Abstract

The purpose of this document is 1) to describe, in detail, the theoretic foundation on which PV1 is based, 2) indicate the manner in which its theoretical foundation has been translated into a practical, useful tool for the analysis of photovoltaic commercialization policy, 3) document both the sources of data and the variables used in the model, and 4) provide the basis for comments from potential users.
NOTE

The PVI model is evolutionary in nature. Although the basic structure of the model is well-defined, modifications to some of the model's functional aspects will be made in the future. Thus, the version verified in this report will undoubtedly be revised. This document is intended to verify the current, January 1981 version of PVI, and will not be updated when improvements to PVI are incorporated.
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PV1 MODEL VERIFICATION AND VALIDATION

1. Introduction

1.1 Purpose

The purpose of this document is to 1) describe, in detail, the theoretic foundation on which PV1 is based, 2) indicate the manner in which its theoretical foundation has been translated into a practical, useful tool for the analysis of photovoltaic commercialization policy, 3) document both the sources of data and the variables used in the model, and 4) provide the basis for comments from potential users.

The remainder of this chapter provides a summary description of the PV1 model, including its basic computations. A more thorough description may be found in "PV1: An Interactive Computer Model to Support Commercialization Policy for Photovoltaics. User Documentation," MIT Energy Laboratory Report MIT-EL-80-026, September, 1980. Chapter 2 includes the theoretical validation and the research environment in which PV1 has been developed, and places PV1 in perspective in terms of the current literature. Chapter 3 presents a line-by-line description and verification of the computer code that comprises the heart of PV1, and includes a series of hand calculations that are compared to the results obtained using PV1. The fourth chapter is a list of data and their sources used in PV1, and the appendix summarizes the results of the verification effort.

1.2 PV1

PV1 is a discrete-time, deterministic computer model, available to the user in an interactive mode via the MULTICS system at MIT.

Figure 1.1 describes the basic idea behind the model. Government actions such as price subsidies and market development spending make PV
more acceptable in the market by directly lowering the price to the consumer, making more consumers aware of PV, and instilling confidence in PV as a technically viable and economic energy technology. Other government actions, such as investments in technology development (TD) and advanced research and development (AR+D) are expected to enhance the basic and production technologies for PV, thereby bringing the DOE goal of $1.60 per peak watt closer.

The more rapidly PV is accepted in the market, the higher the purchase rate. As the production industry takes advantage of increasing economies of scale, the unit costs should decline, further increasing the market acceptance rate for PV. As more PV is sold, the total potential market remaining is reduced.

The model starts with a market potential that is sector and region specific. The potential market acceptance rate is affected by PV characteristics, in particular cost, but also by perceived risk and other product characteristics.

The model includes several important controls and feedbacks. The purchase rate diminishes the potential market. It also lowers PV cost through production experience. The government can lower PV cost directly (through some type of subsidy) or indirectly:

(a) through market development expenditure--the government 'buys,' for demonstrations--lowering production costs through production experience; or

(b) R and D or Technology Development spending, monies spent to improve production processes or to develop newer, lower-cost PV materials.

To implement PV1, the user must:

1. Select from a specified list those sectors of the economy to be analyzed;
Figure 1.1

Conceptual Structure of PVI

Inputs:
- Government Actions

Outputs:
- Purchase Rate
- Cost

Market Potential → Market Acceptance Rate

Diagram: Conceptual Structure of PVI
2. Determine the planning horizon of the model in years; and
3. Define government programs in terms of levels of support, and allocate this support over sectors and regions.

In turn, PV1 will provide the user with output regarding forecasts of PV costs and peak kilowatts of PV installed by year and sector, and the cost of government programs. This last output is not simply an echo of the user's input because the spending for subsidies will not be known until after the level of market penetration is determined.

In this way, PV1 can be used to evaluate government policy options in terms of their relative effectiveness in stimulating the PV market.

1.3 Government Policy Options

The PV model considers 5 types of government controls:

**Advanced Research and Development (AR+D) Spending:** This refers to R and D allocations earmarked for potential breakthroughs in technology, perhaps of the non-silicon variety, expected to have significant, long-term cost reduction capabilities. Greater spending in AR+D is assumed to shorten the time to the development of a breakthrough technology.

**Technology Development (TD) Spending:** This refers to money earmarked for development of production processes that can meet PV program goals. Greater TD spending can shorten the time until PV program goals are met.

**Market Development (MD) Spending:** These are the so-called "government buys" that are used for demonstration programs. They have two major impacts on costs: government buys (in addition to
private sector purchases) lead to greater production quantities and, hence, to lower balance of system (BOS) or non-module costs. With intermediate (current high-volume production) silicon technology, MD spending supports the marketplace for arrays, and the greater that spending, the more efficient the production facility and the lower the array cost. With advanced silicon technology, JPL analyses (1980) suggest that plants will most likely be built at economic size, so MD spending will not affect array price for advanced silicon technology; that spending may, however, shorten the time to the development of advanced silicon technology.

**Advertising:** In order to increase awareness of PV within the potential market, the government will allocate funds to advertise it as an alternative source of electricity. In PV1, the amount spent on advertising is specified by the user as an additional percentage of the MD spending.

**Subsidies:** Subsidies, assumed to be approximated as a percentage of total system price with an upper dollar limit, are other controls available to the government for lowering the price of PV to the user and, hence, accelerating diffusion. These subsidies vary by sector and over time. Later model development will consider more complex forms of government incentive.

### 1.4 PV1 Model Precis

This section gives a brief technical description of PV1. Section II gives complete model details. In what follows, we use the following notation:

\[ i = \text{sector, } i = 1, \ldots, I \]

\[ j = \text{region, } j = 1, \ldots, J \]
\( t = \) time period, \( t = 1, \ldots, T \)

**Government Controls**

\( TD_t = \) annual rate of TD spending

\( ADV_t = \) additional fraction of MD spending for advertising

\( Bj_{ijt} = \) MD investment (in Kwp)

\( X_t = \) annual rate of AR+D spending (in $)

\( SUB_{it} = \) level of PV government subsidy, percent

\( U_{it} = \) upper limit on subsidy, per installation, in sector \( i \) at time \( t \) (in $).

**Basic Market Variables**

\( V_{ijt} = \) number of potential installations, in sector \( i \), region \( j \), at time \( t \)

\( W_{ijt} = \) average installation size (Kwp) in sector \( i \) at time \( t \)

\( Y_{ijt} = \) private sector PV sales (Kwp) at time \( t \)

\( S_{ijt} = \) total PV sales (Kwp) = \( Y_{ijt} + B_{ijt} \)

\( S_{BAR_{it}} = \) estimated sales in sector \( i \) at \( t \)

\( N_{ijt} = \) actual, cumulative number of installations

\( EFF_{ijt} = \) "effective" number of installations (similar to \( S_{it} \)), used for cross-sectoral/region perceptual influence

\( \mu = \) marketing, distribution, and profit mark-up on arrays.

**Acceptability Variables**

\( z = \) system maintenance cost as a fraction of the annualized capital cost

\( L = \) system life, in years, of a PV system

\( F_A(x) = \) fraction of the market aware of PV

\( F_{WA_{ij}}(x) = \) cumulative distribution function (cdf) of warranty acceptability.

\( F_{PB_{ij}}(x) = \) cdf of payback acceptability

\( F_{SUC_{ij}}(x) = \) cdf of prior successes acceptability
\( F_{\text{LIFE}}_{ij}(x) = \text{cdf of system life acceptability} \)

\( P_{\text{ACT}}_{ijt} = \text{unsubsidized price of a PV system per KWp to the purchaser} \)

\( P_{\text{SYS}}_{ijt} = \text{subsidized price of a PV system per KWp to the purchaser} \)

\( h_{ijt} = \text{fraction of the market that will buy an "acceptable" PV system.} \)

\( \text{WA} = \text{warranty period, in months} \)

**Model Calculation**

The main system equation is:

\[
Y_{ijt} = [V_{ijt} \times W_{ijt} - B_{ijt}] \times F_{\text{PB}}_{ijt}(P_{\text{SYS}}_{ijt}) \times F_{\text{SUC}}_{ijt}(\text{EFF}_{ijt}) \times F_{A_{ijt}}(\text{MD,ADV}) \times F_{\text{LIFE}}(L) \times F_{\text{WA}}(WA) \times h_{ijt}
\]

where \( V_{ijt} \) is calculated from \( X_{ijt-1} \) by first accounting for section growth and then reduction potential by actual demand.

Total program cost is calculated as:

\[
\text{Cost} = \sum_{t=0}^{T} X_t \quad (\text{AR+D cost})
\]

\[
+ \sum_{t=0}^{T} T_{D_t} \quad (\text{TD costs})
\]

\[
+ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=0}^{T} B_{ijt} P_{\text{ACT}}_{ijt}[1 + \text{ADV}_t] \quad (\text{MD + Advertising Cost})
\]

\[
+ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=0}^{T} Y_{ijt} [P_{\text{ACT}}_{ijt} - P_{\text{SYS}}_{ijt}] \quad (\text{Subsidy cost})
\]

This cost can be compared to a variety of measures of program value, such as capacity factor, rate of adoption parameters, and cumulative number of installations during the planning period.
2. The PV1 Modeling Approach

2.1 Background

Although similar in objectives to other market penetration models, PV1 is dramatically different in structure. The model is based on theoretical developments and understanding of organizational purchasing as well as on practical consideration associated with empirical model-calibration methods.

Before proceeding to the PV1 model itself, let us consider what the adoption of photovoltaics entails:

Proposition: Adoption of PV is an organization purchase.

This proposition is clearly true for utilities, the industrial, commercial and agricultural sectors. For residential, our analysis of active solar heating and cooling studies (Lilien and Johnston, 1980) has shown that Builders, Architects, and HVAC contractors interact with buyers in the decision of whether to adopt solar equipment for home use, especially in new construction situations.

If we accept this proposition, it has this important corollary:

Corollary: A model of organizational adoption of new products should be adapted for use to evaluate market strategies for PV.

2.2 Organizational Buying Research

Researchers from several disciplines—including economics, sociology and marketing—have looked at organizational buying in their own, special ways. Webster (1979), Sheth (1976), Choffray (1977), Bonoma, Zaltman and Johnson (1977) provide comprehensive reviews of that literature.

Here, we distinguish two types of research about new-product purchasing in industrial markets: we call these Adoption Research and Behavior Research.
Adoption Research has mainly been performed by economists. It deals with an organization's final choice—the adoption or rejection of a new product or technology—and relates that choice to characteristics of the product and the market.

Behavior Research is concerned with understanding the whole purchasing process, both at the individual and organization level, that leads to choice. Exhibit 2.1 suggests how these areas of study differ.

**Adoption Research**

Research on the adoption and diffusion of innovations began in sociology and anthropology at the turn of the century. Since the revolutionary study of the diffusion of hybrid corn among Iowa farmers in the early 1940's, the number of studies has mushroomed, and reaches over 2700 today (Rogers, 1976).

The object of research in this area is to relate the rate of adoption and diffusion of new products to their characteristics as perceived by different groups. To date it has focused mainly on the diffusion of technical innovations with short payoff and for which individuals, not groups are the most likely units of adoption.

**Exhibit 2.1: New Industrial Product Research**

<table>
<thead>
<tr>
<th>Type</th>
<th>Focus</th>
<th>Subject of analysis</th>
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<tr>
<td>Adoption research</td>
<td>Product choice</td>
<td>Influence on choice of:</td>
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<tr>
<td></td>
<td></td>
<td>- Product factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Environmental factors</td>
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<td></td>
<td></td>
<td>- Organizational characteristics</td>
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<td></td>
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<td>- Individual characteristics</td>
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<tr>
<td></td>
<td>Decision process</td>
<td>Organizational decision process analysis at</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- organization level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- individual level</td>
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For example:

- Mansfield (1968) investigated the speed of adoption for fourteen innovations in four industries as a function of a potential customer firm's characteristics. He also investigated the diffusion of new industrial products (e.g. diesel locomotives) within industry and within specific firms.

- In a similar vein, Ozanne and Churchill (1971) look at the adoption of a new automatic machine tool by midwestern industrial firms. Peters and Vankatesan (1973) analyze the diffusion process for a new, small computer. O'Neal et al. (1973) study the adoption of industrial innovations through a business game. Czepiel (1976) studies the diffusion of continuous casting in the American steel industry.

For our purposes, Adoption Research is generally inconclusive. Many results obtained to date have come under criticism (Kennedy and Thiswall, 1972, Gold et al, 1970). Available studies cover a wide range of new products, whose adoption processes could differ considerably. They use generally different designs and methods of analysis. Finally they often study innovations that finally succeeded and do not address the different characteristics of failures.

Behavior Research

Marketers have been poking into the industrial purchasing process for a number of years. Previous work on industrial buying behavior has been essentially concerned with (a) the development of integrated conceptual models, and (b) the empirical verification of hypotheses pertaining to specific aspects of this behavior. For example:
Robinson and Faris (1968) have developed a descriptive model of industrial buying behavior that categorizes this process according to purchase situations.

Webster and Wind (1972) have proposed a descriptive model of organizational buying, incorporating the concept of a buying center, including those involved in a purchase decision. Response of the buying center is analyzed as a function of four classes of variables: individual, interpersonal, organizational and environmental.

Sheth (1973) has developed a model that tries to encompass all industrial buying decisions. The Sheth model distinguishes three main elements of industrial buying: (a) the psychological characteristics of the individual involved; (b) the conditions that precipitate joint decision making; and (c) the conflict resolution procedures affecting joint decision making.

Hillier (1975) proposes a model that concentrates on (a) individual involvement in organizational buying, (b) buyer-supplier functional inter-reationships, and (c) industrial buying as a corporate process.

