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The Photovoltaic Market Analysis Program:
Background, Model Development, Applications and Extensions

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Abstract

The purpose of this report is to describe and motivate the market analysis program for photovoltaics that has developed over the last several years. The main objective of the program is to develop tools and procedures to help guide government spending decisions associated with stimulating photovoltaic market penetration.

The program has three main components: (1) theoretical analysis aimed at understanding qualitatively what general types of policies are likely to be most cost effective in stimulating PV market penetration; (2) operational model development (PV1), providing a user oriented tool to study quantitatively the relative effectiveness of specific government spending options and (3) field measurements, aimed at providing objective estimates of the parameters used in the diffusion model used in (2) above.

Much of this report is structured around the development and use of PV1, an interactive computer model designed to determine allocation strategies for (constrained) government spending that will best accelerate private sector adoption of PV. To motivate the model's development, existing models of solar technology diffusion are reviewed, and it is shown that they a) have not used sound diffusion principles and b) are not empirically based. The structure of the PV1 model is described and shown to address these problems.

Theoretical results on optimal strategies for spending federal market development and subsidy funds are then reviewed. The validity of these results is checked by comparing them with PV1 projections of penetration and cost forecasts for fifteen government policy strategies which were simulated on the PV1 model. Analyses of these forecasts indicate that photovoltaics will not diffuse significantly during the time horizon studied if government market development funds (money allocated to the purchase and installation of PV systems) are withheld. Market development spending has the most positive effect on photovoltaic diffusion in strategies where it is deployed early and concentrated in the residential and commercial sectors. Early subsidy spending had little influence on ultimate diffusion. The analyses suggest that any subsidies for PV should be delayed until photovoltaic costs drop substantially.

Extensions of the model and approach to other technologies are discussed.

1. Introduction

As oil prices rose dramatically in the 1970's, several alternative energy technologies began to emerge as potentially economically viable sources of energy production. In an attempt to accelerate their diffusion, several government agencies (DOE and HUD in particular) have initiated programs aimed at lowering the costs of these new technologies, accelerating their diffusion and increasing their acceptability in the marketplace. The government hopes to achieve new technology penetration goals using a mixture of price subsidies, research and development expenditures and demonstration projects. Currently, large amounts of government funds are being used for developing new technologies such as synfuels, wind and solar energy. In general, these alternative energy technologies are not currently competitive with traditional energy sources and need continued support if they are to become so in the near future. Government program goals are directed toward accelerating diffusion of these alternative technologies primarily by shortening the time until these new technologies become competitive, either through supply side or demand side programs.

Photovoltaics, solar cells which generate electricity from sunlight, provide one potential technology of interest to the Department of Energy. DOE created the National Photovoltaic Program to channel funds into technology and market development to accelerate the diffusion of photovoltaic technology. (These development program options are described in detail in Section 5.) Unfortunately, not much is known about how and when to spend money to accelerate the rate of market diffusion over time; quantitative decision-support tools are needed to evaluate and compare alternative strategies. A model of the

photovoltaic diffusion process, with government policy options as input, and market penetration as output is needed to help provide a basis for strategy evaluations and comparisons.

This report presents the theoretical and empirical support for a market assessment and analysis process aimed at providing decision support for the DOE PV program. The process has three main components: (1) theoretical analyses, aimed at a qualitative understanding of what general types of programs and policies are likely to be most cost-effective in stimulating PV market penetration; (2) an operational model, PVI, providing an interactive, user-oriented tool for quantitative study of the relative effectiveness of specific government spending options, and (3) field measurements aimed at providing objective estimates of the parameters for PVI model analysis.

The PVI model is used to determine allocation strategies for constrained government spending that will most stimulate private sector adoption of photovoltaics over time. By comparing the model's market penetration forecasts for different strategies, government policy analysts can compare the effects of those strategies quantitatively.

Motivation for the model is provided in Sections 2, 3 and 4. Section 2 briefly discusses the energy problem facing the United States and concludes that alternative technologies should be advanced. The section then presents background material on photovoltaics and government's role in stimulating its diffusion. Section 3 summarizes what is known about diffusion processes, concentrating primarily on models of the consumer adoption process and on those factors that influence the rate of adoption. Section 4 reviews other solar-energy diffusion models and demonstrates that a need exists for a more realistic, data based approach

to modeling diffusion phenomena.

Unlike other models of solar diffusion, PV1 is integrally linked to empirical data. Most importantly, PV1 models diffusion rates implicitly, through a consumer-based choice model, rather than through an exogenously defined diffusion function as do earlier models. Section 5 presents the PV1 approach in detail. The section begins with a discussion of the problem, describing the government policy options available for photovoltaics. The structure of the model is then justified theoretically and empirically.

A unique characteristic of the PV1 approach is that it is tied to a field data collection activity. Section 6 motivates that data collection process, linking it to parameterization of the PV1 model.

Section 7 discusses some theoretical results on the optimal deployment of demonstration program and subsidy program resources. These results apply not just to PV, but to many new technologies that are governed by diffusion processes and experience curve cost declines and economics of scale. They provide insight into the kinds of policies that government should find most cost-effective.

Section 8 presents PV1 analyses of 15 different government support strategies. The theoretical results on optimal policy spending strategies are compared with the quantitative results of the model.

The modeling and data collection procedure has led to a number of observations that can be made that are specific to photovoltaics. These are collected and summarized in Section 9. In that section possible extensions to the model are described, and the value of using this approach for other technologies is discussed.

2. The Energy Problem and Photovoltaics

2.1 The Energy Problem

American dependence on foreign oil has been much discussed since the Arab oil embargo in 1973. Shortly after the embargo, President Nixon proposed Project Independence, a program designed to attain independence of foreign oil by 1980. An underestimate of the scope of the problem and an uncooperative Congress doomed the plan from the beginning. President Carter also faced an unresponsive Congress, and only after Iranian oil exports stopped late in 1978 did Congress pass emergency energy legislation. Finally, with apparently real commitment, America strives for a measure of energy independence.

In the short term, however, the prospect of gaining a substantial degree of energy independence is unrealistic. Almost a quarter (24%) of total energy consumption in the United States is provided by imported oil [White, 1980]. To reduce its dependence, America must conserve oil and effect a transition to alternative energies where possible.

Table 2.1 shows a breakdown of American energy consumption patterns. In 1979 the United States consumed 78 quadrillion Btu's (quads) of energy, of which oil (liquid fuels) and natural gas supplied 73%. Imports of natural gas are small and projections indicate that imports of this fuel will remain small in the near future. The story is different with oil. Almost 50% of American oil needs are satisfied by imports. Domestic oil production is capable of handling the needs of the transportation sector only. As there is little choice but to use oil-based derivatives (mainly gasoline) for transportation, the prospect of oil import reductions depends entirely on the potential for switching to other technologies in the residential, commercial, industrial and

Table 2.1
American Energy Consumption Patterns (1979)

<u>Energy Source</u>	<u>Sector</u>				<u>Total U.S. Primary Energy Consumption</u>
	<u>Transportation</u>	<u>Residential/Commercial</u>	<u>Industrial</u>	<u>Electric Generation</u>	
Liquid fuels	20 quads	6 quads	8 quads	4 quads	38 quads
Natural gas	0	8	8	4	20
Coal	0	1	3	11	15
Electricity	0	14	10	0	*
Uranium	0	0	0	2	2
Hydro	<u>0</u>	<u>0</u>	<u>0</u>	<u>3</u>	<u>3</u>
Total	20	29	29	24	78

*Electricity usage in the residential/commercial and industrial sectors is equal to electricity production in the electric generation sector. To add these numbers into the total would be to double count.

Source: National Energy Outlook 1980 [FEA, 1980]

electric generation sectors.

Except for industry's use of oil in petrochemical production, the needs of these sectors could be provided by several alternatives to oil. Coal and nuclear fission are frequently mentioned as substitutes for both oil and natural gas for electricity generation. In the residential, commercial and industrial sectors coal and natural gas could be primary substitutes for oil [White, 1980]. Active solar will probably play only a relatively minor role as a replacement for oil in residential and commercial space heating applications.

Americans currently use natural gas in large quantities. It is therefore unlikely that natural gas will be able to satisfy requirements left by reduced oil consumption. The residential, commercial and industrial sectors burn 19 quads of natural gas annually. Deregulation of new-gas prices by 1985 under the Natural Gas Policy Act (NGPA) and the new-found reserves in Prudhoe Bay should ensure stability in natural gas production in the medium term. Best guess estimates by the Energy Information Administration [EIA,1978] of domestic natural gas production are 17.5 quads in 1990 and 17 quads in 1995. Natural gas demand is expected to rise to 21 quads by 1990, suggesting that imports must actually increase over the next ten years. Some analysts believe, however, that EIA's estimates of natural gas production are conservative and that demand in 1990 can be totally met by domestic production.

The electric generation sector produces 24 quads annually, about 30% of total U.S. energy consumption. Electricity comprises 50% of energy consumption in the residential and commercial sectors and approximately one-third of industrial consumption. Coal and nuclear will be looked to increasingly as replacements for oil and natural gas in the generation of

electricity, freeing up natural gas for use in the residential and commercial sectors. In the future, the relative use of coal and nuclear will be largely determined politically. Although both fuels exist in ample quantities, usage has been hampered by environmental regulations. Coal emits air pollutants such as sulphur dioxide (SO_2) when burned. In addition, mine safety regulations have retarded coal production, making utilities reluctant to switch to coal for fear of supply shortages. Nuclear has been plagued by fear of inadequate safety precautions (Three Mile Island, e.g.) and by problems of nuclear waste disposal. Nevertheless, under a Reagan presidency, there should be a relaxation of environmental controls and a concomitant increase in the use of nuclear and coal as primary fuel sources for electric generation facilities in the near future.

An ideal solution to the United States' long-term energy needs would be to develop and commercialize technologies that produce energy from a renewable resource such as wind, water or the sun. One such technology is photovoltaics.

2.2 Photovoltaics (PV)

Photovoltaic cells (solar cells) produce electricity from sunlight. They represent a potential replacement for fossil fuels currently used in electricity generation. A photovoltaic system is a connected array of solar cells that convert sunlight into direct current electricity. The system is silent and non-polluting. In addition, PV is modular and adapts easily to small-scale needs such as home usage. Nevertheless, drawbacks are significant. PV, today, is extremely expensive and its low efficiency dictates large collection areas for relatively small amounts of electricity production. Even resolution of these problems may not

solve PV's dilemma: institutional, legal and social obstacles may still inhibit PV acceptance. Unquestionably, reductions in solar cell costs and increases in solar cell efficiency (to decrease the size of an installation) are needed for a successful PV program [Pruce, 1979].

Current PV cell cost is about \$7 per peak watt (W_p). Figuring that an average home would require a PV array of 4 peak kilowatts, cell costs alone would amount to \$28,000. Power conditioning equipment (matching array-produced direct current with utility line-based alternating current), installation and indirect costs would add much more to the price tag. A recent multi-home installation proposal made to DOE estimated current cost of about \$75,000 installed per system. Recognizing the need for substantial reductions in cost per peak watt, DOE has set targets of 70¢/ W_p by 1986 and 15-50¢/ W_p by 1990 [DOE, 1980] (in constant dollars). PV should be a competitive energy source at these levels.

2.3 Government's Role in Energy

To reduce American dependence on foreign oil, the federal government has embarked on a program to 1) promote energy conservation, and 2) fund the development of new, alternative energy technologies. Government's intention is to shorten the time until these new technologies will produce competitively priced energy, and also to develop some security of supply.

For photovoltaics (PV), the government has established a program aimed at accelerating private market penetration of PV. Acceleration will be realized through the following objectives:

- Reduce PV system costs
- Gain consumer acceptance of PV by building working PV

demonstration sites

- Create early awareness among potential customers by information dissemination [DOE, 1980].

The Department of Energy (DOE) created the National Photovoltaic Research, Development and Demonstration Program to attain these goals. The program has proposed funding of \$1.5 billion to be allocated over the ten year period 1979-1988. Government purchases of PV cells will generate a base level demand for PV that should provide impetus for PV manufacturers to invest in larger scale production facilities. These purchases should lead to cost reductions through economies of scale and learning curve effects. As costs and, therefore, prices of a PV system drop, private sector adoption should begin. Government PV installations further serve to demonstrate viability to the private sector, thereby increasing acceptance. Major reductions in PV system costs will also be achieved by Technology Development (investment in production-related research) and Advanced Research and Development (investment in basic PV materials research).

Section 2(b) of the Solar Photovoltaic Energy Research Development and Demonstration Act of 1978 enumerates four specific goals for photovoltaic development and adoption:

- (1) To establish "...an aggressive research, development and demonstration program..." for PV systems to produce electricity "...cost competitive with utility generated electricity..."
- (2) To double the annual production of PV systems every year beginning in 1979 and culminating with 2000 peak megawatts annually in 1988.
- (3) To reduce the average cost of installed PV systems to $\$1/W_p$ by

1988.

- (4) To ensure that at least 90% of all PV systems produced in 1988 are purchased by private buyers [DOE, 1980].

The Department of Energy has established comparable goals for several other alternative energy technologies.

2.4 PV Technologies

A number of PV technologies are presently being researched. Of these, single-crystal silicon, cadmium sulfide (CdS), gallium arsenide (GAs), and thin film polycrystalline silicon have received the most attention. Several technologies are unacceptable for small-scale systems because of inefficiencies at such sizes. The differences in these technologies have led to considerable discussion concerning the merits of centralized versus decentralized PV installations. (Centralized and decentralized installations are equivalent to large and small-scale PV systems, respectively.)

A panel sponsored by the American Physical Society concluded that decentralized PV is less financially promising because of its need to use flat plate collecting arrays, and not the more efficient concentrating collectors used in large-scale systems. Other groups, such as the Solar Lobby, contend that as solar cell costs drop, decentralized power will gain in importance. They further believe that PV centralized with utilities has little future because of the enormous land requirements of large-scale PV installations. Nevertheless, there is a consensus of belief that federal government R&D funding of a diversity of technological approaches for PV development is necessary to ensure that PV is competitive by the year 2000 [Gwynne, 1979].

Single Crystal Silicon

To date, PV cells have been made almost exclusively of single-crystal silicon. This technology has been promoted for decentralized PV installations, and will undoubtedly remain the primary source of solar cells in the next ten years. As Table 2.2 shows, attained efficiency for single crystal silicon cells is close to that of predicted efficiency (18% vs. 20%), indicating that large effective reductions in solar cell cost cannot be expected from efficiency gains and instead must come from lower silicon prices and production costs. The Jet Propulsion Laboratory (JPL) is hopeful of producing a single crystal silicon cell that meets DOE's 1982 and 1986 cost targets. Work on lower cost, but lower efficiency, thin film polycrystalline and amorphous silicon cells is also being undertaken at JPL [Pruce, 1979]. The polycrystalline cell seems to hold the most promise in terms of the cost/efficiency dimensions. Automated processes should reduce the cost of cell production, but major advances are imperative if DOE's goal of lowering "solar grade silicon" to \$10 per kg is to be met.

Cadmium Sulfide/Cuprous Sulfide Heterojunction

By placing a thin film of cadmium sulfide back-to-back with a layer of cuprous sulfide, a solar cell with strong light absorbing qualities is made. Known as the cadmium sulfide-cuprous sulfide ($\text{CdS}/\text{Cu}_2\text{S}$) heterojunction, this kind of solar cell is relatively inexpensive, but to date is only about half as efficient as a single crystal silicon cell and two thirds as efficient as a polycrystalline silicon cell. Nonetheless, as seen in Table 2.2, there is potential for doubling the cell efficiency. Unfortunately, these cells degrade and can emit a toxic gas when exposed to high temperatures [Williams, 1979]; such problems must be eliminated if the $\text{CdS}/\text{Cu}_2\text{S}$ solar cell is to have a viable future.

Table 2.2
Efficiencies of Photovoltaic Cells

<u>Photovoltaic Technologies</u>	<u>Status</u>	<u>Efficiency, Percentage Predicted</u>	<u>Percentage Attained</u>
Single-crystal silicon	Commercial	20	18
Polycrystalline silicon	Laboratory	-	12
Gallium arsenide	Laboratory	29	26
CdS/CdTe heterojunction	Laboratory	16	8
CdS/Cu ₂ S heterojunction	Commercial	16	8
Amorphous silicon	Laboratory	-	5.5
Multilayered cell stack	Laboratory	35	28.5
Cells with spectral splitting	Proposed	35	-
Thermophotovoltaic conversion	Laboratory	50	26

Source: Power [Pruce. p. 85,]

Gallium Arsenide

The single crystal gallium arsenide (GaAs) cell is the most recent breakthrough in PV cell efficiency. These cells work at 26% efficiency but only become cost effective when coupled with a concentrator system, capable of intensifying sunlight 100 to 200 times. It is believed that such a total system is more likely to achieve DOE cost targets than regular flat plate collectors. A drawback of the GaAs cells is that without the concentrator, they are too inefficient for small scale systems but, as the concentrator itself is so expensive, its usage only becomes cost effective for large scale operations [Williams, 1979].

