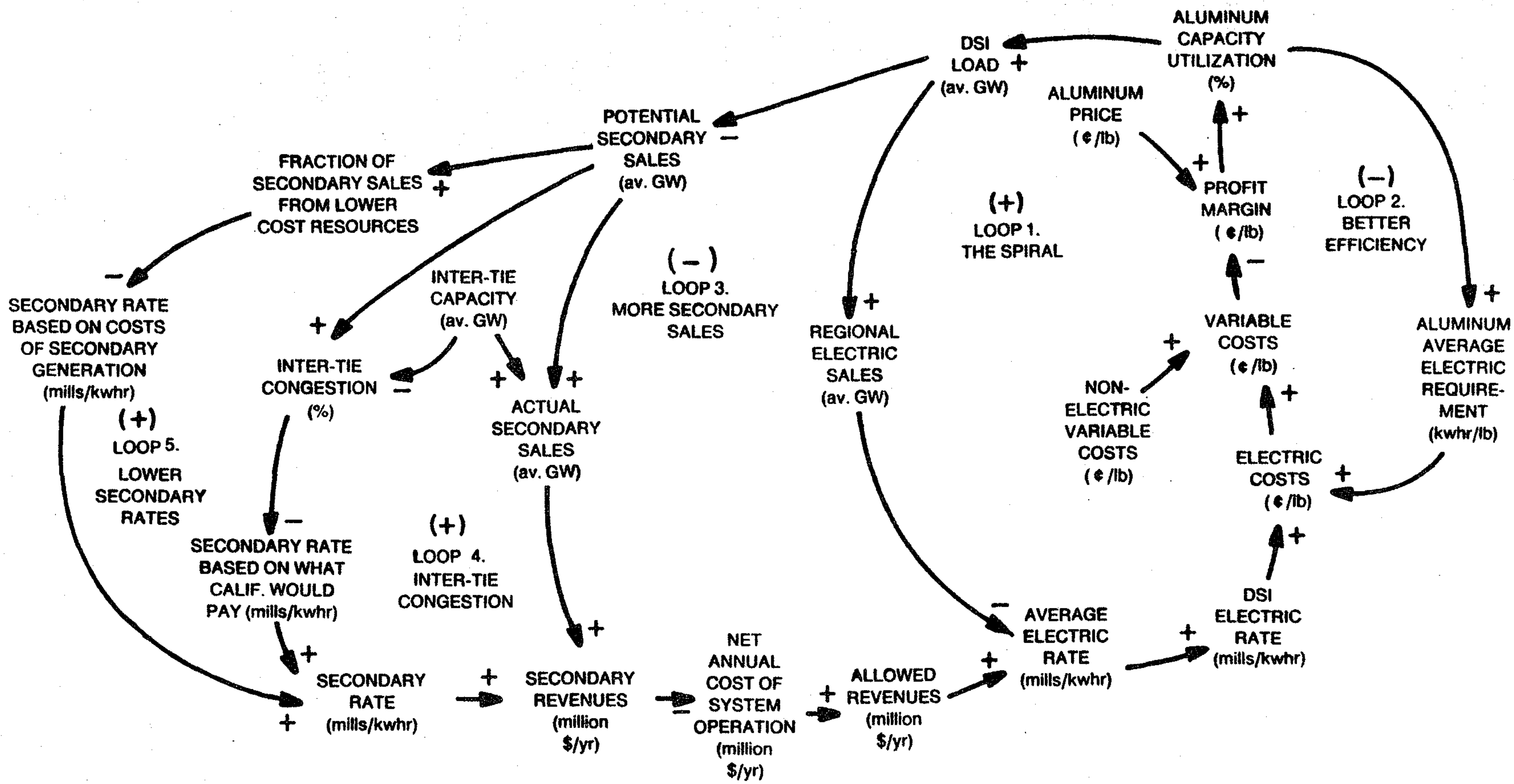

Figure 9. Five Feedbacks Loops Controlling the Aluminum Industry Capacity Utilization.

industry. Thus, the model shows that the region's internal forces would amplify a 4 cents/lb problem into a 5 cents/lb problem. This 25% amplification may not be a major problem relative to the great uncertainties in the worldwide market for aluminum.