In addition, a number of empirical studies have dealt with certain aspects of industrial buying behavior. These studies are mainly:

- Observations of actual purchase decisions (Cyert et al., 1956, Brand, 1972).
- Analyses of the involvement of various organizational functions in industrial purchasing (Harding, 1966; Scientific American, 1970; Buckner, 1967).
Studies of the behavior and decision styles of individual decision participants (Lehman and O'Shaughnessy, 1974; Cardozo and Cagley, 1971; Hakansson and Wootz, 1975; Wilson, 1971; Sweeney et al., 1973; Scott and Bennett, 1971; Wildt and Bruno, 1974; Scott and Wright, 1976).

The most important consideration ignored in the published literature is managerial use. Although available models provide a detailed conceptual structure for the study of industrial buying behavior, they are not operational, and many of their elements have only been empirically validated in a limited way. Most important, these models give little attention to the role played by controllable marketing variables on industrial market response.

Empirical studies, on the other hand, involve a broad range of products and buying situations. Methodological problems compromise the integrity of many of the results, as the studies have often been undertaken in isolation, on the basis of small samples often limited to purchasing agents. Empirical analyses of industrial buying behavior have so far contributed little to the development of a theory of organizational buying.

2.3 **Modeling Organizational Buying Behavior**

An important limitation of current models of organizational buying for an operational model-builder is their lack of parsimony. Typically, these models provide exhaustive lists of variables that might affect organizational buying. They do not, however, distinguish those variables that have a consistently major influence across product classes from those whose influence is of lesser import, dependent on specific purchase situations.
Recognizing these limitations, Choffray and Lilien, (1980) provide a framework to model organizational buying that is more concise than the models developed in the literature. It focuses on the links between the characteristics of an organization's buying center and the three major stages in the industrial purchasing decision process through:

1. elimination of evoked product alternatives that do not meet organizational requirements;
2. formation of decision participants' preferences;
3. formation of organizational preferences.

Although simple, this conceptualization of the industrial purchasing decision process is consistent with the current state of knowledge in the field. It reflects our concern about putting to work the concept of the buying center and explicitly deals with the issues of product feasibility, individual preferences, and organizational choice. This structure also links important characteristics of the buying center to the various stages of the industrial purchasing process.

To develop an operational model requires that customer heterogeneity be explicitly handled. In particular, it must address the following issues:

1. Need specification heterogeneity: Potential customer organizations may differ in their need specification dimensions, that is, in the criteria they use to specify their requirements. Company A may use payback period as a criterion, but Company B uses initial cost only. They also differ in their specific requirements. Company A may require a 3-year payback; Company C may find four years satisfactory.
2. **Buying center heterogeneity**: Potential customers may differ in the composition of their buying center. Who is involved? What are their responsibilities? Company A has a purchasing agent and an engineer involved in the buying process for industrial cooling equipment. The engineer screens alternatives. The purchasing agent buys. In Company B top management is also involved.

3. **Evaluation criteria heterogeneity**: Decision participants may differ in their sources of information as well as in the number and nature of the criteria they use to assess alternatives. Engineers are concerned about reliability. Purchasing agents are concerned about price.

Exhibit 2.2 transforms our conceptual structure into an operational sequence of measurements and models. The first two stages define the market technically and perform a first-level segmentation called macrosegmentation. This characterizes organizations likely to react to the product offering differently because of their industry or other observable characteristics.

The next step is called microsegmentation. Here we divide macrosegments into smaller groups with similar decision process structures. A survey-tool, called a decision-matrix, is used to measure the involvement of different categories of individuals in a particular organization in each stage of the purchasing procedure. Organizations with similar structure across individuals and across decision-process phases are clustered together.

How can we determine the likely purchase behavior of target customers? Our first tool is an Awareness model. It relates the level
Exhibit 2.2. General structure of industrial market analysis procedure.

(reprinted from Choffray and Lilien, 1980)
of marketing support for a product (measured in terms of advertising and personal selling spending rates) to the likelihood that a potential buyer will be aware of the product.

The next model is the Acceptance model. It is designed to account for the process by which organizations eliminate products that are outside their range of acceptability. They do this by setting bounds on price, criteria for reliability, specification on the number of prior successful installations, minimum values of payback period, and so forth. Our procedure is designed to measure organizational differences on those acceptance criteria and to provide managerial feedback leading to (a) insight into product design trade-offs (b) accurate assessment of the market (or microsegment) acceptance rate for a product with a given design.

Next we come to Individual Evaluation models. Decision participants (purchasing agents, engineers, controllers, etc.) do not always share the same criteria about product selection and usually view product alternatives quite differently. These models are decision-participant group specific. They allow sensitivity analysis to be performed evaluating likely industrial market response to changes in product positioning.

Then we reach a difficult problem: purchasing interaction or Group Choice models. When there is disagreement between decision participants about the product to be purchased, what is the firm likely to do? Group choice models are based on a set of hypotheses about the most likely mode of interaction in potential buying organizations. The selection of the one or combination to be used is based on the marketing manager's characterization of how he feels customers in a particular microsegment
Does a single estimate of market share or market potential for a new industrial product provide a sufficient basis for long-term marketing strategy formulation? Probably not: the timing of those likely sales is central. Marketers, then, need knowledge of the future growth for their product as market dynamics take effect.

This issue—growth—is developed in detail in the next section.

For complete model development details, see Choffray and Lilien, 1980.

2.4 Model Adaptation for Photovoltaics

Exhibit 2.3 provides a picture of the adaptation of this model of organizational choice to photovoltaics. The logic of the model begins with an estimate of total market potential in each sector in each region, and reduces this market through a sequential elimination procedure, to provide an annual market penetration estimate.

All other inputs from the market are consumer-based (derived from market surveys, where possible). The choice model is of the sequential elimination type, motivated above. And the diffusion structure—and play-out of sales over time—is calculated endogenously, internally in model, in contrast to other solar energy market penetrations models.

Specifically, there are three guiding principles for the development and use of PVI:

(a) Direct input from the potential marketplace accelerates product development and improves product success rates. (Market Input)

(b) Consumer (and organizational) adoption of product alternatives can be modeled as a two-step process: setting screens and then choosing among acceptable alternatives. (Consumer Choice)
Exhibit 2.3 PV1 Model Structure

Potential Market, Number of Units

Average Size, kWp/Unit

Potential Market kWp

no

Aware of PV?

no

Distribution?

no

Warranty OK?

no

Payback period OK?

no

Successes OK?

no

System Life OK?

no

Purchase?

yes

Total kWp of Installed PV

Subsidy

Technology Development

Advanced Research and Development

Market Development

Growth Rate

Utility Rates

Interactions

Cost Decline Functions

Government Controls

Market Screen
(c) Diffusion-model theory does not currently provide guidance for estimating the rate of market penetration, which should be calculated endogenously. (Diffusion Model Structure)

2.4.1 Market Input: Scores of studies have appeared during recent years about new product success rates and the new product failures. These studies consist mainly of three types:

- **Case analyses** of new products that emerged successfully from R and D programs only to become market failures (Briscoe (1973)).
- **Cross-sectional studies** of new product failures (Cooper (1975), Calantone and Cooper (1977), von Hippel (1978)).
- **Experimental or quasi-experimental studies** that focus either on differences between successful and unsuccessful innovations competing in the same market (Rothwell et al. (1974)) or about factors influencing new product success probabilities (Mansfield and Wagner (1975)).

By and large the results reported by these studies are consistent. They stress, as major causes of failure:

- the lack of appreciation for the way customers perceive and evaluate the new product;
- the misassessment of the firm's existing stock of resources, especially its marketing skills;
- the lack of specific objectives for the new product in terms of its target market and place in the company's product mix.

Some of these studies deserve further discussion. Mansfield and Wagner (1975) systematically analyze organizational and strategic factors associated with probabilities of success in industrial R and D. They relate the probability of technical completion, commercialization, and economic success to three key variables:
speed of market analysis
- percentage of money spent on "demand pull" (as opposed to "technology-push") projects;
- percentage of projects originating in R and D.

Their results show that early market analysis improves all three success rates.

Cooper (1975) reports on the cases of failure of 114 new industrial products and reports a dominant reason for failure as the lack of market research skills and people. Another related result indicates that a detailed market study rated as most deficient among activities performed during the development process.

Mansfield and Wagner (1975) also investigated the effect of the degree of integration of R and D and marketing activities and found that a closer integration of R and D and marketing increases the probability of product success.

Calantone and Cooper (1977) provide an empirically based description of new product failures, along with a profile of the major causes of these failures. They distinguish:
- sales and competitive environment misassessment;
- deficient prior market research;
- deficient engineering and marketing skills;
- lack of integration of the new product/technology into the company's experience base.

Their most frequently reported category of failure—"The Better Mousetrap Nobody Wanted"—comes about when the market for the product fails to materialize.

Evidence about ways to reduce new product failure points strongly to
the need for a better understanding of customers' requirements and the market structure, as well as a closer integration of market research and engineering activities. (See Urban and Hauser (1980) and Choffray and Lilien (1980) for more complete development of the evidence here.) High failure rates and slow market development are related to attempts to sell R and D output directly, as opposed to integrating user input.

The message for PVI is that, for the model to be more useful:
(a) it must be structured to incorporate direct input from the marketplace, and
(b) field survey/direct consumer measurements must be part of the model development and analytical process.

2.4.2 Consumer Choice: A number of models of consumer adoption have been postulated and used in the solar energy area, mostly ranging from the unworkable to the hopelessly naive. We break these models into "economic models," "conjoint models," and "disjoint models," and treat them in turn.

Many of the existing solar energy adoption models treat consumer adopters as if they were engineering economists, calculating payback period and NPVs of investment. These models (a) assume an inherently rational consumer choice process, (b) generally focus on market dynamics as opposed to consumer dynamics, and (c) assume homogeneity in the product characteristics of importance.

Hartman (1978) reviews many of these models, most of which have been developed to model demand for and substitution between existing well-known fuel alternatives. In new product situations, other non-economic variables (tastes, risk uncertainty, inertia) play much larger roles in the decision process. In a study of the market for solar
water heaters, Scott (1977) showed that consumers were willing to pay $1.40 to $1.70 in incremental monthly fuel bills to offset $1.00 in incremental mortgage payments (associated with a solar water heater). The reasons given for this "irrationality" (especially irrational given the tax advantages associated with the mortgage spending incorporated in the mortgage and, hence, mostly deductible) include risk of an unmarketable house, maintenance uncertainty, lack of proven field experience, etc. But, unless a product-specific study is done for a new technology, it is difficult to apply economic models to consumer adoption in a new product situation.

Conjoint analysis methodology is based on a decompositional principle, in which respondents react to a set of product profiles where characteristics are varied fractionally. The method then attempts to find a set of utilities for individual attributes that, given some composition rule (most often additive) are most consistent with the respondents' overall evaluation. Green and Wind (1973) and Green and Srinivasin (1978) provide an overview of this methodology.

Three main problems exist with conjoint analysis. First, all varied dimensions are assumed to be relevant to all respondents (population-response homogeneity). Second, due to measurement constraints, a small number (4-5) of product attributes are the most that can be studied, clearly an insufficient number for complex product decisions. Third, the method assumes simultaneous consideration of product attributes, a model that may not be appropriate here.

The disjoint measurement approach considers consumer choice as a series of screens prior to product trade-off analysis, as illustrated in Exhibit 2.4.
Exhibit 2.4: The Disjoint Measurement Approach

Here a variety of product screens (on payback, ROI, first cost, warranty period, system life) are set up, following field analysis of the criteria used by individuals in a particular sector. If a dimension is not used by consumers in a sector, the screen becomes inoperative (transparent). Along each relevant specification dimension, consumers are asked to specify the minimum or maximum value beyond which they or their organization would not consider the product (see Choffray and Lilien (1979), for behavior theory supporting this approach as well as technical details).

Following this screening step, products are traded off and a probability of product choice (conditioned on acceptability) is calculated. (See Choffray and Lilien (1980), Chapter 6 for the approach here.)

The consumer choice segment of the PV1 model follows the disjoint measurement, screening-prior-to-choice approach. In the PV1 model, the key screening dimensions used prior to screening are payback period, warranty period, number of previous successes and system life. These
dimensions (and the screening values used) were derived from a national study of solar energy adoption conducted by Lilien and Johnston (1980). In that study, other dimensions were tested and rejected as not used or insufficiently understood. The remaining dimensions were retained and, were statistically tested and found independent. The fraction of acceptable market, then can be calculated as the product of the fractions of the market that find each dimension acceptable.

The consumer choice segment of the PVI model follows this disjoint measurement, screening-prior-to-choice approach.

**Diffusion Model Structure:** Given the consumer choice approach outlined above, how will sales play out over time? The area of study focusing on time-rate of sales in new product situations is referred to as diffusion or substitution theory. Some of the more well-known approaches are as follows:

Mansfield's (1968) model is based on the assumption that the probability that a firm will introduce a new technique is: (1) an increasing function of the proportion of firms already using it, and (2) a decreasing function of the size of the investment required. It is assumed that all firms in the market will eventually adopt the innovation. It is also assumed that the profitability of installing the innovation relative to that of alternative investments is appreciably greater than unity.

Let us introduce the following notation:

\[ S(t) = \text{number of firms having introduced the innovation at time } t \]

\[ S^* = \text{total number of firms considered eligible to adopt the innovation} \]

\[ k = \text{integration constant.} \]
Following a series of arguments, Mansfield obtains that:

\[ S(t) = \frac{S^*}{1 + e^{-(k+qt)}} \]

Mansfield's assumption led to estimating \( q \), the imitation or contagion coefficient, as a linear function of the relative profitability of installing the innovation and the size of the investment required.