Other PV Technologies

Thermophotovoltaic conversion has attained 26% efficiency in the laboratory [Pruce, 1979]. This system uses a concentrator to focus sunlight onto a radiator and heat it to about 2000°C. The radiator then re-radiates the light but at longer wavelengths than the incoming sunlight. Silicon cells, which operate more efficiently at these longer wavelengths, then convert the light to electricity. Again, this system is not adaptable to small scale systems because of its need for a concentrator.

Multi-layered cell stacks, combinations of different materials with maximum efficiencies at different wavelengths, have attained very high efficiencies: a GaAs cell in combination with a silicon cell has performed at 28.5% efficiency. Once more, however, these cells are expensive and require the large-scale concentrator systems.

2.5 Technology Assumptions

For the purpose of the analyses reviewed here it is assumed that photovoltaic technology will develop in the direction of small scale

technologies. The major land requirements for large scale installations and apparent reluctance of utility management to accept PV argue for the small-scale development. The cadmium sulfide/cuprous sulfide heterojunction solar cell must also be dismissed for now, because of unresolved toxicity problems. This leaves the silicon technologies as viable alternatives.

JPL [1980] has developed solar cell cost functions for a three stage silicon cell technology development process. The timing of the three stages depends on government expenditures. In the first stage, the JPL cost equation computes cost based on the price of silicon, economies of scale and the current state of technology. The arrival of the second stage depends on technology development spending. This second stage assumes a better method of silicon cell production has been achieved and a second JPL cost function estimates cost based on the same variables as in the Stage 1 equation. The third stage technology's arrival is assumed to be accelerated by advanced research and development spending. Hence, a new kind of solar cell is assumed to be available that reaches DOE's goal of $\$.70/W_p$. The price of silicon has no direct bearing on cell costs in this stage. The market penetration model developed in the next chapters adopts the small-scale technology assumption and uses the three-stage JPL approach in estimating the future costs of photovoltaics.

3. Background on Market Penetration of New Technologies

An understanding of the adoption process of a new technology is key to the development of a good market penetration model. There are two reasons for this: first, it is necessary to specify the important stages of the adoption process for the new technology; second, those factors that influence movement between the adoption process stages and that ultimately affect the rate of market penetration must be identified and quantified.

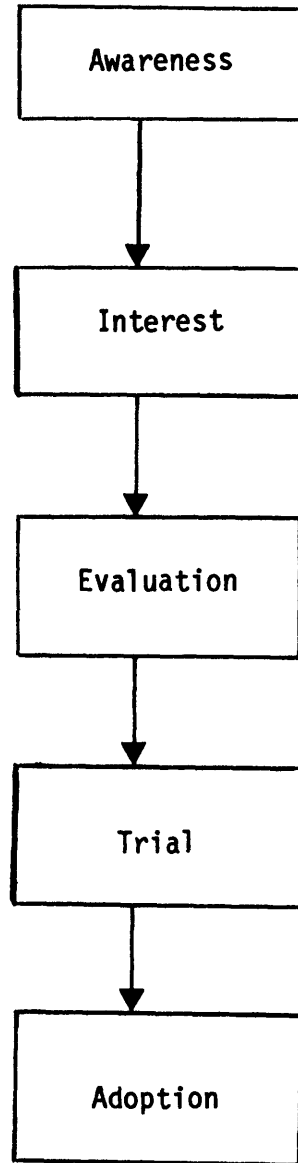
Significant differences exist between the adoption processes of individual and industrial consumers. In industry, as in the commercial, agricultural and central power sectors, adoption is an organizational decision. As such, the adoption process in these sectors is substantially more complex than it is at the individual, home-owner level. Despite differences in complexity, individuals and organizations in general follow many of the same steps toward eventual adoption. This section first examines the individual adoption process, commenting on differences between individual and organizational procedures. The factors that influence the rate of adoption are then described and categorized.

3.1 Stages in the Adoption Process of New Technologies: Individual

Researchers differ a bit in their delineations of the new technology adoption process for individuals, but a five-stage process suggested by Rogers [1962] is a typical classification. This process, diagrammed in Figure 3.1, is applicable both to durable and non-durable products, but for durable goods, stages 4 and 5 are collapsed, there being no distinction between trial and adoption. The characteristics of the five stages give insight into the adoption process.

Figure 3.1

The Individual Adoption Process



Source: Rogers, 1962

The Awareness Stage

In this initial stage the potential adopter learns of the existence of the new technology but possesses little information about it. Awareness may result either from purposive seeking of information by the potential adopter who has a need for the benefits of a new product or technology, or, as most researchers believe, from the individual coming into random contact with information about the new technology.

The Interest Stage

Here, the potential adopter develops interest in the innovation and actively seeks information about it. His personal values combined with social norms will play a part in determining where he seeks information and how he uses this information. The same is true for the organization, where one or more individuals develop an interest in an innovation and then begin to search for information.

The Evaluation Stage

When the potential adopter enters the evaluation stage he has collected enough information about the innovation to come to a decision. He considers all information that is important to him, weighs the advantages and disadvantages of the innovation and makes his decision to adopt or not to adopt. At this stage the advice of peers is sought while the impact of mass communications, important in the awareness and interest stages, becomes secondary.

The organization, unlike the individual, usually has a formalized set of evaluation criteria on which to judge new product adoption, especially for capital expenditures. Certain minimum requirements, for payback or warranty period, e.g., are used to screen out unacceptable products or projects. Evaluation for organizations is most often undertaken by a

combination of individuals.

The Trial and Adoption Stages

For durable products the trial and adoption stages are synonymous. The potential adopter purchases the innovation and uses it. He forms either a favorable or unfavorable impression of the innovation. In the organization, the person who decides to adopt or reject the innovation may or may not be the person who searches for information or the one who makes the in-depth evaluations. Several individuals may combine their judgments in different ways in the final decision process.

Roger's model is not entirely satisfactory because it assumes that all potential adopters will eventually adopt an innovation and also neglects to include a post-adoption stage in which an innovator may participate in promoting or alternatively, criticizing, the innovation. In a revised, but non-operational model, Rogers takes account of these phenomena.

In the case of photovoltaics, the residential homeowner is an individual adopter. Lilien and Johnston [1980], however, in an analysis of active solar heating and cooling studies, suggest that the residential new home-buyer, because of interactions with builders, architects, and HVAC contractors in the decision to adopt solar, is involved more in an organizational-type than an individual adoption process, although more of an individual-type purchase occurs for retrofit installations. Thus, the more formalized evaluation procedures of builders and contractors will become part of the evaluation process when PV is the innovation considered.

Diffusion theory focuses on the last stage of the model, the adoption stage. Nevertheless, an understanding of how people move through the

successive stages of the adoption process is needed to model innovation diffusion over time. To understand how people move through the process it is necessary to understand consumer behavior and the concept of consumer innovativeness.

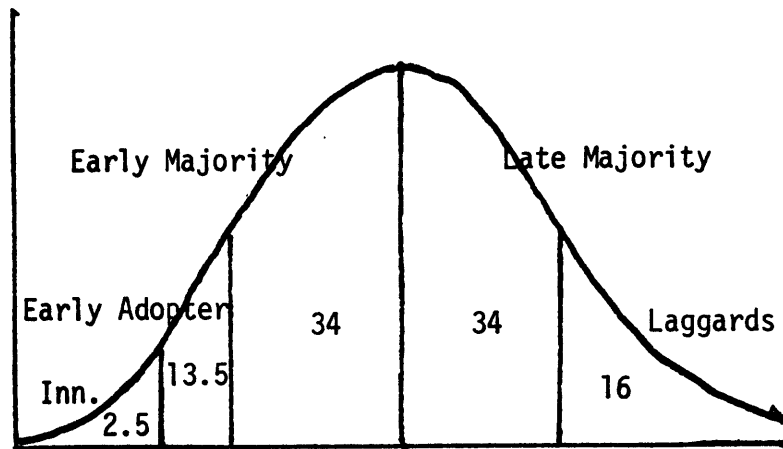
3.2 The Consumer Innovativeness Model

Rogers and Shoemaker [1971] have defined consumer innovativeness as "the degree to which an individual is relatively earlier in adopting an innovation than other members of his system." They have quantified this concept by categorizing all individuals in five groups according to each individual's degree of innovativeness. Figure 3.2 shows Roger's categorization scheme, based on a normal distribution, with the proportion of individuals in each category appearing in each section of the curve. Marketers in general have chosen to accept Roger's categories as useful but have not endorsed the absolute categorical proportions. In fact, much research has been conducted in trying to determine the size of the innovator category for different products: innovators are considered the key to many new products' successes.

Early adopters enter the market after seeing the product is performing acceptably. "Early majority" buyers then follow, again waiting to see how the product performs. If the innovation proves itself among "early majority" people then the product has a good chance of success. A period of strong demand then ensues generated by the "middle majority." Demand tapers off and finally the "laggards" purchase [Ryan, 1977]. There will of course always be a group of non-adopters. Plotting cumulative sales of the innovation against time, the diffusion process just described takes the S-shape shown in Figure 3.3. Researchers have studied many mathematical functions with the S-shape property in an

Figure 3.2

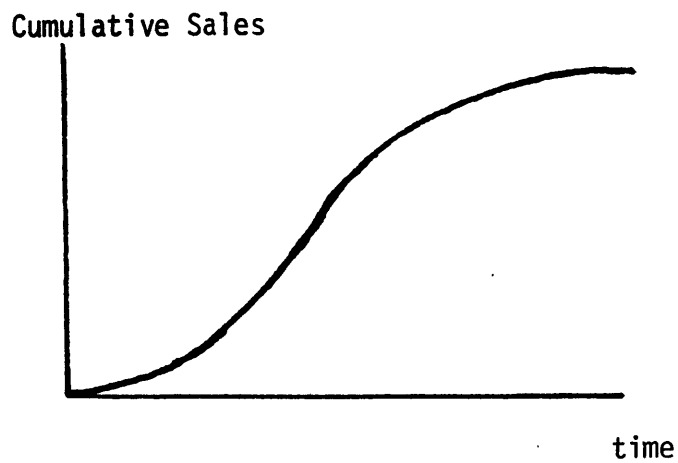
Roger's Adopter Categorization Scheme



Source: [23]

Figure 3.3

The Time Path of Diffusion



effort to forecast sales over time. Results are far from perfect. Generally, there is little prospect of knowing beforehand the relative sizes of the buyer categories.

Although the evidence is far from conclusive, individual innovators tend to be cosmopolitan, read more and travel more [Ryan, 1977]. It is thought that innovators seek new products with a "new, first, original, futuristic, distinctively different" image [Midgley, 1977]. Laggards on the other hand seem to be risk averse, willing to accept only proven products.

The consumer innovativeness model is too simplistic. It places people into five buyer categories irrespective of the product innovation in mind. Furthermore, it categorizes individuals based primarily on their degree of risk aversion to something new, disregarding other potentially important factors which must be considered in the evaluation stage of the adoption process model. In spite of these faults, the consumer innovativeness model does emphasize two important points that must be considered in a market penetration model: (1) many individual consumers wait to see how well a product performs before making a decision to adopt, and (2) there is an underlying distribution of how many other consumers must find the product satisfactory before a given consumer will consider adoption. For innovators, the number of previous purchases is small; for laggards it is very high.

3.3 Factors which Influence the Rate of Diffusion

The rapidity with which a new technology diffuses into the marketplace depends on how the innovation is perceived at the individual or micro level. The individual, in his decision to adopt or reject a new technology, weighs the benefits and drawbacks of the innovation within a

framework of personal and social structure values [Bernhardt, 1972]. Product, personal and social characteristics blend together to influence a potential adopter's overall perception of the innovation. This perception may be distorted either by the manner in which the individual perceives the innovation or by ineffective or misleading communication from those marketing the new technology. From a marketer's standpoint, effective communication of those product attributes that satisfy both individual and social needs is key to improving product perceptions with the resultant increase of an individual's probability of adoption.

Unfortunately, the determinants of adoption are not standard across new technologies. Nevertheless, Zaltman and Stiff [1973], in an analysis of Fliegel and Kivlin's work [1966], categorize a set of common issues or factors that influence the rate of adoption, and, therefore, the rate of diffusion. The list is not exhaustive, nor does each factor listed pertain to all new technological innovations. They point out, moreover, that each innovation may exhibit unique characteristics that also significantly affect diffusion rates. Such appears to be the case with photovoltaics. After presenting a categorization of factors common across most new technologies, we discuss some unique factors affecting the rate of diffusion of photovoltaics.

3.3.1 Common Diffusion Factors

The factors that affect the rate with which potential adopters move through the adoption process are different for each stage.

Awareness: Awareness is created by mass communications such as advertising and public relations. For the later adopting segments, observation of innovation usage and word of mouth are important conveyors of awareness. The individual tendency to expose oneself only to those

mass communications that reinforce one's opinions, and to ignore those one does not agree with is an important effect which limits awareness. (This process is called selective exposure.)

Interest: In the interest stage the individual collects information. If information is readily available from many sources, he moves through this stage quickly. If information is sparse, of the wrong kind or difficult to access, then movement through the interest stage is slow.

Evaluation: In the evaluation stage, the consumer weighs the relative advantages of the innovation with those of alternatives. The potential adopter decides on the relevant criteria along which to evaluate the innovation, the criteria chosen specific to the purpose of the product and the needs of the potential adopter. Several criteria are commonly used in evaluating an innovation. These include:

1. Financial criteria: These criteria may be grouped in two categories--costs and returns. Costs may be further broken down into initial and continuing costs. Fliegel and Kivlin [1966] in a study of farm practices, found that while continuing costs have a negative partial correlation with the adoption rate, initial costs have a positive partial correlation. Zaltman and Stiff hypothesize that the unexpected positive correlation may be explained by a cost-quality relationship in which innovations of high initial cost are perceived as high-quality products. They state that these higher-priced innovations will primarily be durable goods that are purchased infrequently. Apparently, the perceived extra quality more than compensates for the extra cost. It seems likely, however, that durable goods are also prone to incurring higher continuing costs than nondurable goods, so it is not clear whether durability will have an overall positive or negative effect on the rate of adoption.

There is no basis for generalizing these results from the agricultural sector to the residential, industrial, and other sectors, although it is important to recognize both initial and continuing costs in studying diffusion.

The concept of return in some ways captures the cost dimension since it can be used to determine when costs are recovered. Return is a loose term used to describe both payback and return on investment. Financial return can be, and is, measured by many different methods, among them net present value, discounted payback and simple payback. In industry, many companies use several return criteria to evaluate a product. Most individuals rely more on simpler concepts, like simple payback. Short paybacks and large returns on investment will speed up adoption.

2. Social criteria: Again, there are costs and returns. Social costs inhibit the adoption rate by keeping potential adopters from purchasing for fear of social ridicule. It seems that social costs borne by a potential adopter are partially determined by social position. High-status individuals and marginal members of groups may find themselves the least penalized for adopting, the former because they can afford to be innovative and will suffer little if wrong, and the latter because they have nothing to lose and everything to gain.

Social returns were found to be small in the Fliegel and Kivlin farm study although this may not follow in general.

3. Efficiency: A potential adopter evaluates an innovation in terms of its efficiency, that is, how much time the innovation saves and how much discomfort it can alleviate. These can be important evaluation dimensions for innovations dealing with household operation and maintenance.

4. Risk: The risk of an innovation is measured by the innovation's perceived regularity of reward and its divisibility for trial. An innovation that can be trial sampled on a small scale is inherently less risky than one that cannot be trial sampled. The less divisible for trial, the lower an innovation's adoption rate.

The perceived regularity of reward is positively correlated with an innovation's adoption rate. If the reliability of an innovation is poor, then the regularity of reward will be perceived as erratic, uncertainty will be high and the adoption rate will suffer.

5. Communicability: Communicability deals with the ability to effectively convey perceptions to potential adopters. The more complex the innovation, the more difficult it is to convey those perceptions that will positively affect the rate of adoption.

6. Compatibility: If the innovation is not compatible with existing systems, and requires significant adjustments on the part of a potential adopter, then the speed of diffusion will be slowed.

7. Perceived Relative Advantage: The unique attributes of an innovation that are not possessed by the traditional alternatives are key influences on the rate of adoption. The more important these attributes to the potential adopter, the more rapid the rate of adoption. If these attributes are especially visible, perhaps even demonstrable, then the innovation is more likely to diffuse quickly.

3.3.2 Diffusion Factors Unique to Photovoltaics

Photovoltaics is a complex technology. The installation of a PV array requires competent and trained workmen. It is improbable that, in the first years of PV diffusion, workmen skilled in PV installation techniques will be available everywhere to service anyone who wants a PV

array. The diffusion of PV will therefore be slowed by distribution and service factors. Also contributing to diffusion problems will be transportation limitations of shipping PV arrays from geographically separated manufacturers to potential adopters.

If comments about the esthetics of active solar systems are applicable to photovoltaics, then diffusion will be hampered in the residential sector by individuals who think PV is unattractive. Jerome Scott [1976], in a study of homeowner attitudes toward active solar systems, found that on average, an individual would be willing to pay up to \$2000 more to have a collector installed on the back instead of the front of his house.

Finally, the rate of PV diffusion will vary markedly between the new and retrofit markets (mainly residential). Since new homes can be constructed with a south-facing roof, new homeowners are more likely potential adopters than existing homeowner-retrofit customers, whose roofs often do not face due south. Furthermore, it should be easier for a new homeowner to incorporate the cost of the PV installation in his long-term mortgage than it would be for a retrofit installer to obtain favorable financing.