OTHER ELECTRIC UTILITY PLANNING MODELS

Surveys and conferences on models used in the US electric utility industry indicate that feedback loops such as the "death spiral" are usually left out of most planning models. In the Electric Power Research Institute's forum on utility corporate models, for example, only one of a dozen corporate models provided a direct representation of price feedback (EPRI 1981). Forum participants examined this particular model (a system dynamics model used by the Florida Power and Light Company) and found that it contained far less detail than the other 11 corporate models but that it exhibited unique and interesting patterns of behavior. When the reasons for the unique behavior were uncovered, the Florida model was judged to be highly intuitive, and the forum participants concluded by recommending that more corporate modeling groups attempt to "close the loop" in future modeling efforts.

Several of the forum participants met again with other analysts at a Los Alamos workshop on regulatory-financial models used in the US electric utility industry (Ford and Mann 1983). A dozen models were represented by this group of analysts from industry, state agencies, and universities. A survey of the models' treatment of feedback loops such as the "death spiral" showed that only one of the dozen provided for an explicit representation of feedback loops involving customer response to higher prices and involving the financial community's response to company performance. Workshop participants cited a variety of reasons why they chose to leave key feedback loops out of their models. One group, for example, cited problems in justifying the parameter values used in closing feedback loops in advocacy hearings before state public service commissions. Another group recounted their unsuccessful experiences to apply statistical procedures to quantify the appropriate parameters needed to close the feedback loops. And still another group offered the opinion that closing the loops made model results too confusing for upper level management. It was suggested, for example, that upper level management would lose confidence in a model whose projection of electricity demand changed every time a new scenario was devised and the price of electricity was different. Representatives from the Florida Power and Light Company agreed with the difficulty in obtaining parameter estimates, but they discounted the view that upper level management would be confused by projections from a model with information feedback. The Florida planners emphasized that utility companies use some models to generate "numbers" and other models to generate "insights," and that their purpose in adding feedback to their corporate model was to gain insights.

THE BPA CORPORATE MODELS

BPA maintains a collection of detailed models to assist in analysis of policies for the Pacific Northwest region. The models are constructed and updated in different departments, and they are coded in different languages to suit the particular needs of each department. This collection of highly detailed models is referred to as the corporate models. Price feedback is represented in the corporate models as shown in Figure 10. This diagram shows three of the corporate models and the iterative process used to obtain consistency on price projections. The process starts with BPA's best estimate of the likely price of electricity over the planning period. The estimated values are used as input to a demand model which provides a projection of the electric load for each year of the 20 year planning period. The load projection is then used as input to a capacity expansion planning model which determines the amount, mix, and timing of generating unit additions. Generation unit additions are then used by a cost model which finds the annual revenue requirements and the price of electricity that must be charged to meet the revenue targets. The price obtained at the end of this sequence of model calculations is compared with the starting price, and the sequence is repeated until a consistent set of prices is obtained.

The lower half of Figure 10 illustrates the recursive approach used in the system dynamics CPAM model. Here we show eight causal influences involving different CPAM variables that would also appear in the corporate models. With the recursive approach, all the interactions are part of one model, and the feedback loops are active throughout the 20 year simulation.

THE IMPORTANCE OF FEEDBACK

Including feedback in the CPAM model has proved valuable in BPA's analysis of conservation programs because of the increased understanding afforded by the direct simulation of information feedback. The CPAM representation of price feedback, for example, has greatly increased the understanding of the likely difference between gross savings and net savings of alternative conservation programs.

In reviewing the practical benefits of CPAM's use at the Office of Conservation, however, a more important advantage of direct simulation of feedback is the ease with which multiple simulations can be performed to test the effect of conservation policies under a wide range of different conditions. If, for example, BPA wishes to test the effect of a conservation program under a variety of corporate planning assuimptions, e.g., with more rapid growth in the region's economy, with cancellations of nuclear units under construction, with a larger intertie to California, or with a myriad of other changes, a dozen or so parameters are changed and a new set of simulation results are obtained in rapid order. The new simulations are obtained without extensive repreparation of the inputs because of the many feedback loops which automatically adjust for changing circumstances in the new simulation. In the event of cancellations of nuclear units and more rapid growth in the region's economy, for example, CPAM automatically adjusts the development of the region's small hydro resource and the investment in new coal plants in a manner that mimics the likely reaction of utility planners to the increased need for generating capacity. The higher electric rates needed to pay for all the new capacity, in turn, are calculated internally and used in the new calculation of the likely customer investment in conservation and the likely operation of the region's aluminum plants.