Following this basic work has been a series of model modifications. Fisher and Pry (1971) apply Mansfield's logistic model to 17 product areas. Blackman (1974) develops a model that does not assume 100 percent penetration will be reached. The form of that model is:

\[
\frac{d S(t)/S^*}{dt} = \frac{pS(t)}{S^*}(F - \frac{S(t)}{S^*})
\]

where \( F = \) fraction of the market eventually penetrated.

Floyd (1968) adds a linear "patch" to the Blackman and Fisher-Pry models, which tend to overpredict near the end of the forecast period. His model underpredicts. Sharif and Kabir (1976) modify the Floyd patch. Stapleton (1976) suggests the use of a cumulative normal curve (the so-called Pearl (1925) curve) to model the S-shaped phenomena. Nelson, Peck, and Calacheck (1967) postulate that the S-shape follows from a gradual movement from one form of equilibrium to another when a new product enters the market. A similar mathematical statement of the phenomenon assumes that the percent adjustment in any one period is proportional to the percent difference between the actual level of adoption of the innovation and the level corresponding to the new equilibrium. Thus, we obtain:

\[
\log(S(t)) - \log(S(t-1)) = p(\log(k) - \log(S(t)))
\]

where \( S(t) \) is the level of adoption and \( k \), the new equilibrium. If we
replace $\log S(t) - \log S(t-1)$ by $\frac{d \log S(t)}{dt}$ and $p = \log y$, the above equation becomes:

$$\frac{dS(t)}{dt} = \left[ p + \frac{S(t)}{S^*}\right]\ [S^* - S(t)].$$

This model adds an innovation term to the Mansfield model and seems to describe the adoption of consumer durables as well.

A number of recent extensions have been made to these models, addressing the issues of relating three key quantities—innovation, imitation, and ultimate potential—to marketing variables.

Robinson and Lakhani (1975) relate the imitation rate to product price, incorporating a price elasticity into the diffusion equation. Horsky and Simon (1978) incorporate the effect of advertising on the rate of innovation and imitation rates, following from the changing characteristics of the population. Bass (1978) updates his model, incorporating a production-cost learning effect. Implementing his model assumes that the coefficient of innovation and imitation are functions of demand elasticity and of the learning parameter in an experience curve of production cost. Mahajan and Peterson (1978) relate the imitation effect to the competitive structure of the market being entered. Dodson and Miller (1978) suggest that the ultimate purchasing population size varies according to awareness, which is affected by advertising and by word of mouth. Hauser (1978) couples Bass' model with perception-preference-choice models in forecasting adoption and growth. The interested reader should refer to Mahajan and Peterson (1979), Kalish and Lilien (1979), and Huerter and Rubenstein (1978) for more thorough reviews of these efforts.
Almost all the models referred to above report good descriptive results: they fit historical data well. Sahal (1976) notes that it is easy to see after the fact that one form or another of S-shaped curves will describe the phenomena well. He concludes that "...the value of such a model is limited because it sheds little light on the nature of the underlying mechanism. More important, such a model is likely to be of little help in prediction because of the difficulty in choosing (especially at an early stage in the process of diffusion) a specific form from a variety of S-shaped curves that would be appropriate." (p. 230)

Where does this leave solar energy penetration modeling? Warren (1980) reviews the most widely known solar energy market penetration models (MITRE (1977), SRI International (1978), Arthur D. Little (1977), Midwest Research Institute (1977), and Energy and Environment Analysis (1978)) and concludes that "...solar energy market penetration models are not science, but number mysticism. Their primary defect is their penetration analyses which are grounded on only a very simple behavioral theory."

What then are the implications for PV1 modeling? The course we take (building on the choice model suggested in the previous section) is to have endogenous model-generated feedback (rather than exogenous, arbitrary S-curves) provide the time-path of market penetration. Early sales feed back into (a) cost reduction equations, (b) market acceptability functions, and (c) population awareness, and product perception/future-choice generates the increasing sales rate seen in new product purchase situations.
The PV1 model, therefore, uses diffusion model concepts but uses a theory of consumer adoption linked to field data collection, to build those diffusion concepts into the model structure without relying on a specific, externally specified functional form.

2.5 Other PV1 Model Components

A key driving force in the PV1 model is the rate of PV cost declines, both with time and with sales. The cost reduction formulation in PV1 has been designed to conform with the methods suggested by JPL (1980).

A PV installation has 2 components: the PV module itself, and the balance of the system (BOS). BOS consists of power conditioning equipment, structures, and indirect costs. Indirect costs are contingencies, fees, and other costs not included elsewhere.

BOS Cost Reduction: BOS costs are assumed to vary from year to year, as a long-linear function of the total estimated sales rate. This specification is illustrated in Exhibit 2.5.

Module Cost Reductions: The model for module cost reduction is more a function of the state of technology than are BOS costs, and is therefore more complex. It depends on government policies to promote advanced research and development, and on the expectation of government and private purchases of PV. Module cost will also depend on the cost of silicon, the most probable future raw material for PV production.

The reduction in module prices is projected to occur in at least three stages. The date at which a new stage arrives is defined explicitly by the PV1 model user, although the dates may be modeled as an option, as described below. The first, or current stage, is called the "intermediate" technology stage. In this stage, the price of PV is given by:
Source: JPL Estimates

Exhibit 2.5 Price/Cost Versus Sales Rate Relationships for Non-Module System Components
\[ P_{\text{MODULE}} = [2.83 - (84 - P_{\text{Si}}) \times \frac{94}{70000}] + \frac{2.4}{Z} \]

where:

\[ P_{\text{Si}} = \text{price of silicon, $/kg} \]

\[ Z = \text{plant size factor, MW}_p/\text{yr.} \]

The plant size factor, \( Z \), is the size of the plant, in MW\(_p\) annual production, required to produce \(1/4\) of the total MW\(_p\) purchased.

The year that this first stage of module cost reduction ends may be defined by the technology development funded by the government. This date is estimated as:

\[ T = (t_2 - t_0)[1 - \frac{X^8}{\gamma + X^8}] + t_0 \]

where:

\[ T = \text{time to end of stage 1}, \]

\[ X = \text{cumulative TD in millions of dollars}, \]

\[ t_0 = \text{earliest possible date for stage 2 after unlimited funds are spent}, \]

\[ t_2 = \text{date of ultimate price if } X = 0, \]

\[ \beta = \log_2 \left( \frac{t_2 - t_3}{t_3 - t_0} \cdot \frac{t_1 - t_0}{t_2 - t_1} \right) \]

\[ \gamma = D_1 \cdot \frac{t_1 - t_0}{t_2 - t_1} \]

\[ D_1 = \text{most likely annual spending level (millions)} \]

\[ t_1 = \text{most likely date for stage 2 at input spending level, } D_1 \]

\[ t_3 = \text{most likely date for stage 2 of module if annual spending } = 2D_1. \]

The functional form above was selected as a flexible form that can be made to conform to a variety of user-input shapes. See Little (1970).
The variables $t_0, t_1, t_2, t_3, D_1$ are parameters supplied by the user as optional input. The amount of annual TD spending, $D_1$, is a control variable.

The module price in the second stage is no longer a function of plant size, only of silicon prices:

$$P_{\text{MODULE}} = 0.70 + [(P_{\text{Si}} - 14) * \frac{84}{7000}]$$

The date of the end of this second stage, called the "PV Program Goal" technology stage, will be a function of the AR and D funding provided by the government. The functional form is identical to that defining the end of the intermediate technology stage:

$$T = (t_2 - t_0)[1 - \frac{X^8}{\gamma + X^8}] + t_0$$

where $X$ now represents the cumulative level of AR and D funding.

The third, or "AR and D Breakthrough" technology stage, represents an ultimate, low price for PV that will result from some as yet unknown technology. While the data for the beginning of this stage may be computed by the methods outlined above, the actual price is supplied by the PV1 model-user.

More complete details of the model are available in Lilien and Wulfe (1980).
REFERENCES


Hauser, John R., "Forecasting and Influencing the Adoption of Technological Innovations," working paper, Transportation Center, Northwestern University, September 1978.


3. **Verification of the PVI Model Algorithm**

The purpose of this chapter is to verify the PVI interactive computer program. Verification entails showing that the computer program is consistent with the PVI model methodology. (A complete description of the model methodology appears in the PVI user documentation, MIT-EL 80-026.) Since the PVI computer program is written in the PL/1 programming language, a familiarity with PL/1 is necessary to the understanding of the verification results. This chapter presents verification in two ways:

**Part 1:** Separation of the PVI computer program into many short self-contained sections of the program code, with an explanation of the code accompanying each section. Also, a variable description is provided for the first occurrence of each variable in the program.

**Part 2:** Corroboration of the results of a PVI model run with hand calculated values.

The first part forces the programmer to scrutinize individual sections of program code and thereby detect any inconsistencies between the program and the model methodology. The second part provides confirming evidence that the computer program is doing what it should be doing, and that its logic is correct.

Four hundred sixty nine utility regions were selected for inclusion in the PVI data base. To qualify for inclusion a utility must be a retailer of electricity. In the case of private utilities, only those that produce at or above 100 megawatts peak are included. Almost all of the private utilities listed in *Statistics of Privately Owned Utilities, 1977* meet this specification. In the case of public utilities, the
number which produce substantial amounts of electricity was too large to allow inclusion of each utility separately if computation costs were to be held within reason, but were also too great to ignore. A compromise was reached in which the largest public utilities, those that are listed on the McGraw-Hill Electrical World map, are included individually in the PV1 data base whereas all other utilities listed in *Statistics of Publicly Owned Utilities (1977)*, are aggregated on a statewide basis and formed into 50 aggregated utilities (one for each state in the continental U.S., Hawaii, and Washington, D.C.). Since the utilities which comprise these aggregated utilities are spread out statewide, the locations of the aggregated utilities were made the geographic centers of their respective states. The same procedure was used for the cooperative utilities.

Many utility districts in the United States are split into noncontiguous areas. Because insolation and regional influences vary over these areas, the noncontiguous areas were input into the PV1 data base as separate utility regions. The breakdown of the PV1 data base by utility type is as follows:

- Private Utilities 293
- Public and Federal Utilities 127
- Cooperative Utilities 49

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Although approximately sixty separate subroutines comprise the PV1 computer program, only four perform the computations of a model "run." These four are the subroutines verified in this chapter. The most important of the four, algor, calls the other three. In accordance with Part 1 of verification, algor is broken into many smaller sections and an explanation of each section is given.
3.1 Verification: Part 1

Once the user has created a model in PV1, he or she can run the model by issuing the "run" command. The "RUN" subroutine in PV1 then passes control to the subroutine, algor, at which time the variable initializations and computations begin. Algor is also given access to the PV1 data base. To aid the conceptual layout of the PV1 algorithm, Figure 1 presents a general flowchart of how the program functions. All steps in Figure 1 are completed in algor except: the calculations of four constants in the subroutine do_greeks; the calculation of module cost, a relatively simple operation conducted in the subroutine do_modcost; and the calculation of screen_factor, a significantly larger operation which takes place in the subroutine do_screens. Verification of the subroutines do_greeks and do_modcost, because of their simplicity, can adequately be fulfilled by Part 2 alone. The remainder of this Part 1 of the verification, therefore, consists of dividing algor into sections and explaining what each section does. In addition, do_screens is examined. The reader should refer to the program listing of algor in the appendix both for orientation as well as to find how subscripted variables are dimensioned. For example, priv_sales is a three-dimensional array with num_secs*num_districts*num_years elements, the first dimension referring to the number of sectors, the second to the number of utility districts, and the third to the number of years in the model. The first time each variable is encountered a brief explanation will be given. Non-computational lines of program code in algor are omitted from verification. The self-contained sections are separated by horizontal lines.
FIGURE 1

Time loop
Do time = 1 to num-years + 1

Limit last year's sales by market expansion factor, if necessary

\[ \text{time} = \text{num-years} + 1 \]

Yes

Finish

No

calculate module cost

Sector loop
Do sector = 1 to num-secs

Calculate gross systems costs

Region loop
Do region = 1 to num-districts

Calculate avg. size of array, net systems costs, available market effective sites, PV savings, buy back savings, payback

Calculate screen factor

Calculate private sales (sector, region, time)

End

End

End
Section 1

Algor begins with the following variable initializations:

\[
\text{priv sales}(*,*,*) = 0; \text{ where priv sales}(i,r,t) \text{ is private sales in Kwp in sector } i, \text{ region } r, \text{ at time } t.
\]

\[
\text{kw raw md}(,*) = \text{raw md}(,*) ; \text{ where raw md}(i,t) \text{ is government MD purchases in sector } i \text{ at time } t \text{ (in Kwp or millions of $)}
\]

\[
\text{sec sales}(*,-1) = 250; \text{ total PV sales in two years previous to sec sales}(*,0) = 300; \text{ beginning of model in Kwp seed values.}
\]

\[
\text{cum sites}(*,*) = 0; \text{ where cum sites}(i,r) \text{ is cumulative installations in sector } i, \text{ region } r.
\]

\[
\text{asrnd} = 0; \text{ cumulative technology development spending}
\]

\[
\text{advrnd} = 0; \text{ cumulative advanced research and development spending}
\]

\[
\text{hd sqrd} = \text{half distance} * \text{half distance}/2; \text{ where half distance is the distance where an installation has half the interaction effect it would have if it were located nearby. hd sqrd is the interaction factor used in calculating effective installations. half distance is a level 2 default variable, with a default of 125 miles.}
\]

\[
\text{replace} = 1/40; \text{ replace is the fraction of existing homes which must be replaced each year.}
\]

\[
\text{pv sales}(*,*) = 0; \text{ where pv sales}(r) \text{ is cumulative sales in the central power sector in region } r \text{ (in Kwp).}
\]

\[
\text{prev purch}(*,*) = 0; \text{ where prev purch}(i,r) \text{ is the fraction of the available market in sector } i, \text{ region } r \text{ who have already purchased PV. This is the fraction of the current available market.}
\]

Section 2

do r=1 to num districts;
   hundred = trunc(r/100);
   increment(r) = trunc((r-100 * hundred)/20);
end;

This group of statements puts central power sectors into five different groups. It is assumed that a decision to build new capacity is made once every five years at a utility. To avoid all utilities making
that decision in the same year, they have been equally distributed into five groups, each corresponding to a different year in the range \((0, 1, 2, 3, 4)\). These values are incremented each year of the model, and when increment \((r)\) equals 5, that is the year of the utility's new capacity decision.