4. Modeling Approaches in the Solar Energy Area

As Section 3 showed, the factors affecting the rate of diffusion are both varied and complex. No diffusion model exists that captures all relevant diffusion phenomena. Still, even an incomplete model can provide insight into how a product will diffuse, and for some of the simpler diffusion problems, reliable analyses of market penetration can sometimes be produced. The completeness of a model will determine how useful the model can be to the user. To build a "good" model, the modeler must strike a balance between theory, data and the intended use of the model.

This chapter reviews four major solar diffusion models, ending each review with a discussion of model problems. The model reviews are made in the context of how well the models represent the diffusion phenomena described in the previous chapter. Evaluation of the models occurs at several levels.

4.1 Criteria for Evaluation

Lilien [1975] suggests that models should assume different levels of complexity depending upon the use as well as the user. For example, a model aimed at sales forecasting for the purposes of inventory control may be adequate for the operations department, but useless for the advertising department, interested in advertising evaluation.

Little [1970] discusses some criteria for evaluating models. To be useful, he suggests a model should be:

- o simple--understandable to the user
- o robust--absurd answers being difficult to obtain
- o easy to control--amenable to manipulations that provide easy analysis of model sensitivity

- o adaptive--capable of being updated as more data become available
- o complete--including all the most important variables
- o easy to communicate with.

All the models we will review here make explicit or implicit trade-offs in these criteria. It will be shown that other solar diffusion models have not incorporated sound diffusion principles and are in this sense incomplete. Yet, a complete model, one that incorporates all important diffusion phenomena and is as "true" as possible, may not be capable of being tested or used: the data required to estimate its parameters may be either unavailable or difficult to generate. Clearly, as we move to more complete models, we will have more data, estimation and interpretation problems.

We now review four solar penetration models. These models are the Arthur D. Little (ADL) SHACOB model [1977], the MITRE Corporation's SPURR model [1977], the Energy and Environmental Analysis (EEA) MOPPS model [1977] and a model by Stanford Research Institute (SRI) [1978].

4.2 Evaluation of Solar Penetration Models

The models reviewed in this section deal with different aspects of alternative energy technologies. For instance, the ADL model only addresses the market penetration of solar heating and cooling technologies while EEA's model deals with solar as well as with non-solar energy technologies. Nevertheless, the same diffusion phenomena should, in general, be applicable to most of the new, durable alternative energy technologies.

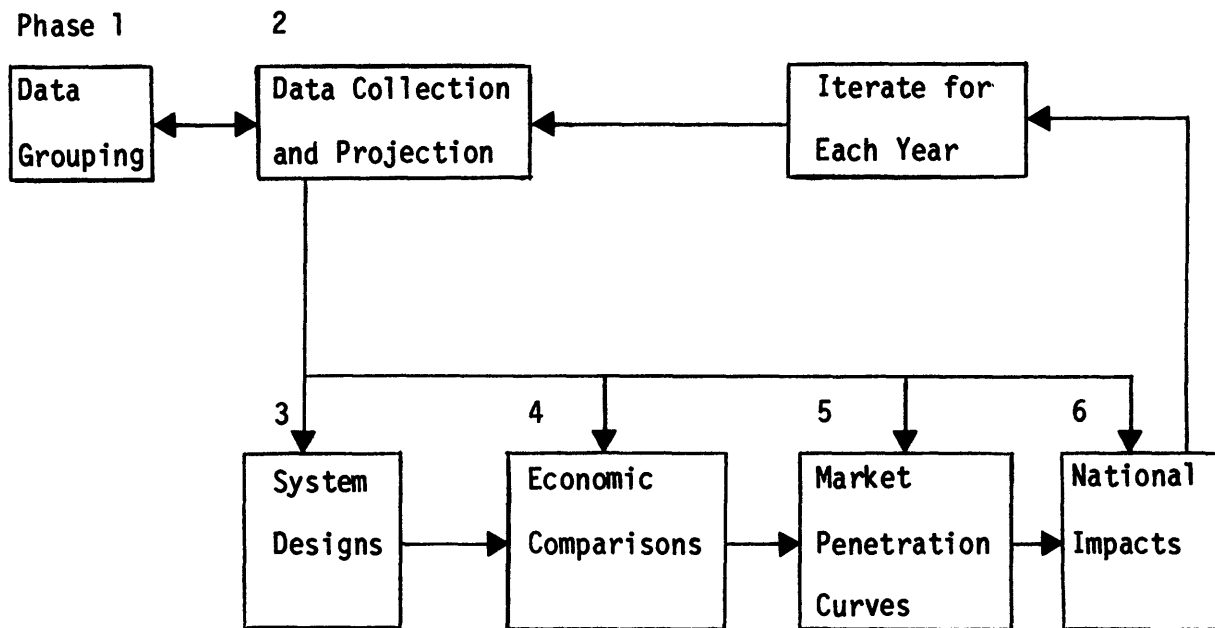
Schiffel et al. [1977] point out that each of the four penetration models here reviewed has six basic components. Figure 4.1 illustrates the relationships of these six components. The following is an

abbreviated summary of Schiffel's description of the six phases of the penetration models.

1. Phase 1: In Phase 1 the relevant market is divided into geographic regions usually on the basis of insolation and climatic conditions. The market is then segregated into a number of building types with different characteristics that might influence eventual adoption. The four models reviewed all deal with building characteristics. Next, the types of energy technologies considered by a model are classified. These technologies include solar hot water, solar heating, wind and many more. The SRI model considers over 20 solar technologies.
2. Phase 2: Data are collected in Phase 2 and a means for projecting changes and future levels of data variables is devised. The data are collected by geographic region for such variables as insolation, fuel costs, market sizes and growth rates.
3. Phase 3: In this phase, an idealized average installation size is calculated by region. An estimate is made of the percentage of the annual energy load that could be supplied by the solar system.
4. Phase 4: Projections of future fuel prices, population growth rates, solar technology prices and energy usage are made. Comparison evaluations are then made between conventional and solar energy sources.
5. Phase 5: An exogenously defined market penetration curve is specified. This curve takes the familiar S-shape. The curve uses parameters based on the economic comparison evaluations of Phase 4 to model diffusion. The purpose of the penetration curves is to show how potential adopters react to the relative economics of solar versus conventional energy.

Figure 4.1

Basic Components of Most Solar Energy Market Penetration Models



Source: [Schiffel, 1977, pg. 8]

6. Phase 6: Sales of the solar technology are calculated. The models then recycle back to Phase 1 for another year in the forecast.

All models reviewed below have this basic structure.

4.2.1 The ADL SHACOB Model

The SHACOB model is used to evaluate the effect of federal solar incentive programs on the growth of solar hot water, space heating and space heating and cooling systems in the residential and commercial sectors. The model takes federal incentives as input to calculate total collectors sold, the percentage of the market penetrated and the cost to government of the incentive programs.

The basic unit of analysis of the SHACOB model is a geographic region broken down both by market and building type and new or retrofit application. SHACOB differentiates 10 building types. Market penetration is calculated for each solar technology for each unit of analysis and is aggregated to provide estimates of annual solar penetration by region. Penetration is estimated in a three-step process:

- 1) Cost of the solar system is retrieved from SHACOB data base
- 2) Payback period is calculated
- 3) An exogenously defined function with an S-curve shape uses the payback period as a parameter. Market sales are read off the curve.

To account for non-financial factors that can influence the rate of diffusion, SHACOB uses a weight (called UTIL) between -1 and 1 to modify the payback up or down. Positive UTIL's accelerate diffusion while negative UTIL's slow diffusion down. The determination of the UTIL value is arbitrary.

SHACOB incorporates learning curve cost declines at both the national

and regional level in its determination of solar system prices. Furthermore, as cumulative production increases, potential adopters' likelihood of purchase is assumed to increase, the result of an hypothesized greater acceptance of solar as a reliable alternative energy source.

Problems with SHACOB: The ADL model has three major problems. First, the use of an arbitrarily defined S-curve function imposes preconceived notions of how diffusion of the solar technology will play out over time; the possible paths that diffusion can take are limited by the modeler's choice of an S-curve function. Second, the use of the UTIL weight is arbitrary and there is no empirical correspondence between the size of the UTIL weight and the positive or negative influences of many factors that can affect the diffusion rate. Third, although it seems reasonable that the likelihood of purchase will increase over time as cumulative sales increase, there is no empirical justification for how SHACOB determines just how large the increase should be.

4.2.2 The MITRE SPURR Model

SPURR is a simulation model that uses a database of energy costs, engineering costs and data for different possible future economic scenarios to assess the impact of fuel costs, energy demand and government incentive programs on market acceptance of solar energy products. The model forecasts penetration for three major sectors:

- 1) buildings (hot water, heating and cooling)
- 2) process heat (agricultural and industrial)
- 3) utility.

We focus on sector 1 here. The buildings component is divided into nine building types for new and retrofit systems. Market potential is

determined by building type, within 16 specified regions and for several electricity-using conventional systems.

Market penetration is calculated using an arbitrary hyperbolic tangent function that produces an S-curve shape. The function has several parameters, among them a "figure of merit" (FOM) which is an index of the relative competitiveness of the new technology. For one and two family residences, FOM is a function of initial cost and annual savings but for other building types the functional form changes.

SPURR incorporates learning curve cost declines in its cost formulation of the solar product.

Problems with SPURR: In using an exogenously-defined S-curve function, SPURR has the same problem as SHACOB. There is no attempt to calibrate the SPURR model with empirical results from the field, which means that the diffusion path predicted by SPURR is an artifact of the S-curve function chosen by the modeler.

4.2.3 The EEA MOPPS Model

The MOPPS Model is comprehensive, and examines the potential of all new energy technologies in the industrial sector. The model attempts to match energy technologies to appropriate markets. It does this by segmenting the industrial sector by two-digit SIC codes and then further segmenting by service sectors. The result is over 2000 industrial market segments. MOPPS measures characteristics of each of these segments and attempts to match them with one of the new technologies.

Having thus defined the market, MOPPS describes new technologies (descriptions provided by ERDA) in terms of optimum plant size, initial costs, operating costs and data of commercial availability. Technologies that fit in with more than one service sector are described separately

for each sector. The idea is to match the needs of a sector with the assets of one of the new technologies.

Next, market penetration is calculated. New technology sales are found in a three-step process:

- 1) First, the proportion of the market in a given segment that finds a technology cheaper than other technologies is determined. This value is known as the "nominal market share."
- 2) Second, a penetration percentage of the total market is found using an S-curve function, with relative rate of return between old and new technologies and historical innovativeness providing the S-curve parameters. The penetration percentage is multiplied by the "nominal market share" to obtain an effective penetration rate.
- 3) Third, using estimates of industry growth rates, the potential market size is projected by multiplying the effective penetration rate by the potential market. Total penetration is found by aggregation over each segment over each technology.

Problems with MOPPS: The model assumes that financial aspects are the only relevant factors influencing diffusion. The absence of a risk factor in the specification of MOPPS undermines its validity. And, again, the use of an exogenous S-curve function to describe diffusion is suspect.

4.2.4 The SRI Model

The SRI model forecasts solar market penetration for every five-year period from 1975-2020. It provides analyses of seven solar energy technologies in nine regions. Model analysis considers three supply/demand scenarios:

- 1) low solar price
- 2) high electrification, high demand
- 3) high non-solar price.

To develop market penetration results, SRI estimates base case energy demand and price for 25 end-use markets using a basic scenario from the SRI National Energy Model. The end-use markets considered are those where solar technologies are competitive (e.g., water heating, space heating). Over 20 different generic solar systems are looked at (including 3 photovoltaic systems). Cost estimates are developed for each solar design.

Economically viable solar technologies are compared with conventional energy sources in the residential/commercial, industrial and utility sectors. Market penetration estimates for each viable solar technology are determined by the relative prices of solar and conventional energy sources as well as by a "gamma parameter." The "gamma parameter" is a value intended to measure a wide range of diffusion rate influencers such as price variations, resistance to change and consumer preferences. Gamma is used to parameterize an S-curve function which is in part specified by a behavioral lag. To specify the behavioral lag function the user subjectively estimates a date by which time it is felt that 50 percent of the market will respond to the introduction of the new technology. Once gamma and the behavioral lag are known the diffusion path assumes a fixed form.

Problems with the SRI Model: The use of the gamma parameter as an index for all non-financial diffusion factors has no theoretical basis. The relative importance of the different factors that go into gamma can only be guessed at. The behavioral lag function is also subjectively

determined, but it does not mix several unrelated diffusion phenomena as does the gamma parameter. As with the other models it uses an arbitrary, exogenously-defined S-curve function to model penetration.

4.3 Conclusions

Models of solar market penetration have, in the past, inadequately addressed diffusion principles. By relying on overly simplified, representations of diffusion phenomena, these models have failed to capture many of the important phenomena described in Section 3. The MOPPS Model incorporates financial aspects of a new solar technology but nothing else. Issues such as level of awareness, distribution, technical risk and esthetics are not considered. It is apparent that the MOPPS model suffers from incompleteness.

The most serious problem with the penetration models reviewed is the exogeneous specification of an S-curve for diffusion. This approach sets diffusion paths arbitrarily by specific functional forms that may bear little relation to reality. Furthermore, the parameters used to calibrate the S-curve are often meaningless mixtures of different diffusion factors. Neither are these parameters tied to empirical data; instead they are subjectively developed.

It appears, then, that a viable approach for PV is (a) to try to incorporate diffusion phenomena specifically in a model, (b) let the diffusion process dictate the diffusion path over time and (c) relate model parameters to data. This approach is developed next.

5. The Structure of the PV1 Model

The primary weakness of previous market penetration models for solar energy systems has been their failure to incorporate sound diffusion principles. By using exogenously-defined arbitrary S-curve functions to predict the time path of market penetration, these models capture only their modelers' pre-conceived notions of what the time path of sales should look like. Warren [1979], in a review of 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 Environmental Analysis (1978)), 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." Warren contends that a good market penetration model must begin with an adequate model of consumer adoption behavior.

The PV1 model is an attempt at explicitly modeling the consumer adoption process in the context of a market penetration model. A second difference of of the PV1 model from other penetration models is that it has an empirical base: the PV1 model relies on a large data base of demographic and behavioral information. PV1 links a consumer adoption process model with a data base, thereby erecting a model structure built on diffusion concepts that are independent of an externally specified functional form.

PV1 is a model written in the PL/1 programming language that forecasts market penetration of photovoltaics over time. It is an interactive model, allowing a user to specify technological information about photovoltaics, and to allocate funds to government policy options,

as input. In turn, PV1 provides forecasts of costs of photovoltaic cells, sales of photovoltaic systems in peak kilowatts and total government program costs. The usefulness of the PV1 model is that it gives a user the ability to simulate a range of government policy options. Comparison of resulting PV1 model forecasts affords a basis for evaluation of the effects of various policies on diffusion. The evaluation of these effects can give government policy makers a clearer picture of the diffusion process and a better feel for deploying government funds in ways which will most stimulate market penetration.

This section describes and motivates the evolution and development of the PV1 model. The structure of the model is then justified theoretically and empirically. As background for the model development we first define the major government policy options available in the National Photovoltaic Program.

5.1 Government Policy Variables

There are five classes of policy variables that the government is most concerned about in the photovoltaic area: subsidy, technology development (TD), market development (MD), advanced research and development (ARND), and advertising (ADV). All five affect both the cost and acceptability of PV in the private sector. Subsidy is the only policy option funded through channels other than the \$1.5 billion available to the National Photovoltaic Program.

Subsidies: As modeled in PV1, government subsidy policy consists of establishing a subsidy rate which is the fraction of the PV system cost that the government will bear. The amount the government subsidizes an individual installation is assumed to be limited by a subsidy ceiling. Subsidies directly reduce the cost of a PV system, thereby shortening the

payback period for a purchaser.

Market Development (MD): Market development is government spending allocated to the purchase and (usually) subsequent installation of PV systems at selected demonstration sites. MD purchases act to accelerate the market penetration of PV by demonstrating PV as a successful energy alternative. In addition, MD purchases have two major impacts on costs: government purchases (in addition to private sector purchases) lead to greater production quantities and, hence, to lower balance of system (BOS) or non-module costs; MD spending also supports the marketplace for arrays, and the greater that spending the more efficient the production facility and the lower the array cost. This latter impact can be substantial for the high volume production required of current silicon technology. With advanced silicon technology, however, JPL analyses (1980) suggest that plants will most likely be built at economic size, so MD spending will not affect array price once advanced silicon technology comes on line.

Advertising (ADV): The government allocates funds to advertising--information dissemination--in order to increase awareness of PV within the potential market. Government advertising will concentrate on promoting PV as an alternative source of electricity. A second, costless component of advertising is the advertising value of a visible government-supported PV installation.