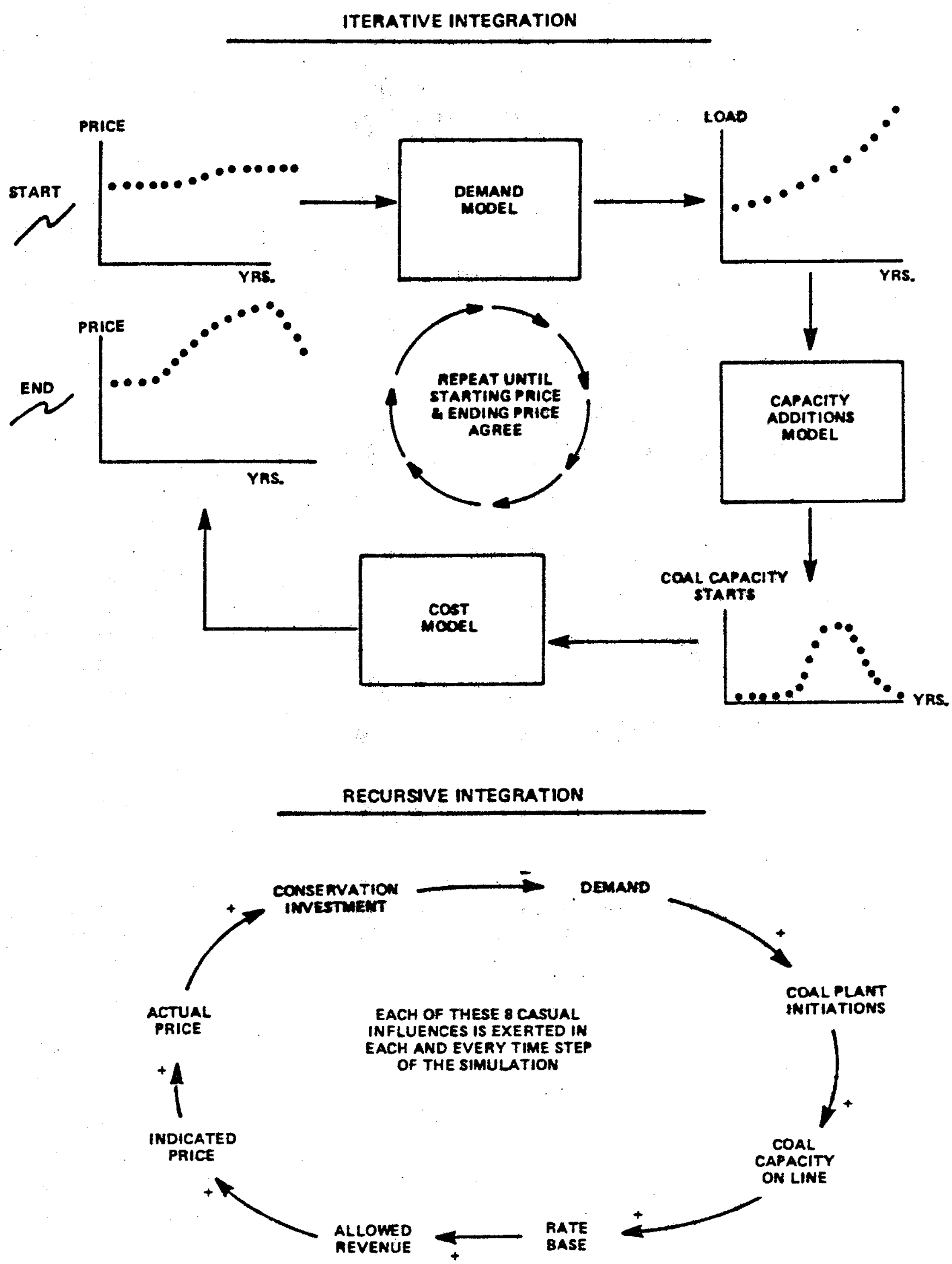

Figure 10. The Two Approaches to Model Integration.

BPA views CPAM as a "screening tool" which can be used to provide rapid turnaround analysis of a wide variety of policies. By screening through many different policy proposals with CPAM, the Conservation Office can narrow the number of proposals to be studied with the more detailed corporate models down to a manageable number. Our principal conclusion, therefore, is that the primary benefit of the inclusion of feedback in the CPAM model is to facilitate the model's use in "screening studies."

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