**Section 3**

call do_greeks (beta, gamma);

This subroutine performs two calculations to derive beta and gamma, if not specified by the user. These constants are used in determining when Stage 2 and Stage 3 technologies will arrive.

**Section 4**

call do_screens $ prepare ();

This entry into do-screens initializes awareness of PV to 0 for all sectors in all regions.

**Section 5**

do i= 1 to num_secs;
do r = 1 to num_districts;
cur_ac_cost(i,r) = rates (ssn(i),r)/(1 + rate_rise);
end;
end;

Where ssn(i) is the sector type of sector \((i)\). There are six specified sector types \((re, cm, in, ot, ag, cp)\).

rates (ssn(i),r) is the short-run marginal rate of electricity for this sector in region \(r\) (this is a database variable)

rate_rise is the annual rate rise of electricity in real terms

These statements initialize the current marginal rate \((cur_ac_cost(i,r))\) to last year's rate.
The program now enters the time loop which appears at the top of Figure 1. All statements prior to this time loop will not be executed again.

```plaintext
do t = 1 to (num_years + 1);
```

Section 6

if t > 2 then do;
  curr_watts = sum(priv_sales(*,*,t-1)) + sum(raw_md(*,t-1));
  last_watts = sum(priv_sales(*,*,t-2)) + sum(raw_md(*,t-2));
  mkt_exp_factor = .3 + 1.7 * exp (-.11091 * (t-2));
  if (curr_watts > (1 + mkt_exp_factor) * last_watts then
    priv_sales(*,*,t-1) = priv_sales(*,*,t-1) * (1 + mkt_exp_factor) * last_watts / curr_watts;
end;

These statements compare total sales in year (t-1) with those in year (t-2). The market expansion factor (mkt_exp_factor) limits total sales in year (t-1), curr_watts, to a maximum of (1 + market expansion factor) times total sales in year (t-2), last_watts. If sales must be limited then they are limited by scaling down sales in proportion to the PV sales in each sector in each district until their sum is equal to total sales in year (t-2) times the market expansion factor.

Section 7

if t > 1 then do;
  do i = 1 to num-secs;
    do r=1 to num_districts;
      cum_sites(i,r) = cum_sites(i,r) + (raw_md(i,t-1) * md_alloc(i,r,T-1) + priv_sales(T,r,t-1))/avg_size(i,r) * pv_effic;
      res_factor = .25;
      if (sectors.type(i) = "nw") then prev_purch(i,r) = 0;
      else if (sectors.type(i) = "rf") then prev_purch (i,r) = prev_purch(i,r) + priv_sales(i,r,t-2)/(avg_size(i,r) * pv_effic * pot_inst(ssn(i),r) * res_factor);
```
if ssn(i) > 1 then res_factor = 1;
else if pot_inst(ssn(i),r) > 0 then
prev_purch(T,r) = prev_purch(i,r)/g_rate(i,r)
+ priv_sales(i,r,t-1)/(avg_size(i,r) * pv_effic
* pot Inst(ssn(i),r) * g_rate(i,r)**(t) * res_factor):
sec_sales(T,t-1) = sec_sales(T,1) + priv_sales(T,r,t-1);
if (ssn(i) = 6 and cum_sites(i,r) > 0)
then cum_sites(i,r) = 1;
end;
end;

In this section cumulative installations are incremented by last
years sales. Note that md_alloc(i,r,t-1) is the fraction of MD allocated
to sector i, region r in time t-1. pv_effic is the system efficiency and
avg_size(i,r) is the average size of an installation in m² in sector
i, region r. g_rate(i,r) is the data base value for the growth rate of
sector i, region r, a value obtained by taking the geometric mean of
state population growth rates for the years 1970 through 1977.
res_factor is the fraction of the existing homes market which has roof
space facing in the south direction.

Note that prev_purch(i,r) must be calculated according to sector
type. Since the market expansion factor may have limited total sales for
the previous year, it is necessary to calculate prev_purch(i,r) after any
necessary limitations have been made.* Thus, if the sector type is new
residential, "nw", then prev_purch(i,r) is set to zero, since the
fraction of the new residential market who have purchased PV in earlier
years must be zero. If the sector type is retrofit, "rf", then the
fraction of the available market who previously purchased is calculated
assuming the market experiences no growth rate. All other sector types
(re, cm, in, it, ag, cp), experience growth through time, and in these

*Prev_purch(i,r) is used in the market screens to reduce the expected
percentage of potential customers by the amount who have already
purchased.
cases prev_purch(i,r) is adjusted for this growth. If the sector is a residential sector (rf or re), then the size of the available residential market is adjusted by res_factor (.25).

Sec_sales(i,t-1) are calculated for the previous year and cumulative installations in the central power sector (ssn(i)=6) are set to 1 if greater than 1 since a utility is a customer of one and only one.

if (t >= arr_date(1)) then tech_dev(t) = 0;
if (t >= arr_date(1)) then tech_dev_priv(t) = 0;
if (t >= arr_date(1)) then arnd(t) = 0;
advrnd = advrnd + arnd(t);
techn_dev(t) = tech_dev(t) + tech_dev_priv(t);
arsnd = arsnd + tech_dev(t);

where
arr_date(1) is the date Stage 2 Technology arrives
arr_date(2) is the date Stage 3 Technology arrives
techn_dev(t) is government TD spending in year t
neg_dev(t) is private TD spending in year t
arnd(t) is ARND spending in year t

Private and government TD spending are set to 0 once Stage 2 arrives, and ARND spending is set to 0 once Stage 3 arrives, their purposes being fulfilled at these points.

Cumulative TD and ARND are incremented to be used in calculating Stage 3 arrival dates in the subroutine do_modcost.

---

Section 8

cur_ac_cost(*,*) = cur_ac_cost(*,*)*(1 + rate_rise);
sili_cost(t) = sili_cost(T-1)*(1 + sili_rise);
ps_factor = sum(sec_sales(*,t-1)) + foreign_sales(t-1))/4000;
mod_cost = do_modcost (t,arsnd,advrnd,ps_factor,beta,gamma);

The first two statements increase the marginal rates of electricity and the cost of silicon. ps_factor is the plant size factor, defined as the size of the plant in MW_p required to produce 1/4 of total MW_p.
purchased. This variable is used to calculate the module cost in the subroutine do_modcost. do_modcost has three module cost functions which correspond to the stages in technology. Their functional forms are defined in the PV1 User Documentation.

Section 9

growth_rate = sum(sec_sales(*,t-1))/sum(sec_sales(*,t-2));
mkt_exp_factor = .3 + 1.7 * exp (-.11091 * Tt-l));
if (1 + mkt_exp_factor) > growth_rate then limit = 1;
else limit = (1 + mkt_exp_factor)/growth rate;
if t=1 then limit = 1;
do j=1 to num_secs:
    if (sec_sales (j,t-1) > sec_sales (j,t-1)/3) then
        est_sales(j) = limit * sec_sales (j,t-1) * sec_sales (j,t-1)
        / sec_sales (j,t-2);
    else est_sales (j) = sec_sales (j,t-1);
end;

This section estimates sector sales for the current year (est_sales(j)).

Section 10

The program now enters the sector loop, found midway down in Figure 1. Each time the beginning of this loop is entered, the number of the sector being worked on is printed as output.

do i = 1 to num_secs:

Section 11

eff_sales = 0;
do j=1 to num_secs:
eff_sales = est_sales (i) * exper_influ(i,j) + eff_sales;
end;

where eff_sales is the effective estimated sales in sector i

These statements calculate effective sales, taking into account the
effects of cross-sectoral cost declines with the variable array
exper_influ(i,j), a set of cross-sectoral influence coefficients.

Section 12

\[ \text{pcu\_cost} = \text{intercepts}(1) + \text{slopes}(1) \times \log_{10}(\text{eff\_sales}/1000+1); \]

\[ \text{s\_ns\_cost} = \text{intercepts}(2) + \text{slopes}(2) \times \log_{10}(\text{eff\_sales}/1000+1); \]

\[ \text{ind\_cost} = \text{intercepts}(3) + \text{slopes}(3) \times \log_{10}(\text{eff\_sales}/1000 + 1); \]

\[ \text{gross\_sys\_costs}(i,t) = (\text{modcost} \times (1 + \text{pv\_markup}) + \text{pcu\_cost} + \text{s\_ns\_cost}) \times (1 + \text{ind\_cost}); \]

where

- \text{pcu\_cost} = \text{power conditioning cost}/W_p
- \text{s\_ns\_cost} = \text{structures and installation costs}/W_p
- \text{ind\_cost} = \text{indirect costs}
- \text{gross\_sys\_costs}(i,t) = \text{gross systems cost for sector i at time t}
- \text{pv\_markup} is the markup by the pv manufacturer

Section 13

if \( \text{raw\_md}(i,t) < 0 \) then \( \text{raw\_md}(i,t) = 1000 \times \text{raw\_md}(i,t) / \text{gross\_sys\_costs}(i,t); \)

This statement puts government MD spending in terms of Kw_p if MD had been previously specified in millions of dollars.

Section 14

The program now enters the region loop which can be found about
two-thirds of the way down on Figure 1.

\[ \text{do } r = 1 \text{ to num\_districts}; \]

Section 15

if \( \text{ssn}(i) = 1 \) then do;
  \text{reacal} = "0"b;
  \text{var\_cost} = (\text{s\_ns\_cost} \times 1000 \times \text{pv\_effic} + \max(0, \text{pcu\_cost} \times 1000 \times \text{pv\_effic} - 689/35) + (1 + \text{pv\_markup}) \times \text{modcost} \times \text{pv\_effic} \times 1000) \times (1 - \text{subsidy}(i,t));
again:

\[ \text{avg\_size}(i,r) = \text{avg\_use}(\text{ssn}(i),r) \times \text{cur\_ac\_cost}(i,r) \times (1 - \text{buy\_back}(t)) \times .1224/((1 + \text{mtn\_cost}) \times \text{var\_cost} \times .1175 - \text{buy\_back}(t) \times (\text{cur\_ac\_cost}(i,r) \times \text{insolation}(r) \times \text{pv\_effic}); \]
if recalc = "1"b then go to out;
if subsidy(i,t) = 0 then go to out;
if (avg size(i,r) > submax(i,t)/subsidy(i,t) * gross sys costs(i,t) * 1000 * pv effic)) then do;
    var cost = gross_sys_costs(i,t) * T000 * pv_effic-submax(i,t)/35;
    recalc = "1"b;
    go to again;
end;
out:

This section calculates the average size of a PV installation in the residential sector. The calculation of average size is based on the variable cost of an array. There are two equations for this calculation. The first is used if the total subsidy is less than the subsidy ceiling. The second is used otherwise.

Section 16

if (avg_size(i,r) < 0 avg_size(i,r) > 90) then
    avg_size(i,r) = 90;
if avg_size (i,r) < 10 then avg_size (i,r) = 10;
end;

if ssn(i) > 1 then avg_size (i,r) = 300;
if ssn(i) = 6 then avg_size (i,r) = 25000/pv_effic;

These statements do the following:
1) Restrict average size of installations to the range
   10-90m² for residential
2) Set average size to (25000/pv_effic) m² for central power
   This is the minimum installation size a utility would adopt.
3) Set average size to 300 m² for all other sector types

Section 17

net_sys_costs(i,t) = max(gross_sys_costs(i,t) - (submax(i,t)/
    (1000 * pv_effic * avg_size(i,r)),gross_sys_costs(i,t)*
    (1_subsidy"(i,t)));
where \( \text{net\_sys\_costs}(i,t) \) is the subsidized system cost for sector \( i \) in year \( t \).

\( \text{submax}(i,t) \) is the maximum subsidy for an installation for sector \( i \) in year \( t \).

\( \text{subsidy}(i,t) \) is the subsidy faction for sector \( i \) in year \( t \).

**Section 18**

if sectors\_type\((i) = "nw" \) then do;

\[
\text{availmkt} = \text{pot\_inst}(1,r) \times \text{g\_rate}(1,r) \times (\text{g\_rate}(1,r) - 1 + \text{replace}) \times \text{avg\_size}(i,r) \times \text{pv\_effic};
\]

go to leap;

end;

Available market in the new residential sector is calculated in this section.

**Section 19**

if sectors\_type\((i) = "rf" \) then do;

\[
\text{adjust} = 0;
\]

if \( i > 1 \) then do;

if sectors\_type\((i-1) = "nw" \) then \( \text{adjust} = \text{cum\_sites}(i-1,r) \);

end;

\[
\text{availmkt} = \text{pot\_inst}(1,r) \times \text{g\_rate}(1,r) \times (1\times\text{replace}) \times \text{cum\_sites}(i,r) - \text{adjust} \times \text{avg\_size}(i,r) \times \text{py\_effic};
\]

\[
\text{availmkt} = \text{availmkt} - .75\times\text{pot\_inst}(1,r)\times\text{avg\_size}(i,r) \times \text{pv\_effic};
\]

go to leap;

end;

Available market in the retrofit residential sector ("rf") is calculated in this section. The variable "adjust" adjusts the market for sales in the new residential market since new residential homes enter the retrofit market after 1 year, if no PV is purchased.

**Section 20**

\[
\text{availmkt} = (\text{pot\_inst}(1,r) \times \text{g\_rate}(\text{ssn}(i),r) \times (\text{cum\_sites}(i,r)) \times \text{avg\_size}(i,r) \times \text{pv\_effic};
\]
if (sectors type (i) = "re") then availmkt = availmkt - (.75-replace) * pot_inst(ssn(i),r) * avg_size(i,r) * pv_effic;

The first program statement calculates the available market for all sectors except for new and retrofit residential. The second statement reduces the available market of the total residential sector by the fraction of homes without south-facing roof space.

Section 21

leap:

if ssn(i) = 6 then do;
  growth = g_rate (1,r) - 1;
  if growth < 0 then growth = 0;
  increment (r) = increment (r) + 1;
  pv_market(r) = avg_use(1,r) * g_rate(1,r)**(t-2) * growth + (avg_use(6,r) * g_rate(1,r)**(5 * new_capacity (r)) - pv_sales(r)) *rep)/insolation (r) + pv_market(r);
  if increment (r) < 5 then availmkt = 0;
else do;
  availmkt = pv_market(r);
  increment(r) = 0;
  new_capacity (r) = new_capacity (r) + 1;
end;
end;

This section calculates the available market for the central power sector. As mentioned earlier, a utility's decision to purchase new capacity occurs once every five years. This is built into the calculation.

The variable "rep" is the fraction of current capacity which must be replaced annually and is set earlier to .05. Note that avg_use (i,r) is a data base variable and is the total electricity usage in the region.

Section 22

eff sites = 0;
do J=1 to num_secs;
  do k = 1 to 10;
This section calculates the effective number of installations in a region by summing PV installations of the ten closest regions weighted by sector and distance interaction effects. The variables `reg(r).neighbor(k)` and `reg(r).distance(k)` represent respectively the utility identifier and distance from region `r` of the `k`th neighbor.

### Section 23