Technology Development (TD): Technology development spending is money earmarked for development of production processes that can meet PV program goals. By effecting early reductions in PV module costs, TD spending can shorten the time until PV program goals are met. The reduction in module prices is projected to occur in at least three

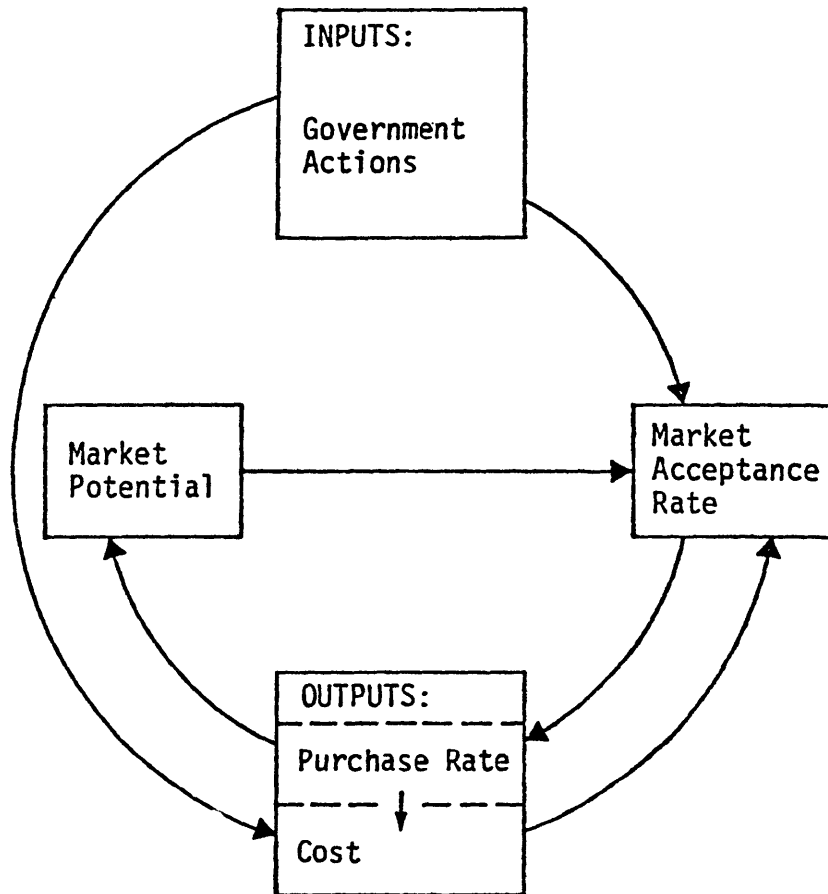
stages. The current stage is called the "intermediate" technology stage, a stage when module costs are still quite high. As TD money is spent, module costs are reduced until no further reductions are possible without a technology change. PV is currently entering a second stage, from which the rate of decline in costs can largely be influenced only by advanced research and development spending.

Advanced Research and Development (ARND): Money allocated to ARND is directed to those research endeavors with potential for breakthroughs in technology, perhaps of a non-silicon variety, and which are expected to have significant, long-term cost reduction capabilities. Greater spending in ARND is assumed to shorten the time to development of a breakthrough technology. Thus, ARND spending acts to shorten stage two of the module cost technology, thereby hastening the arrival of stage three and the breakthrough technology. DOE has set a module cost goal of \$.70 per peak watt by 1986 for a breakthrough technology.

5.2 Overview of the PV1 Model Structure

Figure 5.1 describes the basic conceptual structure of the PV1 model. The PV1 user first specifies an Input Model which defines technological information about PV as well as government policy actions. In addition, the user specifies the number of years for which the model is to forecast PV sales. In each year of the forecast, PV1 calculates a market potential for PV as shown in the Market Potential box. PV1 takes this market potential and reduces it in the Market Acceptance Rate box by screening out potential adopters who find the PV product unacceptable. Government actions, defined by user inputs, such as price subsidies and market development spending, make PV more acceptable in the market by

Figure 5.1

Conceptual Structure of PVI

1) lowering the price to the user, 2) making consumers more aware of PV and 3) instilling confidence in PV as a technically and financially viable energy technology. Once the fraction of the total market who find PV acceptable is calculated, PV1 applies an exogenously defined probability of purchase (given that the product is found acceptable) to arrive at a final purchase rate in the Output box. PV sales feed back into the calculation of market potential in the following year of the forecast.

The Market Acceptance Rate box houses PV1's model of the photovoltaic adoption process. In this box, potential photovoltaic adopters advance through the awareness, interest and evaluation stages discussed in Section 3. The modeling of the awareness stage is discussed in detail in Section 5.3c. Briefly, the awareness of potential adopters is assumed to be affected by advertising and market development installations. In each year of the PV1 forecast, some fraction of the market potential will be made aware of PV. The unaware fraction is screened out at the awareness stage of the adoption process. Those who are made aware proceed to the interest stage.

PV1 handles interest by assuming that information about photovoltaics is accessible to potential adopters, and therefore presents no barrier to adoption. Consequently, PV1 allows all who pass the awareness stage directly into the evaluation stage.

The evaluation stage is the heart of the PV1 model structure. In this stage of the adoption process potential adopters judge PV by comparing it to their current source of electricity, almost always a utility. They make comparisons along a number of dimensions, particularly financial and risk attributes. Each dimension represents a stumbling

block to final acceptance of the PV product. For a potential adopter to accept PV, he must find PV acceptable on each dimension. (The relevant dimensions are discussed in 5.3d.) PV1 models this process using a sequential ordering of market screens, one for each relevant dimension. At each market screen PV1 calculates the fraction of the remaining market potential which still finds PV acceptable. Figure 5.2 illustrates the procedure.

As mentioned earlier, the PV1 model is intimately bound to a large data base. This data base contains information necessary to perform many of the calculations in the market screen phase of the PV1 model. These information requirements impose one last structural constraint on PV1, a constraint which necessitates the fragmentation of the market potential calculation into a large number of smaller market potentials. These become the basic units of analysis for the PV1 model. Each is the market potential of a sector within a region, or a sector-region.

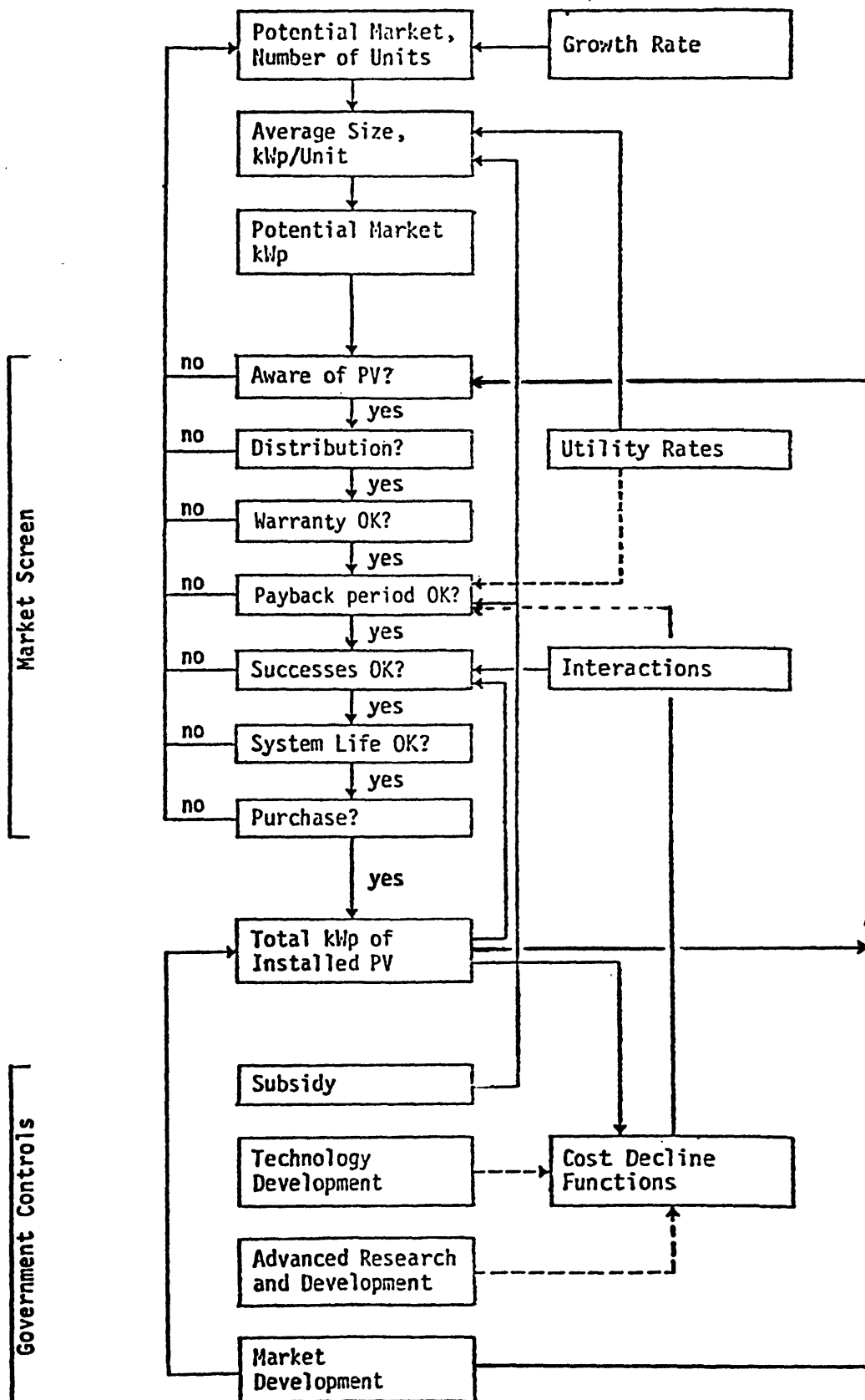
Operationally, these terms are defined as follows:

- Region: A region refers to a utility district when that region is
- (a) contiguous and
 - (b) within the boundaries of a single state

Thus, PV1 treats a utility district that provides power in two non-contiguous areas as two regions.

- Sectors: The term sectors refers to functionally different PV usage groups that, because of differences in methods of production and installation of PV arrays, see different financial costs associated with PV. The six sectors explicitly included in the PV1 model structure are residential, commercial, industrial, agricultural, government/institutional and central power.

Figure 5.2 - PVI Model Structure



Market potential must be calculated at a regional level because local phenomena such as insolation and marginal electricity rates are required for the market screen calculations, calculations which directly influence the relative acceptability of PV. The PV1 regional data base supplies the information needed for these important calculations. PV1 treats the non-contiguous areas of a utility district as separate regions to account for possible differences in insolation values and to limit the effects of government market development installations between non-contiguous regions when they are separated by a substantial distance.

Referring once again to Figure 5.1, PV1 iterates through the diagram for each utility region within each sector for each year of the model forecasts. All major retail utilities in the United States (except Alaska) are included in the data base on which PV1 operates.

5.3 The PV1 Database

Information on 469 private, public and cooperative utility regions is stored in the PV1 data base. This information is broken down sectorally. Included in this data base is information on number of customers, average annual electricity usage, marginal electricity rates, population growth rates and insolation for each sector within each region. In forecasting annual market penetration, PV1 sequentially calculates PV sales in each of the 2812 sector-regions (6 sectors x 469 regions).

The PV1 data base contains only baseline values. For instance, the "number of customers" values are 1978 figures. Clearly these figures change over the duration of PV1 forecast periods. PV1 adjusts these numbers by applying a population growth rate to them for each year of the forecast period. The population growth rate recorded for a sector-region

is an eight year average (1971-1978) of the total population growth rate for the state in which the utility region is located. It is recognized that growth rates should vary both regionally within a state as well as sectorally, and more accurate growth rate figures will be accessible once 1980 Census figures become available.

5.4 Justification of the PV1 Model Structure

The logic of the PV1 model begins with the total potential market in each sector within each region and reduces this market through market screens to derive a value for market penetration. The primary output of the model is a projection of the annual sales in peak kilowatts of installed PV by sector, aggregated over regions. The overall model logic for the calculation of PV sales is summarized in Figure 5.2.

5.4a Market Potential

The annual PV market potential in each sector-region is derived from the "number of customers" value stored in the PV1 data base. Using a sectorally determined average PV installation size, in square meters of array, PV1 converts the number of customers into a market potential in peak kilowatts. For the commercial, industrial, agricultural and government/institutional sectors, PV1 assumes that the average size of a PV installation is 300 square meters. The selection of this value is somewhat arbitrary, and was chosen as a best estimate of the needs of an average non-residential building or farm. As PV1 is developed, the average installation size will be modeled to more accurately reflect electricity needs in these sectors.

There are two underlying assumptions in the computation of average size in the residential sector. First, the total cost of electric energy for a PV user will be the user's cost of electricity before installing

PV, plus the annualized cost of owning a PV system, minus the savings derived from both the reduced usage of utility energy and the savings derived from selling back any excess power produced by the PV unit. Second, it is assumed that the average residential PV user will purchase the PV array size that minimizes the cost of electric energy on an annual basis.

The average size of a residential PV installation is estimated by Lilien and Wulfe [1980] as:

$$W_m = \frac{AU \cdot ER \cdot (1 - R_s/R_p) \cdot b}{VC \cdot (1 + Z) \cdot CRF - R_s/R_p \cdot ER \cdot I \cdot \eta} \quad (5.1)$$

$$10 \leq W_m \leq 90$$

where:

- AU = average annual electricity use, in KWh/yr
- ER = cost of utility generated electricity in \$/KWh
- R_s/R_p = price of sell-back electricity as a fraction of purchased electricity
- b = regression constant = .1224
- VC = variable system costs, \$/m²
- CRF = capital recovery factor = .1175
- I = insolation, KWh/m²yr
- η = system efficiency
- Z = system maintenance costs (annual fraction)
- W_m = average size, m²

For the central power sector, it is assumed that a utility will only purchase PV if it has a need for at least 25 MWp of additional capacity. The average installation size for central power is arbitrarily set at 25 MWp/ η .

The need to put market potential in units of peak kilowatts stems from the standard practice of pricing PV in dollars per peak kilowatt. The conversion of one square meter of installation size into peak kilowatts assumes the form:

$$KW_p = \eta(m^2) \quad \text{where } \eta = \text{system efficiency (about .12)} \quad (5.2)$$

Thus an average industrial PV array of 300 m^2 will produce approximately 36 peak kilowatts. And the total market in a sector-region in a given year is computed as:

$$KW_{srt} = W_{srt} * V_{srt} \quad (5.3)$$

where:

- KW_{srt} = the potential market in peak kilowatts, in sector s , region r , at time t
- W_{srt} = average PV installation size in m^2 , in sector s , region r , at time t
- V_{srt} = number of potential customers in sector s , region r at time t

It is assumed that all planned capacity increases for a utility region (less whatever photovoltaics are installed by utility customers) plus the replacement of existing equipment, together represent the potential market for photovoltaics in the central power sector.

Once market potential has been calculated, the fraction of the market who find PV acceptable is found by successively reducing the market potential through a series of screens. The first screen encountered in PV1 is the awareness screen.

5.4b The Awareness Screen

The potential market in a sector-region is first reduced at the awareness stage of the adoption process. The PV1 awareness screen

eliminates potential buyers who are not aware of photovoltaics. The fraction of the current market that is aware of PV in year t is the sum of:

- (a) the fraction of the market who were aware of PV in year $t-1$ and who remember it; and
- (b) the fraction of the market who were not aware of PV in year $t-1$ but who are informed of PV in year t .

Awareness of PV within the potential market is a function of government advertising campaigns, measured in terms of effective advertising dollars that the government spends annually. There are two sources of "effective advertising dollars":

- 1) Direct advertising dollars which government spends on media and information dissemination. In PV1, this kind of government spending is user specified as a fraction of MD spending.
- 2) Non-monetary advertising. A government purchased market development installation is assumed to have advertising value for demonstrating that PV is viable both technically and economically. The advertising value of a demonstration installation is set at \$3000. Private PV installations also have this value.

Thus:

$$EAD_{srt} = ADPER_t * MD_{srt} + DELTA * \sum_{k=1}^S CUMSITES_{kr} * SI_{ks} \quad (5.4)$$

where:

- EAD_{srt} = effective advertising dollars in sector s, region r at time t
- $ADPER_t$ = fraction of MD spending in time t used for direct media promotion
- MD_{srt} = market development spending in sector s, region r at time t
- DELTA = effective advertising value of a visible PV installation (in dollars). PV1 uses a value of \$3000 for DELTA.
- SI_{ks} = the effective perceptual influence of sector k on sector s. (This variable is described in 5.3c.)

Assuming that the potential market is made aware of PV only by "effective advertising dollars", the fraction of the market aware of PV in year t is given by the following simple model of advertising awareness:

$$A_{srt} = K * A_{srt-1} + (1 - K * A_{srt-1}) * (1 - e^{-(EAD)B}) \quad (5.5)$$

where:

- A_{srt} = fraction of potential market aware in sector s, region r at time t
- K = memory constant. Of those who were aware in time t-1, K is the fraction who remember in time t. In the current version of the model, K is set at .75.
- B = 14
- EAD = effective advertising dollars

The coefficient B is estimated by assuming that one half of an average regional market is made aware of PV when total regional "effective advertising dollars" are \$50,000.

5.4c The Market Evaluation Screens

The fraction of the potential market that successfully passes through the awareness screen next enters the evaluation stage of the adoption process. PV1 subjects the remaining market to four market evaluation screens which further reduce the fraction of the market who find PV acceptable. These screens deal with technical, warranty, system life and payback acceptabilities. In a national study of Active Solar Heating and Cooling Products [1980] these screens were found to be the primary evaluation criteria used. The active solar systems studied are products that share many technological and economic attributes with PV. The marked similarities of these other solar products to PV suggested that the same evaluation criteria could be successfully applied to the PV case.

PV1 handles the logic of the market screen evaluations as demonstrated in the following example of the warranty screen.

Warranty

The PV1 user may specify the warranty period (W) for PV in the Model Inputs. Otherwise, the PV1 default value is 12 months. First, PV1 asks the question, "What fraction of potential adopters would find PV unacceptable if the warranty were less than (W) months?" The answer to this question is provided by survey results used in generating a distribution of the fraction of the market who find PV unacceptable for a range of warranty period values. The distribution is sector dependent, so a separate distribution is required for each of the six sectors. For example, in the residential sector the percentage who find a 12 month

warranty to be unacceptably short is 74 percent. This figure drops to 22 percent for a three-year warranty. The same procedure is taken for the other three evaluation screens. The distributions of these unacceptabilities are built into the PV1 model. It is computationally fortunate that these screening distributions for each sector were empirically found to be independent of one another. This allows the PV1 market reduction algorithm to process the criteria sequentially rather than jointly: if, for instance, a potential market is evaluated at 1,000,000 peak kilowatts, and awareness is 36 percent, warranty acceptability is 26 percent, lifetime acceptability is 63 percent, technical acceptability is 5 percent and payback acceptability is also 5 percent then the total market of those who find PV acceptable is:

$$1,000,000 * .36 * .26 * .63 * .05 * .05 = 147 \text{ peak kilowatts}$$

System Life

As with the warranty, the PV1 user may specify the expected lifetime (L) of the PV system in the Model Inputs. Default is 15 years. PV1 then calculates the fraction of potential adopters who would find PV unacceptable if the expected system life were less than (L) years.

Technical Acceptability

This screen assesses the innovativeness of potential adopters as well as the purchase-risk proneness of potential adopters. For this screen PV1 determines the fraction of potential adopters who would find PV unacceptable if they had not seen at least (I) PV installations already operating successfully. An important implicit assumption here is that all PV installations operate successfully: the PV1 model does not

account for negative word-of-mouth effects from PV field failures. These effects will be modeled in a future revision of PV1. (See Kalish and Lilien, 1980, for preliminary work on this problem.)

The determination of the number of prior successful installations is handled by modeling interaction effects.

Interactions: The six sector types have different influences on each other which we define as sectoral interaction effects. It is hypothesized that PV systems installed in one sector influence the effective number of successful installations perceived by potential adopters in other sectors. In addition, the distance of installations from those potential adopters perceiving them should also influence the number of effective installations that are perceived. Thus, the effective number of installations perceived by potential adopters within a given sector and region is equal to the number of installations within that sector and region plus the effects of installations outside the sector or region. This is computed as:

$$EFF_{srt} = \sum_{n=1}^R \sum_{k=1}^S N_{srt} * SI_{ks} * RI_{nr} \quad (5.6)$$

where:

N_{srt} = actual cumulative number of installations in sector s,
region r, at time t.

SI_{ks} = the effective perceptual influence of sector k on sector s

RI_{nr} = the effective perceptual influence of region n on region r

EFF_{srt} = effective installations perceived in sector s, region r
at time t

Both influence coefficients vary between 0 and 1 and PV1 assumes:

$$\begin{array}{lcl} RI_{rr} = 1 & & RI_{nr} = RI_{rn} \\ & \text{and} & \\ SI_{ss} = 1 & & SI_{ks} = SI_{sk} \end{array}$$

The default values of all other influence coefficients are 0. The PV1 user is free to redefine the SI coefficients.

Values of RI are computed on the basis of a gravity type model, where the interaction between two regions is inversely proportional to the square of the distance (in miles) between them:

$$RI_{nr} = \text{minimum} \left(\frac{d_0^2}{2d_{nr}^2}, 1 \right) \quad (5.7)$$

where:

d_0 = distance at which interaction = 0.5

d_{nr} = distance between regions n and r, in miles

The PV1 database stores distances of a region's ten closest neighbors. Installations from these neighbors are used in calculating EFF_{srt} . Influences from all other regions are regarded as negligible.

Payback

PV1 calculates a simple payback for each sector-region for every year of the forecast period. The form of the payback calculation is:

$$\text{payback} = \frac{\text{system cost} - \text{subsidies}}{\text{pvsave} + \text{bbsave} - \text{mtncost}} \quad (5.8)$$

where:

pvsave = electricity savings (dollars) from using PV instead of the utility

bbsave = money earned from selling excess PV electricity back to the utility

mtncost = annual maintenance costs.

PV1 then determines the fraction of potential adopters who would find PV unacceptable if payback were more than (y) years.

An important assumption of the PV1 model is that all non-utility PV users install systems that are connected in parallel with the utility grid (that is, they use as much of their own PV power as they can, sell the excess to the utility, and purchase back-up power from the utility) and do not use storage systems. These are called "parallel" distributed PV systems. Prices that are paid to the PV user for electricity sold to the utility in PV1 are consistent with rules set down by the Public Utility Regulatory Policy Act (P.L. 95-617, PURPA). Utilities are expected to pay between 30 and 70 percent of a user's marginal electricity rate for such electricity, in compliance with PURPA's "just and reasonable" rule. The variable "bbsave" in PV1 represents the savings to an average consumer from electricity sold back to the utility.

5.4d Market Distribution

The acceptance of PV as a viable alternative source of electricity is not enough to guarantee purchase. It may be, for instance, that in the early stages of marketing PV, manufacturers are simply unable to achieve total geographic distribution. The obstacle to distribution lies not with the shipment of PV equipment, but with the lack of competent local contractors and service personnel. Few such individuals are likely to emerge in small towns and rural areas. Limited distribution acts to screen out another fraction of potential adopters from purchase. To

model the distribution screen, a survey of contractors and builder/developers in each utility region would be required. It would be necessary to assess each contractor and builder/developer's probability of learning PV installation techniques. For the current version (and with some reservation) PV1 uses an average nationwide distribution fraction and applies it to each utility region. At present this fraction is set at .5 and is constant for the duration of PV1 forecasts.

In an aggregate sense, (and PV1 is an aggregate model), the use of one overall distribution fraction is not unreasonable, provided of course that it is accurate. Although distribution will vary over utility regions, the aggregate of all regional market penetrations for a given year will be the same, using either the one average distribution fraction or 469 utility region-specific distribution fractions. Unfortunately, in using the average fraction, the PV1 model may incorrectly distribute installations over regions. In so doing, region-specific technical acceptability screen values (number of prior successful installations) are altered. It is not clear how much bias this introduces into market penetration forecasts. Furthermore, the distribution fraction should realistically increase over time as acceptability increases among contractors and builder/developers. In future revisions of PV1 an attempt will be made to estimate with accuracy an initial distribution fraction (.5 is only a best guess) and then to model the temporal distribution and shift of this fraction.

5.4e Probability-of-Purchase

The final step in the calculation of PV sales requires determining the fraction of the market who will buy, given they have passed through the previous awareness, evaluation and distribution screens. There is no

known survey or statistical method which can estimate ex ante the probability-of-purchase with any reliable accuracy. Techniques commonly practiced for deriving a probability-of-purchase include measurement of purchase intentions of a sample group of potential adopters. Researchers generally apply some arbitrary factor to the purchase intention responses to arrive at an overall probability-of-purchase. Kalwani and Silk [1981] report that "while positive associations between intentions and purchases have generally been observed..., the strength of the relationship uncovered in these analyses has not been viewed as sufficiently marked and consistent to allay the basic concern ... [of] ... many in the marketing research community."

In the same paper Kalwani and Silk present further analyses of a method developed by Morrison [1979] to evaluate the quality of purchase intention measures. Part of the unreliability of estimating probability-of-purchase from purchase intentions is that purchase intention responses are measured with error. Morrison's model provides a framework for evaluating the effect of inaccurate responses.

The probability-of-purchase currently used in PV1 is a best-guess estimate of 10 percent, consistent with data on appliances given by Juster [1966]. The need exists for a better estimate. In the future, a survey to measure purchase intention for PV will be conducted, measurement error will be estimated using Morrison's model, and hopefully an adequate probability-of-purchase will be obtained.

5.4f Market Penetration

Market penetration in a sector-region is calculated by multiplying the fraction of the market who find PV acceptable by the distribution screen fraction and by the probability-of-purchase. Thus, in the example

of the warranty screen section, market penetration would be:

$$147 \text{ peak Kw} * .5 * .1 = 7.4 \text{ peak Kw}$$

PV sales are fed back into the succeeding year to adjust downward that year's market potential estimate. In addition, PV1 updates the database values of acceptabilities for each evaluation screen, for each sector-region, by subtracting out the fraction who have bought. For example, if 10 percent of a given sector-region found a payback of 10 years or more acceptable and ultimately 3 percent buy in that year, then in the following year only 7 percent of the market would find a payback of 10 years or more acceptable. (This is modified somewhat for changes in market potential due to growth, etc.)

One last aspect of the PV1 model is the incorporation of a market expansion factor. If PV sales grow too quickly, such that expected production cannot keep pace with demand, then PV1 limits annual sales by proportionally scaling down sector-region sales until their sum equals some allowable total sales maximum. The market expansion factor is modeled such that in the long run, PV sales cannot grow more than 30 percent annually and can at most double eight years into the model forecast. Functionally,

$$\text{market expansion factor} = .3 + 1.7 * \exp(-.11091 * t) \quad (5.9)$$

Finally, a caveat for use of PV1 model forecasts is in order. As this section has demonstrated, PV1 forecasts are based not only on a number of measured quantities (for instance, the acceptability values) but also on several unknown quantities like the probability-of-purchase. Thus, the PV1 forecasts should not be studied in terms of absolute market penetration numbers. Rather, the major usefulness of PV1 is as a sensitivity tool, allowing a user to compare the likely diffusion of PV

under different market stimulation policies.

5.4g Cost Reduction

The costs of a PV installation figure prominently in several PV1 calculations, most importantly in the calculations of government subsidy costs and the payback screen. The diffusion rate, a function of the payback screen, is thus sensitive to the cost of PV. Although costs cannot be perfectly foreseen into the future, PV1 requires a cost reduction model that can give good estimates of PV costs through the next decade. The reliability of PV1 output depends on the accuracy of this cost reduction model. PV1 uses the cost reduction formulation described below - a formulation designed to conform with methods suggested by JPL [1980].

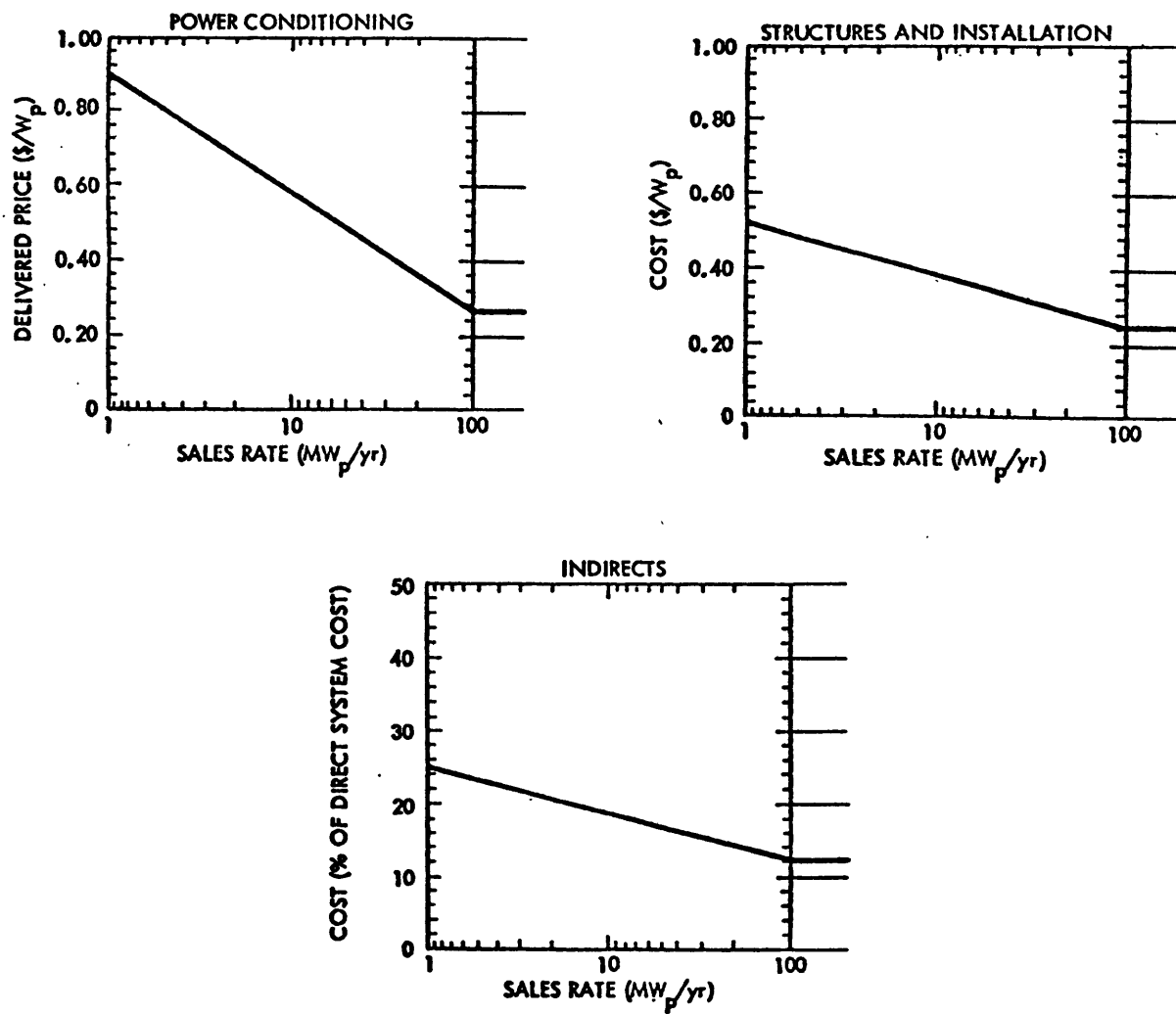
A PV installation has two main components: the PV module itself, and the balance of the system (BOS). BOS consists of power conditioning equipment, structures and indirect costs. Indirect costs are contingencies, fees and other costs not included elsewhere.

BOS Cost Reduction: BOS costs are assumed to vary from year to year, as a log-linear function of the total estimated annual sales rate. Specifications are illustrated in Figure 5.3. Just as there is interaction among sectors for the acceptability of the prior number of successful installations, the sales rate by which a sector's BOS costs are computed is also influenced by the number of sales in other sectors. In PV1, these sectoral influence coefficients can be user specified. The default values are those of the "successes" influence matrix, the matrix used in calculating effective successful installations for use in the technical acceptability screen.

Module Cost Reductions: The model for module cost reduction is more

Figure 5.3

Price/Cost vs. Sales Rate



a function of the state of technology than are BOS costs, and is therefore more complex. It depends on government expenditures for technology development and advanced research and development, and on expectations about 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 cost is calculated in terms of dollars per peak watt.

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 user, or optionally, the dates may be modeled, as shown below. The current stage is called the "intermediate" technology stage. In this stage, the price of PV is given by:

$$P_{\text{MODULE}} = [2.83 - (84 - P_{\text{Si}}) * \frac{94}{70000}] + \frac{2.4}{Z} \quad (5.10)$$

where:

P_{MODULE} = price of PV, \$/W_p

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

Z = plant size factor, MW_p/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 PV1 model assumes a four plant industry for initial commercialization.)