```plaintext
eff_sites = eff_sites + sec_influ(j,i) * cum_sites(T,reg(r).neighbor(k)) * min(hd_sqrd/ reg(r) distance (k) **2,1)
end;
end;

do j = 1 to num secs;
  eff_sites = eff_sites + cum_sites(j,r) * sec_influ(j,i);
end;

pvsave = cur_ac_cost(i,r) * avg_use(ssn(i),r) *(-.1674 + .1224 * log(avg_size(i,r)));
bbsave = cur_ac_cost(i,r) * buy_back * (insolation(r) * pv_effic * avg_size(i,r) - avg_use(ssn(i),r) * (-.1674 + .1224 * log(avg_size(i,r))));
if bbsave < 0 then do;
  bbsave = 0;
  pvsave = cur_ac_cost(i,r) * insolation(r) * pv_effic * avg_size(i,r);
end;
if ((bbsave + pvsave - mtn_cost * net_sys_costs(i,t) * avg_size(i,r) * 1000 * pv_effic) > 0) then
  payback = net_sys_costs(i,r) * avg_size(i,r) * 1000 * pv_effic /
            (bbsave + pvsave - (mtn_cost * net_sys_costs(i,t) * avg_size(i,r) * 1000 * pv_effic));
else payback = 100;
```

This section computes annual electricity savings (`pvsave`) and buyback revenues (`bbsave`) and from these values calculates a simple payback where total annual savings are equal to electricity savings plus buyback savings minus annual maintenance costs. If total annual savings are negative then payback is arbitrarily set to 100 years.
Section 24

screen_factor = do_screens (i,r,t,eff_sites,payback, run_ptr,roi ptr,prev_purch (i,r));

Control is passed from algor to the procedure do_screens. Since do_screens is a simple but tediously long program, an outline will be sufficient.

The market screen factor is computed in do_screens in the following equation:

\[
\text{screen factor} = \text{warr screen} \times \text{inst screen} \times \text{life screen} \times \text{payback screen} \times \text{aware screen} \times \text{dist screen} \times \text{prob\text{purch}()};
\]

where
- \text{warr screen} = warranty screen
- \text{inst screen} = installation screen
- \text{life screen} = system lifetime screen
- \text{payback screen} = payback screen
- \text{aware screen} = awareness screen
- \text{dist screen} = distribution screen
- \text{prob\text{purch}()} = probability of purchase given the system is found acceptable

Values for the first four screens are found by table look-up. For instance, if payback = 15 years then a table look-up would find the corresponding fraction of people who find the system acceptable to be four percent in the residential sector. (The value is sector dependent.) Since table indices are discrete, the program approximates values through simple linear interpolations.

The awareness screen is calculated by

\[
\text{aware screen} = .75 \times \text{last aware}(r) + (1-.75 \times \text{last aware}(r)) \times (1-\exp(-13.86 \times \text{eff\_ad\_dollars}));
\]
if ssn(i) = 6 then aware_screen = 1;

where
- \text{last aware}(r) is awareness in the last year in region r
- \text{eff\_ad\_dollars} is the effective advertising dollars spent by government in millions

The second programming statement sets awareness to 1 in the central
power sector, it being assumed that all utilities will be aware of PV.

Effective advertising dollars are computed as

\[
delta = 0.60
\]

\[
eff_{\text{ad}}\text{dollars} = (\text{ad\_percentage}(t) + \delta) \times (\text{sum}(\text{raw\_md}(*,t)) \times \text{gross\_sys\_costs}(k,t) \times \text{md\_alloc}(k,r,t))/1000;
\]

where

- \( \text{ad\_percentage}(t) \) is the fraction of regional MD spending spent additionally on advertising.
- \( \delta \) is the fraction of MD spending that in itself has advertising effectiveness.

Note that dist\_screen and probpurch() are set in the system.

Finally, adjustment must be made for previous purchasers of PV. This is achieved by reducing all of the acceptance screens by the fraction who previously purchased times a normalizing factor. For example, the lifetime screen is adjusted as

\[
\text{life\_screen} = (\text{life\_screen} - \text{prev\_purch})/(1 - \text{prev\_purch});
\]

Section 25

\[
\text{priv\_sales}(i,r,t) = \text{availmkt} \times \text{screen\_factor};
\]

if \( \text{ssn}(i) = 6 \) then do;

- if \( \text{priv\_sales}(i,r,t) < 25,000 \) then \( \text{priv\_sales}(i,r,t) = 0; \)
- \( \text{pv\_sales}(r) = \text{pv\_sales}(r) + \text{priv\_sales}(i,r,t); \)
- if \( \text{pv\_sales}(r) > 0 \) then \( \text{cum\_sites}(i,r) = 1; \)
end;

finish;
end;

Private sales in sector \( i \), region \( r \) at time \( t \) are calculated. If the sector is central power then sales are set to 0 unless sales are greater than 25000 kWp - we assume this is a minimum purchase.

This concludes Part 1 of the verification. All computational statements in algor have been examined and are correct.
3.2 Verification: Part 2

A seven sector, three year model was created and run using data from only three utility districts, CA1010, WI1470 and FL2180. The reason for using three utilities instead of all 469 in the data base is that verification by hand calculations is made much easier and that verification can be generalized by induction to the entire database with no loss of validity. These hand calculations were performed exhaustively for the new residential sector of CA1010 and superficially for the WI1470 and FL2180 new residential sectors. This part of the verification entails demonstrating that the hand calculations coincide with the PV1 model results which appear in the appendix. It is designed to show that the PV1 computer program iterates correctly over each utility district and that the aggregation of model results is performed successfully.

The text which follows first gives the data base values that algor used in its computations. Next are the step by step hand calculations for the new residential sector of CA1010, which through successive stages, generated values for net and gross systems costs, available market size and finally private sales in peak kilowatts. Most variables are intermediate values, although several, such as gross_sys_costs(1,1) can be found in the PV1 results in the appendix. The variable of key importance is priv_sales(i,r,t), which in the PV1 results is an aggregated value over the three utility districts. Private sales in the new residential sector of the three utility districts are hand calculated, summed and compared with the PV1 result for verification of the PV1 aggregation procedure.
### 3.2.1 Data Base Values for the Three Utilities

The following data base values for the three utility districts correspond identically with the input values on coded keypunch forms. In addition, a random check of twenty other utilities' data base values showed identical correspondence with input values. Those checks strongly indicate that the data base has been created successfully.

<table>
<thead>
<tr>
<th></th>
<th>CA1010</th>
<th>WI1470</th>
<th>FL2180</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>1</td>
<td>155</td>
<td>370</td>
</tr>
<tr>
<td>insolation</td>
<td>2058</td>
<td>1575</td>
<td>1965</td>
</tr>
<tr>
<td>g-rate</td>
<td>1.01317</td>
<td>1.007152</td>
<td>1.03199</td>
</tr>
<tr>
<td>pot-inst</td>
<td>2.713x106</td>
<td>2.419x105</td>
<td>1.873x105</td>
</tr>
<tr>
<td></td>
<td>4.06x105</td>
<td>29,630</td>
<td>20,470</td>
</tr>
<tr>
<td></td>
<td>768</td>
<td>688</td>
<td>506</td>
</tr>
<tr>
<td></td>
<td>13,400</td>
<td>890</td>
<td>1,253</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>avg-use</td>
<td>6,407</td>
<td>7,813</td>
<td>11,169</td>
</tr>
<tr>
<td></td>
<td>52,880</td>
<td>28,559</td>
<td>39,922</td>
</tr>
<tr>
<td></td>
<td>1.747x107</td>
<td>2.833x106</td>
<td>3.571x106</td>
</tr>
<tr>
<td></td>
<td>1.065x105</td>
<td>80,146</td>
<td>56,676</td>
</tr>
<tr>
<td></td>
<td>8,000</td>
<td>8,000</td>
<td>8,000</td>
</tr>
<tr>
<td></td>
<td>5.37x1010</td>
<td>4.757x109</td>
<td>4.78x109</td>
</tr>
<tr>
<td>rates</td>
<td>.0563</td>
<td>.0439</td>
<td>.0375</td>
</tr>
<tr>
<td></td>
<td>.0461</td>
<td>.0416</td>
<td>.0305</td>
</tr>
<tr>
<td></td>
<td>.0360</td>
<td>.0267</td>
<td>.0140</td>
</tr>
<tr>
<td></td>
<td>.0343</td>
<td>.0445</td>
<td>.0180</td>
</tr>
<tr>
<td></td>
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<td>.02</td>
</tr>
<tr>
<td></td>
<td>.02</td>
<td>.02</td>
<td>.02</td>
</tr>
</tbody>
</table>
3.2.2 Verification of Subroutine do greeks

do_greeks calculates values for two parameters used in Stage 2 and Stage 3 arrival date equations. The functional terms of these parameters are:

Stage 2

\[ \beta(1) = \log_2 \left( \frac{t_2 - t_3}{t_3 - t_0} \cdot \frac{t_1 - t_0}{t_2 - t_1} \right) \]

\[ \gamma(1) = D_1^{\beta(1)} \cdot \frac{t_1 - t_0}{t_2 - t_1} \]

where

- \( t_0 \) = earliest possible date for Stage 2 if unlimited TD funds are spent
- \( t_1 \) = most likely date for Stage 2 at input level TD = \( D_1 \)
- \( t_2 \) = date of ultimate price if TD = \( D_1 = 0 \)
- \( t_3 \) = most likely date for Stage 2 of module if TD = 2\( D_1 \)

Stage 3

Calculations of \( \beta(2) \) and \( \gamma(2) \) for Stage 3 have the same functional form as Stage 2, but the input parameters have the following meanings:

- \( t_0 \) = earliest possible date for Stage 3 if unlimited funds are spent
- \( t_1 \) = most likely date for Stage 3 at input spending level ARND = \( D_1 \)
- \( t_2 \) = date of ultimate price if ARND = \( D_1 = 0 \)
- \( t_3 \) = most likely date for Stage 2 of module if ARND = 2\( D_1 \)

The hand calculated values for these variables yield:
Stage 2

\[ \beta(1) = \ln\left(\frac{30-5}{5-3}\right) \times (\frac{8-3}{30-8})/\ln(2) \]
\[ = 1.51 \]
\[ \gamma(1) = (50^{**1.51}) \times (8-3)/(30-8) \]
\[ = 82.37 \]

Stage 3

\[ \beta(2) = \ln\left(\frac{50-9}{9-6}\right) \times (\frac{14-6}{50-14})/\ln(2) \]
\[ = 1.60 \]
\[ \gamma(2) = (50^{**1.60}) \times (14-6)/(50-14) \]
\[ = 117.4 \]

Since these values are used in subroutine `do_modcost` to determine Stage 2 and Stage 3 arrival dates, it is assumed that the parameter values are correct since the arrival date values are also correct (see below).

3.2.3 Verification of Subroutine `do_modcost`

A copy of `do_modcost` resides in the appendix. The logic of this subroutine is as follows:

1) Using parameters beta and gamma from `do_greeks` calculate the arrival dates of Stage 2 and Stage 3 technologies. The hand calculated values were identical to the values calculated by PV1.

2) Use cost decline function 1 if Stage 2 technology has not arrived yet. Use function 2 if Stage 2 has arrived but Stage 3
has not. Set the module cost equal to the ultimate price (a level 2 default currently set to $1.00) if Stage 3 has arrived. The functional forms of these cost functions were checked with the PV1 User Documentation equations and were found to be identical. The only remaining check needed for verification of do_modcost is that the value of the module cost is passed correctly. Since this value is used in computing gross systems cost, and the hand calculation of gross system cost was identical to that computed by PV1, do_modcost must have passed the correct value.

3.2.4 Year 1 Hand Calculations: CA1010 Sector New Residential

The following hand calculations for the new residential sector of utility CA1010 are used to verify the results of the PV1 run found in the appendix. Two hand calculated values for the variables, gross_sys_costs(1,1) and net_sys_costs(1,1) can be directly compared to values in the PV1 output for gross and net systems costs for sector new residential in year 1. These values are identical. Unfortunately, it is impossible to compare hand calculated private sales directly since the PV1 output is aggregated over the three utility districts, but it is possible to verify private sales by first using the hand calculated value of private sales for CA1010 and then adding the PV1 calculated values of private sales (which are in part obtained using a debug procedure on MULTICS), summing them with the hand calculated value, and comparing with the PV1 aggregated value. If the summed value is identical with the PV1 aggregate value then PV1 is verified.

The values of the hand calculations for the new residential sector of CA1010 are as follows:
asrnd  =  0 + 52
cur_ac_cost(*,*) + rates (*,*)
sili_cost = 84
ps_factor = 7*300/4000 = .525
modcost = (2.83 - (84-84) * 94/7000 + 2.4/1525) = 7.40
growth rate = 300/250 = 1.2
mkt_exp_factor = .3 + 1.7(exp(-.1109 * 0) = 2
limit = 1
est_sales (1) = 300 * 300/250 = 360
(2) = 360
(3) = 360
(4) = 360
(5) = 360
(6) = 360
(7) = 360

i=1
eff_sales = 360 * (1+1+.3+.2) = 900
cu_cost = .90 - .31 * log10(900/1000 + 1) = .8136
s_n_s_cost = .52 - .14 * log10(1.9) = .481
ind_cost = .25 - .07 * log10(1.9) = .2305
gross_sys_costs(1,1) = (7.40(1.2) + .8136 + .481) 1.2305 = 12.52
raw_md(1,1) = 1000 * 10/12.52 = 799
fixed_cost = 1779
var_cost = -38.31
avg_size = 90
net_sys_costs(1,1) = 0
availmkt = (2.713x10^6 * 1 * (.01317 + 1.40)) * 90 * .12
         = 1.1184x10^6
eff_sites = 0
pvsave = .0563 * 6407 * (-.1674 + .1224 * ln(90)) = 138.29
bb/save = .0563 * .6 * (2058 * .12 * 90 - 6407 * (-.677 + .1224
            *ln(90))) = 667.83
payback = 0
\[ \text{eff_ad_dollars} = (0.6 + 0.2) \times 55 \times 0.003425 = 0.1507 \]

\[ \text{life_screen} = 0.2564 \]

\[ \text{warr_screen} = 0.2558 \]

\[ \text{inst_screen} = 0.07 \]

\[ \text{payback_screen} = 1 \]

\[ \text{aware_screen} = 1 - \exp(-13.86 \times 0.1507) = 0.8762 \]

\[ \text{dist_screen} = 0.5 \]

\[ \text{probpurch()} = 0.1 \]

\[ \text{screen_factor} = 0.0006718 \]

\[ \text{priv_sales(1,1,1)} = 0.0006718 \times 1.1184 \times 10^6 = 751 \]

Thus, private sales in the new residential sector of CA1010 are 751 peak kilowatts.

To calculate sales in the other two utility districts, values must first be computed for the available markets of new residential for WI1470 and FL2180 in year 1:

\[ \text{WI1470: availmkt} = (2.419 \times 10^5 \times 1 \times (0.007152 + 1/40)) \]
\[ \times 90 \times 0.12 = 83,998 \]

\[ \text{FL2180: availmkt} = (1.873 \times 10^5 \times 1 \times (0.031995 + 1.40)) \]
\[ \times 90 \times 0.12 = 115,292 \]

Using the MULTICS debug subroutine, Probe, values for the screen factor for WI1470 and FL2180 were obtained.

\[ \text{WI1470: screen_factor} = 1.89969 \times 10^{-4} \]

\[ \text{FL2180: screen_factor} = 2.0700 \times 10^{-4} \]

Private new residential sales in year 1 in these districts are

\[ \text{WI1470: priv_sales(155,1,1)} = 83,998 \times 1.89969 \times 10^{-4} \]
\[ = 15.96 \]

\[ \text{FL2180: priv_sales(370,1,1)} = 115,292 \times 2.0700 \times 10^{-4} \]
\[ = 23.87 \]
Thus, total new residential private sales in year 1 are:

$$751 + 16 + 24 = 791$$

Referring to the PV1 output in the appendix, it is found that new residential private sales in year 1 are identical to this hand calculated value. This result provides conclusive evidence that the aggregation procedures in PV1 function correctly.
4. Description of Data and Variables

The PV1 computer program uses information from a permanent data base in its model calculations. The information resides in two PL/1 data structures, run_data and misc_data. Copies of the PL/1 program code for these two data structures appear in the appendix. The purpose of this chapter is to acquaint the user with the variables which are used in performing calculations in the four subroutines which were verified in Chapter III. First, the list of data base variables is presented complete with descriptions of the sources of the data. Second is a list of all other variables which have roles in the calculations performed in the four subroutines but which are not permanently stored in the PV1 data base.

4.1 Description of the PV1 Data Base Variables

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>insolation(r)</td>
<td>kWh/m²·yr</td>
<td>SOLMET interpolated data</td>
</tr>
<tr>
<td>pot_inst(i,r)</td>
<td>000's of customers</td>
<td>There are three sources:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1) Private utilities - Statistics of Privately Owned Utilities, 1977</td>
</tr>
<tr>
<td>avg_use(i,r)</td>
<td>kWh/customer/yr</td>
<td>Same as pot_inst(i,r)</td>
</tr>
<tr>
<td>rates(i,r)</td>
<td>fraction</td>
<td></td>
</tr>
</tbody>
</table>
g_rate(i,r)  

reg(r).neighbor  

reg(r).distance  

"Estimates of the Population of Counties and Metropolitan Areas: July 1, 1979 and 1978," U.S. Department of Commerce


Distances between utilities calculated using longitude and latitude values of utility locations.

Note: Variables subscripted by i, r, and t are dimensioned by num_secs, num_districts, and num_years, respectively.
4.2 Description of Variables

Variable Name
num_secs[i]
num_years [t]
num_districts[r]
priv_sales(i,r,t)
raw_md(i,t)

kw_raw_nd(i,t)

sec_sales(i,t)
cum_sales(i,t)
asrnd
advrnd
replace
half_distance
hd_sqrd
rep
new_capacity(r)

pv_sales(r)
prev_purch(i,r)

beta
gamma
rate_rise
cur_ac_cost(i,r)
curr_watts
last_watts
mkt_exp_factor
md_alloc(i,r,t)
avg_size(i,r)

pv_effic
tech_dev(t)
tech_dev_priv(t)
arnd(t)
sili_cost(t)

Units
sectors
years
utility districts
Kw_p
Kw_p or millions of dollars
Kw_p or millions of dollars
Kw_p installations
Millions of dollars
Millions of dollars
fraction
miles
miles^2
percent
pure number
Kw_p
fraction
parameter-number
parameter-number
fraction
$/Kwh
Kw_p
Kw_p
pure number
fraction
meters2
fraction
millions of dollars
millions of dollars
millions of dollars
$/Kg
<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>sili_rise</td>
<td>fraction</td>
</tr>
<tr>
<td>ps_factor</td>
<td>number</td>
</tr>
<tr>
<td>modcost</td>
<td>$/Wp</td>
</tr>
<tr>
<td>growth_rate</td>
<td>fraction</td>
</tr>
<tr>
<td>limit</td>
<td>fraction</td>
</tr>
<tr>
<td>est_sales(i)</td>
<td>Kw_p</td>
</tr>
<tr>
<td>eff_sales</td>
<td>Kw_p</td>
</tr>
<tr>
<td>pcu_cost</td>
<td>$/Wp</td>
</tr>
<tr>
<td>sales_cost</td>
<td>$/Wp</td>
</tr>
<tr>
<td>ind_cost</td>
<td>fraction</td>
</tr>
<tr>
<td>gross_sys_costs(i,t)</td>
<td>$/Wp</td>
</tr>
<tr>
<td>pv_markup</td>
<td>fraction</td>
</tr>
<tr>
<td>fixed_cost</td>
<td>$/average installation</td>
</tr>
<tr>
<td>subsidy(t)</td>
<td>fraction</td>
</tr>
<tr>
<td>var_cost</td>
<td>$/installation</td>
</tr>
<tr>
<td>buy_back(t)</td>
<td>fraction</td>
</tr>
<tr>
<td>mtn_cost</td>
<td>fraction</td>
</tr>
<tr>
<td>insolation(r)</td>
<td>Kwh/m2_yr</td>
</tr>
<tr>
<td>submax(i,t)</td>
<td>$/installation</td>
</tr>
<tr>
<td>net_system_costs(i,t)</td>
<td>$Wp</td>
</tr>
<tr>
<td>adjust</td>
<td>installations</td>
</tr>
<tr>
<td>availmkt</td>
<td>Kw_p</td>
</tr>
<tr>
<td>pvsave</td>
<td>$/yr</td>
</tr>
<tr>
<td>bbsave</td>
<td>$/yr</td>
</tr>
<tr>
<td>payback</td>
<td>years</td>
</tr>
<tr>
<td>screen_factor</td>
<td>fraction</td>
</tr>
<tr>
<td>eff_ad_dollars</td>
<td>millions of dollars</td>
</tr>
</tbody>
</table>

Note: Variables subscripted by i, r and t are dimensioned by num_secs num_districts and num_years respectively.
algpor: procedure (run_ptr, roi_ptr);
%
%include model;
%include procedures;
%include run_data;

dcl (run_ptr, roi_ptr) pointer;
dcl (pcu_cost, s_n_s_cost, ind_cost, modcost) float;
dcl replace float;
dcl adjust float;
dcl (eff_sales, eff_sites) float;
dcl (screen_factor, ps_factor, advrnd, asrnd, hd_sqrd, d) float;
dcl value float;
dcl (beta(2), gamma(2)) float;  /* Parameters of module cost decline */
dcl availmkt float;
dcl cur_ac_cost (num_secs, num_districts) float;
dcl est_sales (num_secs) float;
dcl at (num_secs, num_districts) float;
dcl a2 (num_secs, num_districts) float;
dcl (b, c1, c2, payment, pv_elec_cost) float;
dcl avg_size(num_secs, num_districts) float;
dcl (curr_watts, last_watts) float;
dcl (growth_rate, mkt_exp_factor, limit) float;
dcl cum_sites (num_secs, num_districts) float;
dcl sec_sales (num_secs, -1:numyears) float;
dcl (growth, pv_market(480), new_capacity(480)) float;
dcl increment(480) fixed;
dcl (hundredrep, pv_sales(480)) float;
dcl kw_raw_md(num_secs, num_years) float;
dcl (pvsave, bbsave, ratio) float;
dcl no_bit init (*0'b), yes_bit init (*1'b);
dcl daylight float;
dcl (i, j, k, r, t, n) fixed;
dcl (beg_time, end_time) fixed bin (71);
dcl (start_pf, end_pf, z) fixed bin;
dcl cpu_time_and_paging_entry (fixed, fixed bin(71), fixed);
dcl sysprint file;
dcl recalc bit;
dcl var_cost float;
dcl prev_purch(num_secs, num_districts) float;
dcl payback float;
dcl res_factor float;
call cpu_time_and_paging_ (start_pf, beg_time, z);
put skip(2) list (*"Running");

priv_sales(*,*), = 0;
kw_raw_md(*,*), = raw_md(*,*);
sec_sales (*,-1) = 250;
sec_sales (*, 0) = 300;
cum_sites(*,*) = 0;
asrnd, advrnd = 0;

replace = 1/40;
hd_sqrd = half_distance * half_distance / 2;
rep = .05;
new_capacity(*) = 0;

dv_market(*) = 0;

dv_sales(*) = 0;

prev_purch(*,*) = 0;
do r = 1 to num_districts;
    hundred = trunc( r/100);
    increment(r) = trunc( (r-100*hundred) / 20 );
end;

call do_greeks (beta, gamma); /* Compute constants for mod cost decline. */
call do_screens$prepare();

do i = 1 to num_secs;
do r = 1 to num_districts;
    cur_ac_cost(i,r) = rates(ssn(i),r) / (1 + rate_rise);
end;
end;

do t = 1 to (num_years + 1);
    if t > 2 then do:
        curr_watts = sum( priv_sales(*,*,t-1) ) + sum( raw_md(*,t-1) )
        last_watts = sum( priv_sales(*,*,t-2) ) + sum( raw_md(*,t-2) )
        mkt_exp_factor = .3 + 1.7 * exp( -.11091 * (t-2) );
        if ( curr_watts > ( 1 + mkt_exp_factor ) * last_watts ) then
            priv_sales(*,*,t-1) = priv_sales(*,*,t-1) * ( 1 + mkt_exp_factor )
            *last_watts / curr_watts;
    end;
end;

if t > 1 then do:
do i = 1 to num_secs;
do r = 1 to num_districts;
    cum_sites(i,r) = cum_sites(i,r) + ( raw_md(i,t-1) * md_alloc(i,r,t-1)
        + priv_sales(i,r,t-1) ) / ( avg_size(i,r) * pv_effic );
    res_factor = 1;
    if (ssn(i) = 1) then res_factor = .25;
    if (sectors.type(i) = "nw") then prev_purch(i,r) = 0;
    else if (sectors.type(i) = "re" & pot_inst(ssn(i),r) > 0) then
        prev_purch(i,r) = prev_purch(i,r)/g_rate(1,r) + priv_sales(i,r,t-1)
        / (avg_size(i,r)*pv_effic*pot_inst(ssn(i),r)*g_rate(1,r)**(t)
        * (res_factor + replace));
    else if type(i) = "rf" then