The year that this first stage of module cost reduction ends may be defined by the user. Alternatively, the user may model the duration of the first stage by specifying the duration in terms of government technology development funding. PV1 estimates the duration through the following relationship:

$$T = (t_2 - t_0) \left[1 - \frac{X^\beta}{\gamma + X^\beta} \right] + t_0 \quad (5.11)$$

where:

T = time to end of stage 1,

X = cumulative TD in millions of dollars,

t_0 = earliest possible date for stage 2 after unlimited funds are spent,

t_2 = date of ultimate price if $X = 0$,

D_1 = most likely annual spending level

t_1 = most likely date for stage 2 at annual input spending level, D_1

t_3 = most likely date for stage 2 of module if annual spending level is $2D_1$.

and

$$\beta = \text{Log}_2 \left[\frac{t_2 - t_3}{t_3 - t_0} \cdot \frac{t_1 - t_0}{t_2 - t_1} \right] \quad (5.12)$$

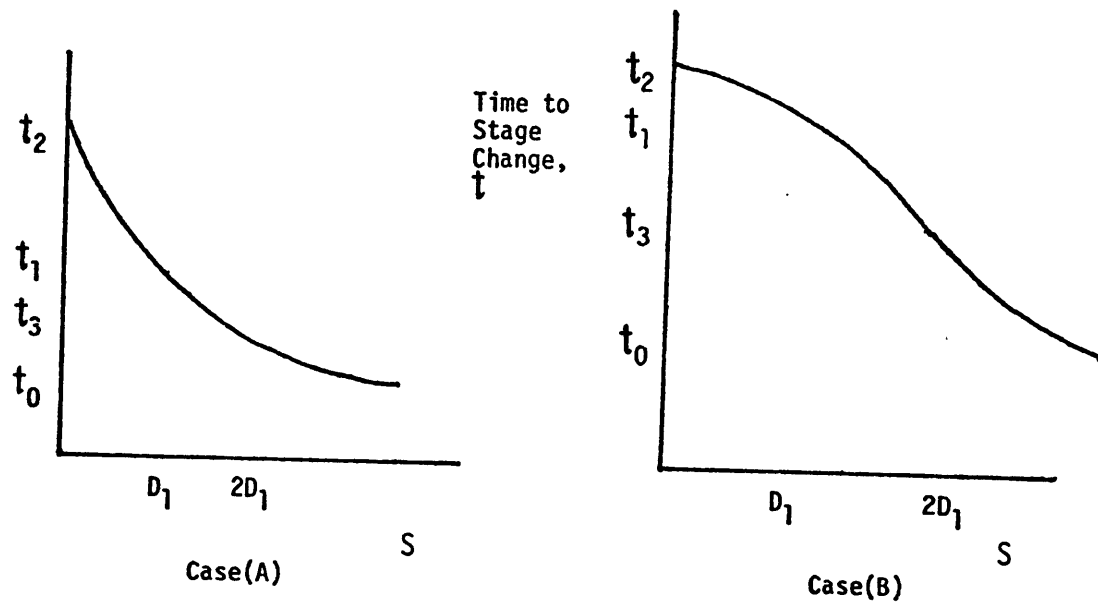
$$\gamma = (D_1 t_1)^\beta \cdot \frac{t_1 - t_0}{t_2 - t_1} \quad (5.13)$$

The variables t_0 , t_1 , t_2 , t_3 , and D_1 are parameters supplied by the user as optional input. The amount of annual TD spending, D_1 , is a control variable. The model itself will discontinue the allocation of TD in the year that Stage 2 technology arrives. Effects of the input parameters are illustrated in Figure 5.4.

The module price in the second stage is no longer a function of plant size, only of silicon prices. Plants are assumed to be producing at minimum efficient scale. Price in Stage 2 is modeled by:

Figure 5.4

Illustration of TD and ARND Spending Effects
on Technology Arrival Dates



S = Annual TD or ARND Spending

$$P_{\text{MODULE}} = 0.70 + [(P_{Si} - 14) * \frac{84}{7000}] \quad (5.14)$$

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

$$T = (t_2 - t_0) \left[1 - \frac{Y^\beta}{\gamma + Y^\beta} \right] + t_0 \quad (5.15)$$

where Y now represents the cumulative level of ARND funding.

The third, or "ARND Breakthrough" technology stage, represents an ultimate, low price for PV that will result from some as yet unknown technology. While the date for the beginning of this stage may be computed by the methods outlined above, the actual price is supplied by the user. The PV1 default is \$.70/W_p.

Total Cost: Disregarding subsidies, the final cost to the consumer of a PV installation is the cost per peak watt, installed, times the number of peak watts in the array. The cost per peak watt, installed, is a function of module price, BOS costs and a manufacturer's markup.

$$\begin{aligned} \text{Total cost/W}_p &= [P_{\text{MODULE}} * (1 + \text{markup}) + \text{pcucost} + \\ &\quad + \text{sns cost}] * (1 + \text{indcost}) \end{aligned} \quad (5.16)$$

where:

P_{MODULE} = module cost

pcucost = power conditioning cost

sns cost = structures and installation cost

indcost = indirect cost fraction

markup = manufacturer's markup fraction

In a future revision of PV1, a revised JPL cost formulation will incorporate a cumulative sales effect into the module cost calculation.

6. Field Data Collection

A unique characteristic of the PV1 model is that it is tied to a field data collection activity. Data collected in field surveys are incorporated into the PV1 model for calibration of the acceptability distributions of the evaluation screens. This section motivates that data collection process, linking it to parameterization of the PV1 model. In addition, and unrelated to the model, this section describes how direct product development strategy guidance can be derived from the field measurement procedure. The design and implementation of surveys in the residential and agricultural sectors are described.

6.1 Motivation for the Data Collection Activity

In recent years, a large number of studies have reported on the causes of new product successes and new product failures (see Choffray and Lilien, 1980, for discussion). In general, their results point to a single cause as the most frequent reason for market failure or delay of market success in the new product area:

- the product developer is out of tune with the way customers perceive and evaluate the product.

Thus, for DOE's market development program to be successful, not only must PV costs be lowered, but perceptions and expectations of PV must be measured early to provide feedback that can be integrated into the product development process. These measurements of consumers' perceptions, expectations and attitudes toward PV can be made with the use of a field survey. Results of the survey can suggest areas for product improvement, or a need for better communication of product features that are poorly perceived.

As important as field measurement is to the development of a

successful product, it is no less important as a means for calibrating a model that is expected to provide reliable forecasts of PV market penetration. Without a strong link to how customers actually perceive PV, the usefulness of the model would be seriously impaired. There are several major objectives that field measurement must fulfill if it is to gather information that can be incorporated into the PVI model:

- o to measure changes in the level of photovoltaic awareness and attitudes toward PV on a region-specific basis
- o to measure the sphere-of-influence of a PV demonstration installation. (How are awareness and technical acceptability affected by distance from an installation?)
- o to act as an identifier of demographic and behavioral characteristics of early potential adopters (innovators) of photovoltaics
- o to determine acceptability distributions for a set of important PV evaluation criteria
- o to provide design feedback from potential adopters so that the market development program can achieve maximum effectiveness.

To realize these objectives, field measurements must be obtained periodically so that changes in attitudes, perceptions and awareness can be monitored.

6.2 Measurement Approach

This subsection motivates the measurement approach taken for PV. Sampling designs are described for surveys conducted in the agricultural and residential sectors.

Useful results from surveys are only obtained when the survey design is made carefully and scientifically. It is necessary to be aware of,

and to try to minimize, threats to validity of measurement results. Controlled measurement demands pre- as well as post-action measures to evaluate the effect of an activity. For ease of description of measurement experiments we use Campbell and Stanley's notation [1963] which defines O as an observation (attitude measurement) and X as a treatment of exposure (to an experiment). In the past, the typical solar study has been a no-control post-test only experiment:

$$X \quad O \quad (6.1)$$

Boring [1954] states that "such studies have such a total absence of control as to be of almost no scientific value."

A most popular design that adds control both for external effects and for internal validity is the pre-test-post-test control group design:

$$\begin{array}{l} R \quad O_1 \quad X \quad O_2 \\ R \quad O_3 \quad \quad O_4 \end{array} \quad (6.2)$$

(where R refers to randomized assignment to groups). The effect of X (exposure to a demonstration site, for example) is read here as

$$(O_2 - O_1) - (O_4 - O_3)$$

where the subscripts refer to sample numbers.

A typical tracking study, used in advertising assessment for consumer products, uses a modified version of design (6.2), (6.2a):

$$\begin{array}{l} R \quad O_1 \quad (X \quad O_2) \\ R \quad O_3 \quad \quad O_4 \end{array} \quad (6.2a)$$

Here, exposure to a site is self-reported. Such a design is threatened with biased misclassification ("Did you see X?"), but careful

separation of the probe for X -exposure and probe for O_2 during the interview can minimize this source of bias.

If we view X_i as a set of random stimuli occurring at different times to different segments of the public (X_i might include a midwest natural gas shortage, a Middle East embargo, the modification of solar incentives, etc.), it becomes clear that a design like (6.3)

Time			
$t = 1$	$t = 2$	$t = 3$. . .
O_{11}	O_{12}	O_{13}	
O_{21}	O_{22}	O_{23}	(6.3)
O_{31}	O_{32}	O_{33}	

must be in the field already to capture these effects. A post-survey (like (6.1)) to evaluate the effect of planned or environmental change has no scientific value.

Thus, a carefully designed, random sample must be in the field periodically to read the effect of uncontrollable events on changes in solar attitudes and awareness as well as to read the effect of the field experiment unit.

How should that survey be designed? The normal tracking-study design would be:

Time			
Area	$t = 1$	$t = 2$. . .
1	$R(X_{11}O_{11})$	$R(X_{21}O_{12})$. . .
2	$R(X_{21}O_{21})$	$R(X_{22}O_{12})$. . .
.	.	.	(6.4)
.	.	.	
.	.	.	

Here, separate random samples are developed at each time-point. Group averages can be compared, but changes in attitudes at the individual level cannot be measured because different individuals are involved. We propose a variation of (6.4) that alleviates this problem. In (6.5) we consider region only and use the superscript A, B, etc. to refer to cohort, or group studied.

$$\begin{array}{ccc}
 \text{Time} = 1 & \text{Time} = 2 & \text{Time} = 3 \\
 R O_1^A & & \\
 R O_1^B & (X_2 O_2^B) & \\
 & R(X_2 O_2^C) & (X_3 O_3^C) \\
 & & R(X_3 O_3^D) \dots
 \end{array} \quad (6.5)$$

Here, cohort B is remeasured at 2; cohort C is remeasured at 3, etc. The imbedded design:

$$R O_1^A \dots R(X_2 O_2^C) \dots R(X_3 O_3^D)$$

is identical with a single row of design (6.4); in addition, we have the important remeasurement of changes within a cohort: $O_2^B - O_1^B$, for example.

Our measurement approach assumes that the likelihood of adopting photovoltaics is a function of (a) system economics, (b) psychological perceptions of the system, (c) demographic/life style variables and (d) regional influence factors. A normal cross-section of observations can be used to calibrate an individual choice model.

Where we wish to read the effect of a demonstration site, however, we need remeasurements. The design proposed here allows us to measure and calibrate the following key model:

$$\text{Intent}_{it} = f(\text{Intent}_{i,t-1}, \text{Economics}, \text{Life Style}, \text{Site Exposure}, \text{etc.}) \quad (6.6)$$

where the above equation suggests that changes in intent to purchase are affected by likely exposure to the PV site. Note that the individual remeasurement modeled above, embedded in our research design, allows for modeling at the individual level.

The importance of modeling at the individual level follows from the observation that if you have 10 regions, then with design 4, you have 10 observations:

$$O_{i2} - O_{i1} = \Delta_i, \quad i = 1, \dots, 10$$

With individual modeling, you might have a natural sample of 1000-2000 observations. The additional degrees of freedom for estimation allow for much more modeling flexibility and development of more useful information.

An important point to reemphasize is that the (common) design (6.4) is embedded in design (6.5). All information available from (6.4) can be obtained from (6.5) plus much more resulting from evaluation of effects at the individual level.

Variations on (6.5) are possible where portions of the cohort are remeasured after varying lengths of time. This design is useful when wearout of various program-effects are being tested.

Note that design (6.5) also allows for controlled experimentation (via direct mail, for example) to random subsets of the group between the first and second measurement. The residential study, described shortly, incorporates the first column of design (6.5).

As a first step in the measurement process, we must develop and test measurement instruments. This involves the recognition of the important issues that need to be measured.

6.2.1 Issue Recognition and Questionnaire Design

The PV data collection activity is a three-stage process. First, we identify relevant issues that the field survey should address. This is accomplished by either a focus group interview or by a series of individual face-to-face interviews. Second, the issues developed in these interviews are discussed, and then developed into attitudinal, perceptual, behavioral and demographic questions and statements that are put together into a pilot study questionnaire. The pilot study is fielded with a small sample of the relevant population and results are checked for questionnaire design and wording problems or possible omissions. Third, the questionnaire is reworked to eliminate its problems and then fielded in a large-scale survey.

Since PV-related issues vary sectorally, different questionnaires have been administered to the different sectors. The two following examples describe how data have been collected in the residential and agricultural sectors.

6.2.1a Questionnaire Development for the Agricultural Sector

In 1977, a government-funded PV installation was officially opened in Mead, Nebraska. The array provided electricity to a small irrigation pump that supplied water to a cornfield on a University of Nebraska experimental farm site. PV is especially appropriate for this application since pumping for irrigation is needed most on days when solar energy is most abundant. The opening provided a prime opportunity to measure farmer attitudes and perceptions of PV both pre- and post-observation of the installation. In preparation for this, a questionnaire was developed which was designed to measure sector demographics, price-acceptance distributions, number of prior successes

of an innovation before it is accepted as reliable, cost decline factors and energy usage and needs. Other areas of concern were also probed to identify issues that would assist in future demonstration designs in other sectors. Using an open-ended format, two project members conducted interviews in nearby Lincoln, Nebraska with individuals who were involved in and knowledgeable about farm management and irrigation practices. The people interviewed were:

1. A farm business writer, who also owned a small farm;
2. A large farm owner-operator;
3. A farm-extension county agent;
4. A farm machinery dealer;
5. A bank farm-loan officer;
6. An official of the Farm Bureau;
7. The Department Head of Agricultural Engineering at the University of Nebraska;
8. University of Nebraska Professor of Agriculture and Water Resources;
9. University of Nebraska Public Relations and Communications Editor in charge of the PV demonstration project;
10. Radio and TV station farm editors in Lincoln.

The issues that emerged from these interviews were developed into questions and perceptual statements for a pilot study questionnaire. The pilot study was tested among farm owners in Massachusetts and New Hampshire. The questionnaire was then modified and a final version prepared for large-scale data collection at Mead on opening day.

The sample design for the larger-scale agricultural sector survey provided measurements from three types of respondent:

1. Farmers who had not been exposed to the PV demonstration
2. Farmers who had just been through the PV demonstration
3. Farmers who were interviewed just before and just after seeing the demonstration.

The actual sample design is summarized as:

	<u>Measurement</u>	<u>Demonstration</u>	<u>Measurement</u>	<u>Total</u>
Group 1	0			104
Group 2		X	0	105
Group 3	0	X	0	<u>87</u>
				296

The study did not incorporate methods for periodic observation and remeasurement.

6.2.1b Questionnaire Development for the Residential Sector

Two focus group interviews were conducted in July, 1980. The first group was composed of ten participants: six women and four men. All were married homeowners living in several of the more affluent suburbs of Boston, Massachusetts. All participants had non-electric hot water and heating systems. The respondents were selected at random within their communities and were interviewed at a professional facility in Lexington, Massachusetts.

Mention of PV was carefully avoided at the beginning of the interview. Focus group members were guided into a discussion of solar energy. A questionnaire about PV was then introduced. The members completed the residential questionnaires and made suggestions for possible improvements. The questionnaire was modified to take account of potential problems and a pilot telephone survey was subsequently

conducted in the same Massachusetts suburbs where the focus group members lived. A large-scale survey will be fielded shortly and sampling will be conducted according to the first column of sample design (6.5). The resulting survey instruments are included as Appendix 2.

6.3 Calibration of the Acceptability Distributions

Recall that technical, warranty, system life and payback acceptabilities were found to be the primary criteria used by potential adopters in evaluating the PV system. One objective of the PV field surveys is to collect data which yield acceptability distributions for these four market evaluation screens. The procedure taken to derive the acceptability distributions is straightforward. For example, in the agriculture survey farmers were asked to specify their minimum requirements for system life, payback period, and number of prior successful installations they would have to see before considering a photovoltaic-powered irrigation system. (At the time of the survey, warranty was not considered an important evaluation criterion. A second study measured minimum requirements for warranty.) From their responses, cumulative acceptability distributions were derived: thus we look up for any given value of a parameter, the proportion of farmers who find the level of the evaluation criterion acceptable. The cumulative distributions are incorporated into the PV1 model. Should future studies find these distributions changed, then the current distributions will be replaced.

Acceptability distributions for the residential, commercial, industrial and public authority sectors are currently determined from information supplied in interviews with HVAC consultants and architects (Lilien and Johnston, 1980). These individuals estimated the

acceptability distributions for each sector, and averages of their estimates were used as the distributions for PV1. The residential study soon to begin will supply PV1 with new distributions for the residential sector.

In sum, there were a number of field-related sources for the data incorporated in the PV1 model. The supporting data are found summarized in Lilien and McCormick, 1979 and Lilien and Johnston, 1980.