        prev_purch(i,r) = prev_purch(i,r)/(1-replace+g_rate(1,r));
    else if pot_inst(ssn(i),r) > 0 then
        prev_purch(i,r) = prev_purch(i,r) / g_rate(1,r) + priv_sales(i,r,t-1) /
( avg_size(i,r)*pv_effic*pot_inst(ssn(i),r)*g_rate(1,r)**(t) )
    sec_sales(i,t-1) = sec_sales(i,t-1) + prev_purch(i,r,t-1)
    if (ssn(i) = 6 & cum_sites(i,r) > 0)
        then cum_sites(i,r) = 1;
end;

total_sites(i,t-1) = sum( cum_sites(i,*));
end;
end;
if t > num_years then go to finish;

put skip edit (".")(a); /* Write a blip */

if (t >= arr_date(1)) then tech_dev(t) = 0;
if (t >= arr_date(1)) then tech_dev_priv(t) = 0;
if (t >= arr_date(2)) then arnd(t) = 0;
advrnd = advrnd + arnd(t);
tech_dev(t) = tech_dev(t) + tech_dev_priv(t);

/* Write a blip */

if (t >= arrdate(1)) then techdev(t) = 0;
if (t >= arrdate(1)) then techdevpriv(t) = 0;

advrnd = advrnd + arnd(t);
techdev(t) = techdev(t) + tech-devpriv(t);

sillcost(t) = sill_cost(t-1) * (1 + sillrise);
ps_factor = (sum(sect_sales(*,t-1)) + foreign_sales(t-1)) / 4000;

modcost = do_modcost(t, asrnd, advrnd, ps_factor, beta, gamma);
growth_rate = sum( sect_sales(*,t-1)) / sum( sect_sales(*,t-2));
mkt_exp_factor = .3 + 1.7 * exp(-.1091 * (t-1));
if ( (1 + mkt_exp_factor) > growth_rate ) then limit = 1;
else limit = (1 + mkt_exp_factor) / growth_rate;

if t = 1 then limit = 1;
do j = 1 to num_secs;
  if (sec_sales(j,t-2) > sec_sales(j,t-1)/3) then
    est_sales(j) = limit * sec_sales(j,t-1) * sec_sales(j,t-1);
  else est_sales(j) = sec_sales(j,t-1);
end;
do i = 1 to num_secs;
put edit (i) (f(2));
eff_sales = 0;
do j = 1 to num_secs;
eff_sales = est_sales(i) * exper_influ(i,j) + eff_sales;
end;

pcu_cost = intercepts(1) + slopes(1) * log10( eff_sales/1000+1);
s_n_s_cost = intercepts(2) + slopes(2) * log10( eff_sales/1000+1);
ind_cost = intercepts(3) + slopes(3) * log10( eff_sales/1000+1);
gross_sys_costs(i,t) = (modcost*(1 + pv_markup) + pcu_cost + s_n_s_cost) * (1 + ind_cost);
if raw_md(i,t) < 0 then raw_md(i,t) = -1000 * raw_md(i,t)
/ gross_sys_costs(i,t);
do r = 1 to num_districts;
if ssn(i) = 1 then do:
  recalc = "0"b;
  var_cost = (s_n_s_cost*1000+pv_effic + max(0,pcu_cost*1000+pv_effic-689/35) +
(1+pv_markup)*modcost+pv_effic*1000)
*(1-subsidy(i,t));
again:
  avg_size(i,r) = avg_use(ssn(i),r)*cur_ac_cost(i,r)
  *(1-buy_back(t))*1224 / ((1+ mtn_cost)+var_cost*1.15 -
  buy_back(t)*cur_ac_cost(i,r)*insolation(r)*pv_effic);
  if recal = "1"b then go to out;
  if subsidy(i,t) = 0 then go to out;
  if (cur_cost(1) > subsidy(i,t)) / modcost(i,t)
*gross_sys_costs(i,t)=1000*pv_effic)) then do;
   var_cost = gross_sys_costs(i,t)*1000*pv_effic - submax(i,t)/35;
   recalc = 1*1;
   go to again;
end;

out: if(avg_size(i,r) < 0 | avg_size(i,r) > 90) then avg_size(i,r)=90;
if avg_size(i,r) < 10 then avg_size(i,r) = 10;
end;

if ssn(i) > 1 then avg_size(i,r) = 300;
if ssn(i) = 6 then avg_size(i,r) = 25000/pv_effic;
net_sys_costs(i,t)=max(gross_sys_costs(i,t)-(submax(i,t)/(11000pv_effic*avg_size(i,r))))
gross_sys_costs(i,t) * (1-subsidy(i,t)));

if sectors.type(i) = "nw" then do;
   availmkt = (pot_inst(1,r)*g_rate(1,r)**(t-1))
*avg_size(i,r)*pv_effic;
   go to leap;
end;

if (sectors.type(i) = "rf") then do;
   adjust = 0;
   if i > 1 then do;
      if sectors.type(i-1) = "nw" then adjust = priv_sales(i-1,r,t)
/(avg_size(i-1,r) * pv_effic);
   end;
   availmkt = (pot_inst(1,r)*g_rate(1,r)**(t-1)*adj)*avg_size(i,r)*pv_effic;
   availmkt = availmkt - .75*pot_inst(1,r)*avg_size(i,r)*pv_effic;
   go to leap;
end;

if (sectors.type(i) = "re") then availmkt = availmkt
- (.75-replace)*pot_inst(ssn(i),r)*avg_size(i,r)*pv_effic;
leap:
if availmkt < 0 then do;
   availmkt = 0;
end;
if ssn(i) =6 then do;
growth = g_rate(1,r) - 1;
if growth < 0 then growth = 0;
increment(r) = increment(r) + 1;
pv_market(r) = ( avg_use(6,r) * g_rate(1,r)**(t-2) * growth
+ ( avg_use(6,r) * g_rate(1,r)**(5*new_capacity(r))
- pv_sales(r)) * rep ) / insolation(r)
+ pv_market(r);
if increment(r) < 5 then availmkt = 0;
else do;
   availmkt = pv_market(r);
   increment(r)=0;
   new_capacity(r) = new_capacity(r) + 1;
end;
end;
eff_sites = 0;

do j = 1 to num_secs;
    do k = 1 to 10;
        eff_sites = eff_sites + sec_influ(j,1) * cum_sites(j,reg(r).neighbor(k))
            * min(hd_sqrd/reg(r).distance(k)**2,1);
    end;
end;

eff_sites = eff_sites + cum_sites(i,r);

pvsave = cur_ac_cost(i,r)*avg_use(ssn(i),r)*(-.1674+.1224*log(avg_size(i,r)));

bbsave = cur_ac_cost(i,r)*buy_back(t)*(insolation(r)*pveffic
            - avg_size(i,r)*avg_use(ssn(i),r)*(-.1674+.1224*log(avg_size(i,r))));

if bbsave < 0 then do;
    bbsave = 0;
    pvsave = cur_ac_cost(i,r) * insolation(r) * pveffic * avg_size(i,r);
end;

if ((bbsave+pvsave-mtn_cost*netsys_costs(i,t)*avgsize(i,r)*1000*pv.effic).
    > 0) then
    payback = net_sys_costs(i,t)*avg_size(i,r)*1000*pv.effic/(bbsave+
            pvsave - mtn_cost*netsyscosts(i,t)*avg_size(i,r)*1000*pv.effic);
else payback = 100;

screen_factor = do_screens (i, r, t, eff_sites, payback, run_ptr, roi_ptr, prev_purch(i,r));

priv_sales(i,r,t) = availmkt * screen_factor;

if ssn(i) = 8 then do;
    if priv_sales(i,r,t) < 25000 then priv_sales(i,r,t) = 0;
    pv_sales(r) = pv_sales(r) + priv_sales(i,r,t);
    if pv_sales(r) > 0 then cum_sites(i,r) = 1;
end;
end;

finish:
end;

do t = 1 to num_years;
    tech_dev(t) = tech_dev(t) - tech_dev_priv(t);
end;

raw_md(*,*) = kw rawData(*,*)

end_time = virtual_cpu_time();
call cpu_time_and_paging (end_pf, end_time, z);
end_time = end_time / 1000000;
begin_time = begin_time / 1000000;
put skip(2) list (*Algor took*, (end_time - begin_time), " seconds.");
put skip list (*Algor used ", (end_pf - start_pf), " page faults.");
end;
Procedure to compute the fraction of the available market that actually purchases PV. This fraction is computed as the product of a series of screens. Screens are based on things potential buyers find important when they make their purchase decisions. */

do_screens: procedure (k, r, t, eff_sites, payback, run_ptr, roi_ptr,
                   prev_purch) returns (float);

%include model;
%include run_data;
dcl (run_ptr, roi_ptr) pointer;
dcl (i,k, r, t) fixed;
dcl warr_life_table(19,11) float based (roi_ptr);
dcl warr_years(19) fixed init(1,2,3,4,5,6,10,12,15,18,
                           24,25,30,36,60,84,90,120);
dcl inot_inst_breaks(12) fixed init(1,2,3,4,5,6,7,10,15,20,25,50);
dcl cp_payback(5) float init(0,.32,.50,.68,1.0);
dcl cp_costs(5) float init(1.40,1.20,1.00,.80,.60);
dcl inot_inst_dist(12) float init(.104,.303,.676,.762,.887,.919,
                           .921,.946,.962,.968,.984,1.0);
dcl ag_inst_dist(11) float init(.439,.533,.57,.608,.645,.672,.698,.725,.751,.778,.848);
dcl inst_breaks(12) fixed init(1,2,3,4,5,6,8,10,12,20,25,50);
dcl inst_dist (12) float init(.14,.277,.440,.462,.696,.766,.772,
                           .864,.935,.957,.973,1.0);
dcl payback_dist(2,21) float init(1,1,0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0).
                           .20,.15,.12,.09,.07,.06,.04,.03,.02,.01,.01,.00,.66,.56,.46,
                           .39,.32,.26,.20,.15,.11,.09,.06,.04,.03,.02,.01,.01,.00,.00);
dcl pay_year fixed;
dcl pay_frac float;
dcl (warr_index,life_index) fixed;
dcl (a,b) float;
dcl life_years(11) float init(3,4,5,6,10,12,15,20,25,30,40);
dcl (dist_screen,aware_screen) float;
dcl (life_screen,warr_screen,inst_screen,payback_screen) float;
dcl (eff_sites, payback, prev_purch) float;
dcl screen_factor float;
dcl eff_ad_dollars float;
dcl delta float;
dcl j fixed;
dcl last_aware (475) float static;
dcl sqrt2 static float;

   if (t < beg_distrib) then return (0.0); /* no distribution yet */
   else dist_screen = .5;
   delta = .60;
   eff_ad_dollars = (ad_percentag2(t) + delta) * ( sum( raw_md(*,t) ) * gross_sys_costs(k,t)
       * md_alloc(k,r,t) ) / 1000;

   if ssn(k) = 1 then go to rescalc;
   if ssn(k) = 2 then go to commcalc;
   if ssn(k) = 3 then go to indcalc;
   if ssn(k) = 4 then go to othercalc;
if ssn(k) = 5 then go to agcalc;
if ssn(k) = 6 then go to indcalc;

commcalc:
if lifetime > 24 then life_screen = 1.0;
if (lifetime > 19 & lifetime < 25) then
  life_screen = .801 + (lifetime-19)*.165/5;
if (lifetime > 14 & lifetime < 20) then
  life_screen = .710 + (lifetime-14)*.091/5;
if (lifetime > 9 & lifetime < 15) then
  life_screen = .42 + (lifetime-9)*.29/5;
if (lifetime > 4 & lifetime < 10) then
  life_screen = .244 + (lifetime-4)*.174/5;
if lifetime < 5 then life_screen = lifetime*.244/4;

life_screen = (life_screen - prev_purch)/(1-prevpurch);
if life_screen < 0 then life_screen = 0;

if warranty(2) > 59 then warpscreen = 1.0;
if (warranty(2) > 36 & warranty(2) < 60) then
  warpscreen = .784 + (warranty(2)-36)*.034/23;
if (warranty(2) > 23 & warranty(2) < 37) then
  warpscreen = .716 + (warranty(2)-23)*.068/13;
if (warranty(2) > 11 & warranty(2) < 24) then
  warpscreen = .187 + (warranty(2)-11)*.529/12;
if (warranty(2) > 9 & warranty(2) < 12) then
  warpscreen = .165 + (warranty(2)-9)*.022/7;
if warranty(2) < 5 then warpscreen = warranty(2)*.165/4;

warr_screen = (warr_screen-prev_purch)/(1-prevpurch);

inst_screen = .07;
do i = 1 to 12:
  do j:
    if eff_sites > inst_breaks(i) then do;
      inst_screen = inst_dist(i);
go to paycalc;
  end;
go to paycalc;
end:

rescalc:
if lifetime > 24 then life_screen = 1.0;
if (lifetime > 19 & lifetime < 25) then
  life_screen = .833 + (lifetime-19)*.117/5;
if (lifetime > 14 & lifetime < 20) then
  life_screen = .667 + (lifetime-14)*.091/5;
if (lifetime > 9 & lifetime < 15) then
  life_screen = .483 + (lifetime-9)*.184/5;
if (lifetime > 4 & lifetime < 10) then
  life_screen = .233 + (lifetime-4)*.25/5;
if lifetime < 5 then life_screen = lifetime*.233/4;

life_screen = (life_screen - prev_purch)/(1-prevpurch);
if life_screen < 0 then life_screen = 0;

if warranty(1) > 59 then warpscreen = 1.0;
if (warranty(1) > 36 & warranty(1) < 60) then
  warpscreen = .784 + (warranty(1)-36)*.083/23;
if (warranty(1) > 23 & warranty(1) < 37) then
  warr_screen = .617 + (warranty(1)-23)*.167/13;
if (warranty(1) > 11 & warranty(1) < 24) then
  warr_screen = .223 + (warranty(1)-11)*.394/12;
if (warranty(1) > 4 & warranty(1) < 12) then
  warr_screen = .117 + (warranty(1)-4)*.106/7;
if warranty(1) < 5 then warr_screen = warranty(1)*.117/4;

warr_screen = (warr_screen-prev_purch)/(1-prev_purch);
if warr_screen < 0 then warr_screen=0;

inst_screen = .07;
do i = 1 to 12;
  if eff_sites > inst_breaks(i) then do;
    inst_screen = inst_dist(i);
go to paycalc;
  end;
end;
go to paycalc;

othercalc:
if life_time > 24 then life_screen = 1.0;
if (life_time > 19 & life_time < 25) then
  life_screen = .742 + (life_time-19)*.20/5;
if (life_time > 14 & life_time < 20) then
  life_screen = .501 + (life_time-14)*.171/5;
if (life_time > 9 & life_time < 15) then
  life_screen = .27 + (life_time-9)*.301/5;
if (life_time > 4 & life_time < 10) then
  life_screen = .185 + (life_time-4)*.085/5;
if life_time < 5 then life_screen = life_time*.185/4;