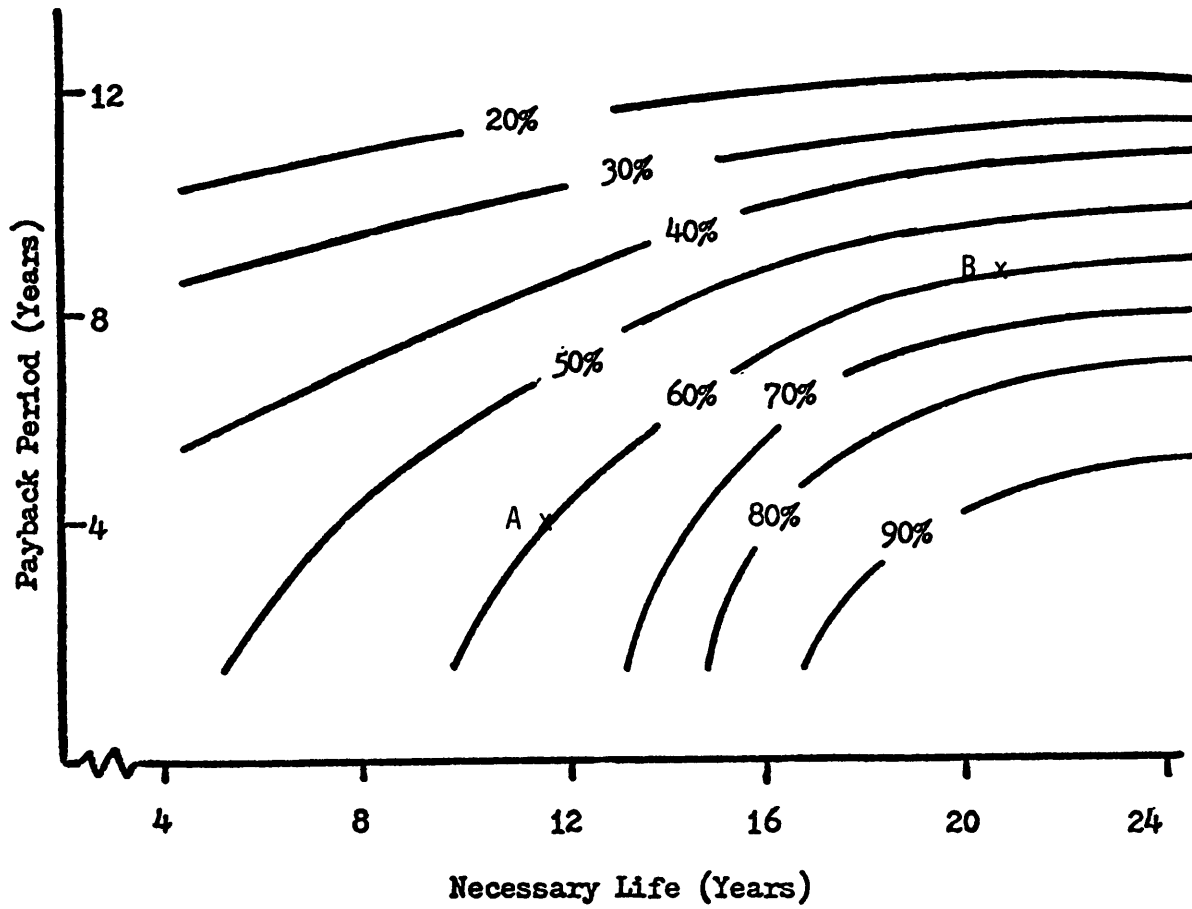
6.4 Product Development Guidance

The acceptability distributions can also be used to provide PV-product development guidance. The system designer, in developing the PV product, would like to know how much total acceptance will increase with an incremental change in say the payback period or the lifetime of the system. He can compare this information with incremental cost and thereby make a rational decision on system design trade-offs. This situation is analogous to government's problem in allocating funds between the different policy options.

A useful means for exploring system design trade-offs is the iso-acceptance curve, conceptually the same as the indifference curve used in economics. Figure 6.1 presents iso-acceptance curves for payback period versus system lifetime in the agricultural sector. Each curve is sketched through the locus of points with the same overall probability of acceptance on the two system characteristics. These curves represent the trade-offs between system characteristics. Thus, the same percentage of farmers are satisfied with each pair of values along a given iso-acceptance curve. Referring to cost estimates, the system designer can determine target values for payback and system lifetime for a given level of acceptance.

Figure 6.1

Payback Period vs. Necessary Life Acceptability Curves



Source: [16, pg. 67]

Consider Figure 6.1. Two points, A and B, are marked. A represents a 4-year payback and a 12-year lifetime. B represents an 8-year payback and a 20-year lifetime. Were either of these conditions to occur, 60 percent of farmers would find PV acceptable on these two dimensions. Thus, farmers on average are willing to pay a 4-year payback "premium" (8-4) to obtain an extra 8 years (20-12) in system life (assuming current system design is at point A). Figure 6.1 also indicates that although low values of payback and high values of system life are needed to get high acceptance (5 and 17 years respectively for 80 percent), less stringent values will still capture some market (e.g., 11 and 11 is acceptable for 25 percent). This information would be important to a marketer or a design engineer.

7. Insight into PV Policy Development

PV1 is an expensive simulation model to use, both in terms of computation costs and time used waiting for output. It is impossible to simulate all possible government policy strategies to find the best one. The size of the PV model (containing over 100,000 decision variables for a 20-year model, related to one another in a highly non-linear way) precludes analytical or numerical optimization. It is therefore useful to develop insight into the structure of optimal government spending policies to guide the search for superior policies. This section presents some theoretical results that shed light on:

- 1) The structure of optimal deployment of market development (MD) spending on PV demonstration installations.
- 2) Optimal subsidy strategies for new technologies which are governed by diffusion processes and experience cost declines.

These results will suggest a subset of policy options that should lead to the most effective government strategies. Section 8 compares these theoretical results with sample PV1 simulation results under 15 different government policy strategies.

7.1 Optimal Market Development Deployment

Lilien [1979] modifies a diffusion model introduced by Bass [1969] to study the theoretical implications of market development spending on market penetration over time. The Bass model was selected for analysis because it is simple, flexible, and has been applied to a number of different product applications. The analysis of the modified model suggests optimal strategies in terms of:

- 1) The timing of demonstration programs, and
- 2) The allocation of demonstration programs over sectors.

Assumptions necessary to the analysis of the model somewhat limit the applicability of the results. Nevertheless, there are several general implications which give insight into how and when government funds should be deployed.

Bass's model of diffusion takes the following simple form:

$$\frac{ds(t)}{dt} = (p + q \frac{s(t)}{s^*})(s^* - s(t)) \quad (7.1)$$

where:

$s(t)$ = number of firms having adopted an innovation by time t
($s(0) = 0$)

s^* = total number of firms considered eligible to adopt the innovation

p = coefficient of innovation; this equals the rate of product adoption when there have been no previous purchases

q = coefficient of imitation; the effect of previous purchases on the rate of adoption.

Lilien modifies this model to study first the effect that the timing of demonstration programs has on market penetration.

7.1a The Timing of Demonstration Programs

Under Lilien's modification, the Bass model takes the form:

$$\frac{ds(t)}{dt} = (p + q \frac{T(t)}{s^*})(s^* - s(t)) \quad (7.2)$$

where:

$T(t) = s(t) + A(t)$, where $A(t)$ is the number of government-sponsored demonstration programs installed by time t .

Analysis of this modified model proceeds under two important but reasonable assumptions: the first assumption is that government demonstration installations are indistinguishable from privately owned installations, implying that imitators are equally influenced by any successful product. The second assumption is that neither the

coefficient of innovation, p , nor the coefficient of imitation, q , depends on demonstration programs (p and q are not functions of $A(t)$).

Since $A(t)$ is a cumulative total of government-sponsored installations, it can be shown by separation of $ds(t)/dt$ into two components that $ds(t)/dt$ will be maximal when all demonstration program resources are used as early as possible. Intuitively, this follows since one would expect that early deployment of the maximum number of installations would lead to high early acceptability on the technical screen described in Section 2, thereby accelerating market penetration. Clearly, this early deployment forces acceptability on the technical screen to be always equal to or greater than the acceptability generated by any other deployment over all time. This result is general and should apply to innovations that are technically sound where government development programs are applicable. Kalish and Lilien [1980b] have investigated the timing of a PV demonstration program when negative feedback from various types of system failures is possible and show that, currently, a demonstration program should not yet begin.

The usefulness of this analysis is limited by the assumption that government has an allocation of installations to build, instead of the more realistic assumption of a fixed monetary budget, since it does not consider experience curve cost declines. To illustrate, if stated government policy is to build 100 installations independent of cost, then it makes sense to put them up as early as possible. If, on the other hand, a budget of \$10 million is allocated to demonstration programs, then a greater number of cumulative installations can be built if the funds are deployed over time instead of early and all at once, assuming the innovation sees cost declines over time. Thus, if the cost of the

innovation is expected to decline, and the government is limited by a fixed monetary budget, then the solution to temporal deployment becomes more complex. Nevertheless, if cost reductions are caused by increases in cumulative sales (learning curve effects), then a sufficient number of government installations must be deployed early to cause the future cost reductions.

7.1b Allocation over Sectors

Optimal allocation of government demonstration programs over sectors is studied by modifying the Bass model under the assumption that diffusion rates vary by sector. It is assumed that q , the coefficient of imitation, is a function of the cumulative level of demonstration program support, A , so that

$$q = f(A)$$

Bass's equation now becomes:

$$\frac{ds_i(t)}{dt} = (p_i + f_i(A_i(t)) \cdot T(t))(s_i^* - s_i(t)) \quad (7.3)$$

$i = 1$ to the number of sectors.

If $T(t)$ is replaced by $A(t) + s(t)$ then a sectoral imitation parameter appears in the equation, namely, d , where

$$d_i = A_i \cdot f(A_i)$$

Lilien concludes that if each sectoral imitation parameter, d_i , is a concave function of the number of demonstration installations, then optimal allocation occurs when installations are spread out over sectors. A concave function implies that each additional demonstration project yields a positive but diminishing marginal return for diffusion over the previous installation.

If each sectoral imitation parameter is a convex function then all demonstration installations should be allocated to one sector. A convex function implies that each succeeding installation generates an increasing marginal diffusion rate. Note, however, that in a finite market it is impossible to have always increasing marginal returns. Thus, all imitation parameter functions must ultimately become concave.

A likely functional form for the imitation parameter then is one that is at first convex and then turns concave. This implies that the first few demonstrations will show increasing marginal returns but eventually additional demonstrations will muster only diminishing marginal returns. This functional form assumes an S-curve shape. An optimal strategy for an S-shaped response is to concentrate installations in one area at a time until marginal private sales begin to slack off and then to spread out.

7.2 Optimal Subsidy Strategies

As with the timing of demonstration programs analysis, insight can also be gained into optimal subsidy strategies through analysis of a theoretical, mathematical model. Kalish and Lilien [1980a] study a simple formulation of a supply-demand model for a new innovation under the assumption that the subsidy a consumer receives is some constant percentage of the purchase price paid. To make theoretical analysis tractable, the authors impose several simplifying assumptions:

- 1) There are no subsidy ceilings (limits) in effect
- 2) Tax considerations are ignored
- 3) Firm pricing behavior is analyzed only as a cost-plus or short-term profit maximization problem - net present value profit maximization is ignored.

- 4) The cost per unit of production is a decreasing function of cumulative production
- 5) Demand for the innovation is a function of price to the consumer and of word-of-mouth effects. Exogenous variables, such as the state of the economy, which might affect demand, are considered static.
- 6) Consumers do not try to anticipate government subsidy. (It is plausible, for instance, that a consumer may delay action in anticipation of future government policy.)

In contrast to assumptions (1) and (2), the federal and state governments offer a variety of subsidy programs, many with subsidy ceilings and many in the form of a tax credit instead of a flat rate percentage decrease in price. Although the Kalish-Lilien model ignores these differences, the analysis is likely to hold suggestions about the effect a price subsidy strategy is likely to have on new product diffusion.

Kalish and Lilien analyze their supply-demand model under different scenarios of varying demand elasticities and changing firm revenues. An understanding of their main results requires the following definitions:

- $p(t)$ = price charged by firm at time t
- $x(t)$ = cumulative sales (same as number of adopters)
- $r(t)$ = the portion of the price, $p(t)$ actually paid by the customer. ($1-r(t)$ = subsidy rate)
- $x(t)$ = $f(x(t), p(t), \dots)$ demand equation
- $\eta(t)$ = price elasticity of demand

Their analyses also assume a single producer industry. From their assumptions they develop three fundamental results.

Result 1: If demand for the innovation is constant over time and elastic ($\frac{d\eta}{dt} = 0$, $\eta > 1$) then the optimal subsidy strategy is to spend in a continuous and monotonically non-increasing fashion if firm revenues are non-decreasing over time. Non-decreasing firm revenues are assured when word-of-mouth effects are positive ($\frac{df}{dx} \geq 0$) and prices decline with experience ($\frac{dp}{dx} \leq 0$).

Price will decline with experience under the assumptions of 1) experience curve cost declines and 2) price set on a cost plus or short-term profit maximization basis. It is unlikely that the government would consider subsidizing an innovation unless the innovation exhibits such price decline and positive word-of-mouth effects. In general, however, the assumed condition of constant price elasticity of demand is unrealistic. The next result relaxes this condition.

Result 2: The conclusion of Result 1 still holds under the relaxed assumption of an elastic but now varying elasticity, as long as the price elasticity of demand decreases with price declines as well as with time ($\frac{d\eta}{dr} \geq 0$, $\frac{d\eta}{dt} \leq 0$).

The new condition that elasticity decrease with declines in price is reasonable to expect for products early in their life cycles, where, if risk of purchase is extremely high, it is doubtful that drops in price will stimulate increasing percentages of quantity demanded. Such a scenario is especially true of unusual and high priced innovations because of their inherent riskiness. Yet, in many instances, innovations of this kind are initially priced at levels in the inelastic region of the demand curve because cost declines have not been marked enough to allow competitive pricing. For these innovations, the subsidy strategy of Results 1 and 2 is an inappropriate one with which to start. Whereas

this strategy may be correct to implement early in the life cycle, clearly some other strategy must be determined for innovations just entering the marketplace in a region of price inelasticity.

Result 3: If demand for the innovation is inelastic and constant over time ($\eta < 1$, $\frac{d\eta}{dt} = 0$) and if revenues are non-decreasing, then the optimal subsidy strategy is to fully subsidize installation costs at the beginning until the subsidy budget is exhausted. Of course, if firm revenues are non-increasing, then the subsidy should be withheld as long as possible in the hope that revenues will become non-decreasing in the near future.

Explicit conditions for non-decreasing revenues could not be developed. Nevertheless, as with Result 1, the condition that elasticity must remain constant is unrealistic. As cumulative production increases and costs consequently fall, the price of the innovation will approach and finally enter the elastic region of the demand curve. Alternatively, word-of-mouth effects may shift the demand curve such that demand becomes elastic with no significant change in price.

Kalish and Lilien conclude that an optimal subsidy policy is to subsidize fully when the innovation first comes on the market, as long as the product "works" and its price is low enough so that subsidized price brings it into a price-elastic region. The subsidy should be decreased over time once demand becomes elastic and non-increasing. This two-part strategy will be effective for the "good" product, one that generates positive word-of-mouth effects thereby sustaining itself on the marketplace. Government subsidy spending for the "good" product grows proportionally to firm revenues when installations are fully subsidized, but then peaks and declines with the lessening of the subsidy rate. If

firm revenues do not initially grow because of high product price, the subsidy should be delayed until costs decline sufficiently for sales to increase. At that point the strategy outlined at the beginning of the paragraph should be implemented.

One obvious omission of the Kalish and Lilien analyses is the case where demand is elastic at the unsubsidized price, but the elasticity is increasing. The situation will generally occur when demand moves from the inelastic to the elastic region of the demand curve since elasticity is likely to continue to increase. In this region of the demand curve, government can stimulate increasing marginal sales in the private sector for each incremental percentage increase in the subsidy rate. A policy of full subsidization would seem to be recommended in this instance.

7.3 Consequences for Photovoltaics

Recall that government subsidy spending for PV is independent of the \$1.5 billion allocated to the other government policy options. Thus, the DOE-PV program need make no trade-offs between spending money on subsidies versus other programs as is the situation with market development spending. In this sense, the theoretical analysis of optimal subsidy strategies is a self-contained problem for photovoltaics. Realistically, however, spending in the other policy options must be coordinated with the subsidy strategy if maximum PV diffusion is to be achieved. Clearly, if at times these other options are more cost-effective in bringing down the cost of a PV installation, then some subsidy spending should be delayed until more opportune moments arise. For instance, the discrete decreases in PV costs expected from changes in stage of technology might be reason enough to withhold subsidy funds until they can be used more effectively in conjunction with TD and ARND

spending.

Finally, government's allocation of funds to the PV demonstration program (MD) depends on its allocation to technology development (TD) and advanced research and development (ARND). The \$1.5 billion allocated to the National Photovoltaic Program must be split between MD, TD and ARND. Both TD and ARND spending work to lower PV costs, and in so doing increase the fraction of the market who find PV acceptable by raising the acceptability level on the payback screen. There is a trade-off between raising the technical acceptability through MD spending and raising the payback acceptability through TD and ARND spending. PV1 will be a useful tool in the determination of a reasonable division of funds between the three policy options.

8. Some Sample PV1 Analyses

The results of the last section gave insight into optimal allocation strategies for market development and subsidy expenditures. Although the implications of these results are somewhat confined by the assumptions on which they are based, they simplify the search for superior allocation strategies. In this section, market penetration and cost forecasts from the PV1 model are analyzed for 15 different government policy strategies. These strategies were selected to compare with the results outlined in Section 7. They provide the basis for an initial sensitivity analysis of the theoretically optimal strategies.