life_screen = (life_screen - prev_purch)/(1-prev_purch);
if life_screen < 0 then life_screen = 0;

if warranty(4) > 59 then warr_screen = 1.0;
if (warranty(4) > 36 & warranty(4) < 60) then
  warr_screen = .823 + (warranty(4)-36)*.064/23;
if (warranty(4) > 23 & warranty(4) < 37) then
  warr_screen = .742 + (warranty(4)-23)*.081/13;
if (warranty(4) > 11 & warranty(4) < 24) then
  warr_screen = .258 + (warranty(4)-11)*.484/12;
if (warranty(4) > 4 & warranty(4) < 12) then
  warr_screen = .242 + (warranty(4)-4)*.016/7;
if warranty(4) < 5 then warr_screen = warranty(4)*.242/4;

warr_screen = (warr_screen-prev_purch)/(1-prev_purch);
if warr_screen < 0 then warr_screen=0;

inst_screen = .007;
do i = 1 to 12;
  if eff_sites > not_inst_breaks(i) then do;
    inst_screen = not_inst_dist(i);
go to paycalc;
  end;
end;
go to paycalc;

agcalc:
if life_time > 24 then life_screen = 1.0;
if (life_time > 19 \& life_time < 25) then
    life_screen = 0.658 + (life_time - 19)*0.253/5;
if (life_time > 14 \& life_time < 20) then
    life_screen = 0.513 + (life_time - 14)*0.145/5;
if (life_time > 9 \& life_time < 15) then
    life_screen = 0.089 + (life_time - 9)*0.424/5;
if life_time < 10 then
    life_screen = 0.089 * life_time/9;
life_screen = (life_screen - prev_purch)/(1-prev_purch);
if life_screen < 0 then life_screen=0;

if warranty(5) > 59 then warr_screen=1.0;
if (warranty(5) > 36 \& warranty(5) < 60) then
    warr_screen = 0.784 + (warranty(5)-36)*0.034/23;
if (warranty(5) > 23 \& warranty(5) < 37) then
    warr_screen = 0.716 + (warranty(5)-23)*0.068/13;
if (warranty(5) > 11 \& warranty(5) < 24) then
    warr_screen = 0.187 + (warranty(5)-11)*0.529/12;
if (warranty(5) > 4 \& warranty(5) < 12) then
    warr_screen = 0.165 + (warranty(5)-4)*0.022/7;
if warranty(5) < 5 then warr_screen = warranty(5)*0.165/4;

warr_screen = (warr_screen-prev_purch)/(1-prev_purch);
if warr_screen < 0 then warr_screen=0;

inst_screen = 0.063;
do i = 1 to 11;
    if eff_sites > i then do;
        inst_screen = ag_inst_dist(i) - .345;
        go to paycalc;
    end;
end;
go to paycalc;

indcalc:
if life_time < 4 then life_index = 1;
if life_time >= 4 then life_index = 2;
if life_time >= 5 then life_index = 3;
if life_time >= 8 then life_index = 4;
if life_time >= 10 then life_index = 5;
if life_time >= 12 then life_index = 6;
if life_time >= 15 then life_index = 7;
if life_time >= 20 then life_index = 8;
if life_time >= 25 then life_index = 9;
if life_time >= 30 then life_index = 10;
if life_time >= 40 then life_index = 11;
warr_index = 1;
do i = 1 to 19;
    if warranty(ssn(k)) >= warr_years(i)) then warr_index = i;
end;
a = warr_life_table(warr_index,life_index+1);
b = warr_life_table(warr_index,life_index);
if life_index < 11 then life_screen = (a-b)*(life_time-life_years(life_index))
    /(life_years(life_index+1) - life_years(life_index)) +b;
else life_screen = warr_life_table(warr_index,life_index);
lifescreen = (lifescreen-prev_purch)/(1-prev_purch);
warr_screen = 1.0;

inst_screen = .007;
do i = 1 to 12:
    if effsites > inot_inst_breaks(i) then do;
        inst_screen = inot_inst_dist(i);
    go to paycalc;
end;
end;

paycalc:
if ssn(k) = 5 then do:
    if payback > 19 then payback_screen = .063;
    if (payback < 20 & payback > 14) then
        payback_screen = .063 + (20-payback)*.067/5;
    if (payback < 15 & payback > 9) then
        payback_screen = .130 + (15-payback)*.335/5;
    if (payback < 10 & payback > 4) then
        payback_screen = .465 + (10-payback)*.42/5;
    if payback < 5 then payback_screen = .885 + (5-payback)*.115/5;
payback_screen = (payback_screen-prev_purch)/(1-prev_purch);
go to final;
end;
else do;
    payyear = trunc(payback);
payfrac = payback - pay_year;
if pay_year >= 20 then do;
    payyear = 19;
payfrac = 1;
end;
if (ssn(k) = 1 | ssn(k) = 2 | ssn(k) = 4) then i = 1;
if (ssn(k) = 3 ) then i = 2;
if (ssn(k) = 6) then do;
    payback_screen = 0;
do j = 2 to 5;
    if (net_sys_costs(k,t) > cp_costs(j) &
        net_sys_costs(k,t) <= cp_costs(j-1)) then
        payback_screen = (cp_costs(j-1) - net_sys_costs(k,t))*(cp_payback(j) - cp_payback(j-1)) /
        (cp_costs(j-1) - cp_costs(j)) + cp_payback(j-1);
end;
if (net_sys_costs(k,t) <= cp_costs(5)) then payback_screen = 1.0;
payback_screen = (payback_screen-prev_purch)/(1-prev_purch);
go to final;
end;
payback_screen = payback_dist(i,pay_year+1) - (payback_dist(i,pay_year+1)
    - payback_dist(i,pay_year+2)) * payfrac;
if (ssn(k) = 3 ) then payback_screen =
    (payback_screen-prev_purch)*.66/(.66-prev_purch);
else payback_screen = (.93*payback_screen-prev_purch)
    *.93/(.93-prev_purch);
go to final;
final:

\[
\text{inst\_screen} = \frac{(\text{inst\_screen}-\text{prev\_purch})}{(1-\text{prev\_purch})};
\]

if \( \text{eff\_ad\_dollars} > 1 \) then \( \text{eff\_ad\_dollars} = 1 \);

\[
\text{aware\_screen} = 0.75 * \text{last\_aware}(r) + (1 - 0.75 * \text{last\_aware}(r)) * (1 - \exp(-13.86 * \text{eff\_ad\_dollars}));
\]

if \( \text{ssn}(k) = 6 \) then \( \text{aware\_screen} = 1 \);

\[
\text{screen\_factor} = \text{warr\_screen} \times \text{inst\_screen} \times \text{life\_screen} \times \text{payback\_screen} \times \text{aware\_screen} \times \text{dist\_screen} \times \text{probpurch();}
\]

if \( r=1 \) then do;

\[
\text{eff\_ad\_dollars} = \text{eff\_ad\_dollars} \times 1;
\]

end;

if \( \text{screen\_factor} < 0 \) then \( \text{screen\_factor} = 0 \);

if \( \text{screen\_factor} > 1 \) then \( \text{screen\_factor} = 1 \);

\[
\text{return (screen\_factor)};
\]

/***********************************************************/

probpurch: procedure() returns (float);

\[
\text{return (0.1)};
\]

end;

prepare: entry();

\[
\text{last\_aware}(*) = 0;
\]

\[
\text{sqrt2} = \text{sqrt(2)};
\]

\[
\text{return};
\]

end;

end;
/* Procedure to compute some constants for algor. These constants are
parameters for use in computing the arrival dates of the technologies. */

do_greeks: proc (beta, gamma);

%include model;
dcl (beta(2), gamma(2)) float;
dcl (zt(2), ut(2), dt(2), it(2)) float;

zt = zero_time;
rt = unit_time;
dt = double_time;
it = infinite_time;

if ^(as_date_set) then do;
  beta(1) = (log ((zt(1) - dt(1)) / (dt(1) - it(1)))
            * (ut(1) - it(1)) / (zt(1) - ut(1)))) / log(2);
  gamma(1) = (most_likely(1) ** beta(1)) * (ut(1) - it(1)) / (zt(1) - ut(1));
end;

if ^(at_date_set) then do;
  beta(2) = (log ((zt(2) - dt(2)) / (dt(2) - it(2)))
            * (ut(2) - it(2)) / (zt(2) - ut(2)))) / log(2);
  gamma(2) = (most_likely(2) ** beta(2)) * (ut(2) - it(2)) / (zt(2) - ut(2));
end;

end;
/* Procedure to compute module costs. Called solely by algor.
   Slightly deceiving in that it uses a lot of external data from the
   model structure that is not passed to it, but otherwise very
   straightforward. */

do_modcost: procedure (t, asrnd, advrnd, ps_factor, beta, gamma) returns (float);

%include model;
dcl t fixed;
dcl (asrnd, advrnd, ps_factor) float;
dcl modcost float;
dcl (beta(2), gamma(2)) float;
dcl no bit init ('"0"b), yes bit init ('"1"b);

if (t < arr_date(1)) then do; /* Stage 2 isn't here yet */
   if (as_date_set = no) then do; /* User didn't define Stage 2 arrival */
      arr_date(1) = infinite_time(1) + (zero_time(1)-infinite_time(1)) * 
                    (1 - asrnd ** beta(1)) / (gamma(1) + asrnd ** beta(1));
   end;
   modcost = cost_decline1 (ps_factor, sili_cost(t));
end;
else if (t < arr_date(2)) then do; /* Stage 2 is here, but not Stage 3 */
   if (at_date_set = no) then do;
      arr_date(2) = infinite_time(2) + (zero_time(2)-infinite_time(2)) * 
                    (1 - advrnd ** beta(2)) / (gamma(2) + advrnd ** beta(2));
   end;
   modcost = cost_decline2 (sili_cost(t));
end;
else modcost = ult_price; /* Stage 3 is here */
return (modcost);

/*******************************************************************************/

cost_decline1: proc (ps_factor, sili_cost) returns(float);
dcl (ps_factor, sili_cost) float;
return (2.83 - (84 - sili_cost) * 94/7000 
       + (2.4 / ps_factor));
end;

cost_decline2: proc (sili_cost) returns (float);
dcl sili_cost float;
return (max (0.70, 0.70 + (sili_cost-14) * 84 / 7000 ));
end;

/*******************************************************************************/
This structure is used to hold the data that is contained in the database file (db_file) which is needed for the number crunching in algor. Because of the quantity of data needed from the file, this structure is used instead of incorporating the data into the model data structure. */

dcl 01 run_data based (run_ptr),
  02 insolation (475) float,
  02 reg (475),
    03 neighbor(10) fixed,
    03 distance(10) float,
  02 sector (5),
    03 pot_inst (475) float,
    03 g_rate (475) float,
    03 avg_use (475) float,
    03 avg_bill (475) float,
    03 buy_back_rate (475) float,
    03 rates (475) float,
  03 dist (475),
    04 means (5) float,
    04 s_devs (5) float,
    04 erfc (5) float;
/* This include file contains the layout of the data
   needed by give and possibly other procedures to do their thing.
   The data resides in the segment called >udd>SOLAR>data>misc_data. */

dcl 01 misc_data based (misc_ptr),
   02 all_weight (5, 475) float,
   02 state_weight (5, 475) float,
   02 id (475) char(6),
   02 names (475) char (30),
   02 states (475) char(2),
   02 grouping(9),
   03 name char(20) var,
   03 num_els fixed,
   03 members (475) fixed;
Do you want results broken down by any of the surrounding variables? Enter yes or no.

### Year 1

<table>
<thead>
<tr>
<th>Sector</th>
<th>Annual installed peak kilowatts</th>
<th>Average cost per peak watt (subsidized)</th>
<th>Average cost per peak watt (gross)</th>
</tr>
</thead>
<tbody>
<tr>
<td>newres</td>
<td>791 799</td>
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<table>
<thead>
<tr>
<th>Sector</th>
<th>Government spending (millions)</th>
<th>Quads</th>
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Government technology development spending (millions) = 50.00
Private technology development spending (millions) = 2.00
AR and D spending (millions) = 50.00

### Year 2

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<th>Sector</th>
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<th>Average cost per peak watt (subsidized)</th>
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### Year 2

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Government technology development spending (millions) = 50.00
Private technology development spending (millions) = 2.00
AR and D spending (millions) = 50.00

### Year 3

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Government technology development spending (millions) = 50.00
Private technology development spending (millions) = 2.00
AR and D spending (millions) = 0.00

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<th>Year</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
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