Here we use the words "model" and "strategy" interchangeably. Note that the way we use the word "model" should not be confused with the PV1 model. Instead a model is the set of user-defined inputs that specify government policy actions, stages of the PV technology, the duration of the forecast period, the number of sectors in the forecast and many other control variables of lesser importance. To make comparisons of the 15 strategies meaningful, all variables unrelated to government policy were fixed with the exception of the annual real rise in electricity rates, which is 3 percent for the first eight strategies and 10 percent for the last seven. The decision to use two electricity rate rises was made in consideration of the instability of oil prices. Clearly as the cost of utility generated electricity increases, the PV product will look better and better in the eyes of potential adopters. The model results demonstrate this relationship dramatically. It is recognized that many utilities use fuels other than oil in their electricity generation and that the use of one overall electricity rate rise for all fuels is probably inadequate. To remedy this oversimplification, a database of

utility fuel mixes is currently being assembled to allow the PV1 user to input fuel-specific rate rises. In using these rate rises PV1 will assume that utilities annually increase electricity costs commensurate with the rise in their fuel costs.

Descriptions of the 15 government allocation strategies appear in Tables A-1 to A-15 of Appendix 1. These tables present summary cost and penetration results. Table A-1 serves as an overall reference, presenting results for the baseline strategy in which total government spending was set to a minimal level of \$75 million in market development. All other spending was set to zero.

All strategies were specified as 6-sector, 15-year models. Except for the baseline strategy, all strategies were allocated approximately \$1.5 billion over the first ten years of the forecast period, consistent with the funding available to the National Photovoltaic Program. This money was specifically allocated to the market development (MD), technology development (TD) and advanced research and development (ARND) policy options. Since the number of model runs was limited, TD and ARND spending allocations were made identical in all strategies to allow for a controlled analysis of the effects of MD spending on PV diffusion. TD spending was held invariant at \$100 million for the first four forecast years and ARND spending was held constant at \$100 million for the first seven. (In all models, TD spending causes Stage 2 technology to arrive in year 5 and ARND spending causes Stage 3 to arrive in year 8. An explanation of the specifications of Stage 2 and Stage 3 arrival dates is given in the appendix to this chapter). MD spending was set at \$75 million in strategies 2, 3, 4, and 5 and then upped to \$500 million in strategies 6-15. Strategies 2, 3, 4, and 5 consumed less than \$1.5

billion because MD funding was set to a minimal level. For each strategy, advertising costs come to 20 percent of MD spending.

Subsidy policy for the 15 strategies was specified independent of the other policy options because subsidy funding is not provided by the National Photovoltaic Program. Unlike MD, TD, and ARND, which are constrained by a total \$1.5 billion budget, subsidy funds are assumed to be unlimited. Nevertheless, PV1 can simulate a constrained subsidy budget by setting annual subsidy rates to zero after the budget ceiling has been reached. As will be seen in Table 8.1 later, cumulative subsidy spending varies dramatically. This is because cumulative subsidy spending is calculated as a fraction of the dollar volume of private PV sales, and dollar volume varies considerably across strategies. Some of the variance in dollar volume is caused by the effects that different strategic allocations of MD, TD, and ARND have on PV costs and acceptabilities. Much of the difference in subsidy spending, however, can be attributed to the application of different subsidy rates. For instance, strategies 6 and 7 are identical except for the sizes of the subsidy rates, yet cumulative subsidy spending differs by \$2.23 billion.

Although the spending variances make comparisons of market penetration forecasts difficult between some pairs of strategies, there are many important, and to some degree generalizable, results which proceed from the analyses of this section.

For analysis purposes, the warranty of a PV system was set to 30 months and the lifetime to 20 years and both were left unchanged for all strategy runs. Thus, acceptabilities on the warranty and lifetime screens also remained constant, and can be considered as having negligible responsibility for differences in market penetrations between strategies.

8.1 General Results

Government spending can accelerate diffusion by increasing the awareness and the acceptability of PV. In the 15 model runs, government spending influences market penetration in three ways:

- 1) MD spending increases awareness
- 2) MD installations increase technical screen acceptability
- 3) MD, TD, ARND and subsidies all work to lower PV costs, and thus increase the payback acceptability.

From analysis of the 15 model runs, the following general conclusions follow concerning the relationship between government spending and market penetration of PV. Detailed comparison analyses of the strategies are included in the next subsection.

1. Market Development Spending: Without MD spending PV technology does not diffuse. This seems to be true regardless of how much government spends on TD and ARND. Further, the availability of as much as a 40 percent subsidy is not enough to stimulate much additional adoption when MD spending is low. Even full subsidization is relatively ineffective in early forecast years. There are two major reasons for the delay: first, awareness of PV remains low throughout the forecast period because advertising expenditures, which in PV1 are a fraction of MD spending, are negligible; second, diffusion is delayed because potential private adopters are unwilling to risk a product that has little demonstrated reliability. The lack of government purchased installations therefore causes the technical screen acceptability to be near zero.

If all other government policy variables remain the same, MD spending has the greatest positive effect on market penetration when it is spent in the early years. By deploying MD funds rapidly, government creates immediate widespread awareness of PV and also accelerates technical

screen acceptability, and because both awareness and technical acceptability are functions of cumulative installations, they maintain high values after MD funds dry up. These preliminary findings corroborate the theoretical results of Section 7.

Concentration of MD funds in certain sectors dramatically accelerates overall PV penetration into the private sector. It was found that the agricultural sector is particularly receptive to early MD expenditures, but that annual sales peak quickly, after which time MD spending has no further significant effect. Concentrated allocations of MD spending have the greatest impact on diffusion acceleration in the residential and commercial sectors. This occurs primarily because the residential and commercial sectors are the two largest in terms of total market potential and number of potential adopters. In principle, diffusion is accelerated fastest in sectors where contact between intra-sector members is greatest--therefore the largest ones.

To illustrate, assume that the technical acceptability screen distributions are identical for all sectors. As government market development sponsored installations are built, and greater percentages of potential adopters pass through the technical screen, *ceteris paribus*, proportionately more sales result in large sectors than in small sectors. This means that, in absolute terms, greater numbers of potential adopters will actually adopt in the larger sectors. Since technical acceptability is calculated based on an absolute number of prior successful installations, the diffusion of photovoltaics will be accelerated fastest, for a given MD expenditure, in the largest sectors. This result holds as long as inter-sectoral interactions are less than unity; if all interactions are unity, then MD funds should be spent in

sectors where installations can be bought at greatest value per peak watt. Furthermore, since all installations would cause identical perceptual effects, regardless of PV array size, government could derive the most benefit from an installation in the sector using the smallest average PV installation size, i.e., the residential sector.

2. Subsidy Spending: Whereas MD spending is crucial in the early years of PV diffusion, subsidy spending assumes a vital role in later years. The size of the subsidy necessary to drive diffusion depends totally on the relative cost of PV electricity to utility-generated electricity. In early years, when the cost of PV is highest and marginal electricity rates are lowest, private adoption of PV can only be stimulated by complete or near-complete subsidization. The average subsidy cost to government per peak watt is extremely high, and though much is spent, little is purchased. It is a tricky business, however, to try to locate a subsidy level that is not too costly to government but that is still able to attain a reasonable stimulation of the market.

An unfortunate fact about photovoltaic subsidies is that they seem to have no permanent stimulating effect on PV sales: when subsidies expire, annual sales fall back to levels little different than pre-subsidy sales. The cause of subsidy's inability to create permanent sales effects lies in the PV cost structure. The PV cost formulation does not incorporate learning curve effects: thus, subsidies induce greater cumulative sales, but the cost reductions which can accelerate adoption do not result. Instead, costs are partially determined using an economies of scale approach. While economies of scale certainly exist in the BOS cost structure, as well as in Stage 1 module technology, where plants are not at minimum efficient scale, the presence of a learning

cost curve decline also seems justified. JPL's omission of learning curve effects from the PV cost formulation was based on the belief that the PV technology changes so rapidly that such effects never develop; a future revision of PV1 is expected to incorporate a cumulative sales effect. Obviously subsidies will have more impact on the rate of diffusion when learning curve effects are modeled. It is not clear how important the learning curve effects are expected to be but the possibility exists that they will be overshadowed by cost declines associated with TD and ARND spending during the years of Stage 1 and Stage 2 technologies. After Stage 3 arrives, and a relatively stable technology is put in place, learning curve effects will probably assume importance.

The most salient benefit of government subsidization occurs when the price of PV hovers just above a threshold level where modest decreases in price can produce quantum increases in PV sales. An infusion of subsidy money in this situation can invigorate the market. The threshold price level is determined by the relative costs of PV and utility-generated electricity. The faster PV costs decrease and the higher the real annual electricity rate rise, the more rapidly the threshold price level is reached. The results of the 15 strategies indicate that the price of PV nears the threshold level only after Stage 3 technology comes on line, suggesting that subsidy spending be delayed until that time. The wisdom of this strategy is reinforced if the assumption is correct that learning curve effects only take on importance in third stage technology. The theoretical results of Section 7, which are derived for new technologies that experience learning curve cost declines, should then apply. This is partially borne out by comparison of some of the strategy results.

8.2 Detailed Analyses of Government Policy Actions

The analyses of this section use Tables A-1 to A-15; the reader should refer to these tables to see differences in the time path of diffusion as well as to obtain detailed strategy descriptions. Table 8.1 presents projections of cumulative megawatts installed and W_p /dollar of government investment for the 15 cases, providing a rough summary comparison.

1. The Base Case-Minimal Government Support: Table A-1 presents the baseline results. A minimal \$75 million in MD was allocated in Strategy 1 to develop as threshold-model for comparison. Here over 90 percent of final cumulative sales are private. Approximately 75 percent of cumulative installed peak kilowatts are in the agriculture sector. Although agriculture seems to be a prime target for diffusion acceleration, it becomes clear in other strategies that this sector is generally unresponsive to later government spending.
2. Comparison of Strategies 1, 2, and 3: All three strategies have minimal MD spending. Strategies 2 and 3 have large allocations of TD and ARND funds. Strategy 3 has a 40 percent subsidy for all 15 forecast years. There is virtually no difference in cumulative sales for these strategies. PV costs in strategies 2 and 3 reach low levels much faster than in Strategy 1, yet prices are not low enough to stimulate sales. Even the 40 percent subsidy, which costs the government an additional \$142 million over the baseline, cannot initiate more than a few hundred extra peak kilowatts in sales.
3. Comparison of Strategies 3 and 4: Both strategies are identical except for the subsidy rate which is raised to 80 percent in Strategy 4. Through the first seven years, differences in sales are not remarkable.

Yet when the price of PV drops to about 45 cents per peak watt in year 8, sales take off in Strategy 4. It is clear that the cost of PV must be reduced substantially if the sales rate is to accelerate. In achieving this reduction in cost and increase in sales an enormous subsidy cost is incurred: \$3.59 billion. All but \$66 million of this figure is spent in the last 8 years; however, this is a relatively cost effective strategy, yielding .88 W_p/\$ of investment.

4. Comparison of Strategies 4 and 5: Strategy 5 has full subsidization through the first 10 years, and 40 percent thereafter. Sales in Strategy 5 approximately double each year from year 5 to year 10. Undoubtedly, the market expansion factor is limiting sales during this period. By year 10 cumulative sales in Strategy 5 are triple those in the same year of Strategy 4. The reduction in the subsidy rate in year 11 to 40 percent, however, stops sales. In fact, sales in year 14 of Strategy 5 are little different from those of the baseline strategy, about 20,000 peak kilowatts.

5. Comparison of Strategies 6 and 2: Strategy 6 is identical to Strategy 2 except that MD spending is increased to \$50 million annually for years 1 through 10, and is then eliminated in years 11 through 15. Total cumulative sales in Strategy 6 are double Strategy 2's, but private sales are only about 50 percent more. Table 8.1 presents cumulative private market penetration in relation to subsidy spending. Since only MD spending varies between these two strategies, all sales differences must be MD-induced. Noting that total cumulative sales between them in years 10 through 15 differ by less than 3000 peak kilowatts, it is evident that MD spending promoted about 60,000 peak KW in additional private sales during the years it was being spent. This sales increase

Table 8.1

Cumulative Subsidy Spending Versus Market Penetration

<u>Strategy</u>		<u>Cumulative Subsidy Spending (\$000,000)</u>	<u>Cumulative Private Market Penetration (000 KW_p)</u>	<u>Average Subsidy Cost Per Peak Watt (\$)</u>	<u>Peak Watts Installed Per Dollar of Gov't Spending</u>
	1	0	147	0	1.95
	2	0	147	0	.12
Elect.	3	141	147	.96	.11
Rate	4	3,587	4,203	.85	.88
Rise=	5	1,130	726	1.56	.32
3	6	0	209	0	.13
percent	7	2,225	1,335	1.67	.35
	8	3,989	1,792	2.23	.32
<hr/>					
	9	8,632	13,561	.64	1.33
	10	9,341	15,598	.60	1.42
Elect	11	1,409	1,052	1.34	.35
Rate	12	2,336	2,866	.82	.73
Rise=	13	3,025	4,394	.69	.95
10	14	1,936	4,299	.45	1.21
percent	15	3,903	7,244	.54	1.32

is hardly exceptional, but it can be attributed to heightened awareness and greater technical screen acceptability, both the result of large amounts of MD spending. The fact that sales are so similar in later years is somewhat puzzling; the explanation is that heightened awareness caused most of the extra private sales. When MD spending ran out, awareness fell back to a low level, the additional sales not enough to sustain a level of awareness much higher than in Strategy 2.

6. Comparison of Strategies 6 and 7: Strategy 7 is Strategy 6 with subsidy. The full subsidy allocated in the first two years of the Strategy 7 forecast stimulates few sales, undoubtedly because technical acceptability, awareness, and even payback acceptability are low. (Note that in spite of full subsidization the subsidized cost per peak watt is still high, a situation caused by the federal subsidy dollar ceiling limit.) Market penetration and subsidy spending grow dramatically thereafter until year 11, when the reduced 40 percent subsidy takes effect. Afterwards, private annual sales are little different than in the baseline case. Demand is in such an inelastic region that a drop in price from \$2.03 to \$1.22 per peak watt induces only about 2500 additional peak KW in sales. (MD spending accounts for about 2500 KW in year 15 of the baseline strategy.)

7. Comparison of Strategies 7 and 8: In Strategy 8, \$500 million in MD funds are deployed over a 5-year period instead of a 10-year period as in Strategy 7. Total penetration is increased by 26 percent but subsidy spending increases by 79 percent from \$2.23 billion to \$3.99 billion. The average subsidy cost per peak watt jumps from \$1.67 to \$2.23 (see Table 8.1). Nevertheless, once again, annual sales drop precipitously when the subsidy rate is lowered in year 11.

Much of the additional subsidy spending in Strategy 8 occurs in early

years when total subsidization costs per installation are high. In those years higher awareness and higher technical and payback acceptabilities, caused by concentrated MD spending, result in higher sales and therefore additional subsidy costs. It seems that, in spite of increased penetration, the strategy of accelerating MD expenditures fails because it is unable to generate more than mediocre, non-increasing sales in later years. In the same sense, the extra subsidy money spent is also ineffective. Perhaps a not unreasonable criterion for government to adopt in its decision to intensify subsidy expenditures is that the average subsidy cost per peak watt must diminish with extra subsidy spending.

8. Comparison of Strategies 9 and 7: These strategies are identical, but in Strategy 9 the real annual rise in the price of electricity is increased from 3 percent to 10 percent. Divergences in market penetration between the two strategies begin in year 6 and by year 15 total penetration differs by 12 million peak Kw. Although subsidy increases to a cumulative \$8.6 billion in Strategy 9, the average subsidy cost per peak watt falls to \$.64. This compares quite favorably to \$1.67 in Strategy 7. Comparisons of PV costs in Tables A-7 and A-9 plainly reveal that the reduction in gross cost per peak watt is involved in the stimulation of diffusion. The reduction in cost is caused by increased economies of scale in balance of systems costs resulting from higher annual sales. The increase in sales occurs because payback acceptability mushrooms, the outcome of the rise in price of utility-generated electricity relative to that of PV electricity. Most important of all is that sales in years 11-15 of strategy 9 are large and annually increasing. Apparently, annual sales can sustain lower gross PV costs

which in turn sustain annual sales.

The results of strategies 9 and 7 imply that the relative costs of PV and utility electricity will ultimately determine PV's place in the market. The analysis is not suggesting that a 3 percent real annual rise in the price of utility electricity will effectively block PV penetration, or that a 10 percent rise will guarantee market success; only that the electricity rate rise will play the key role in determining how greatly and how quickly PV diffuses.

9. Comparison of Strategies 10, 11, and 12: Comparisons of these strategies show how different subsidy strategies affect diffusion. Only subsidy rates are varied between strategies. Since the application of subsidy rates is the same in years 1-10 of strategies 11 and 12, subsidy spending and market penetration are also identical. The termination of subsidy funds in Strategy 11 kills off sales in years 11-15. In maintaining a 40 percent subsidy these last five years, however, PV sales in Strategy 12 are boosted 1.8 million peak Kw over sales in the same period in Strategy 11. The additional subsidy cost of these sales is \$973 million. Yet, as a result, average subsidy cost per peak watt drops to \$.82 from \$1.34. The effectiveness of subsidy spending is thus substantial when gross PV costs approach the threshold level where demand becomes elastic.

Strategy 10 has generally higher subsidy rates than Strategies 11 and 12 and sales are consequently much stronger. Even though PV sales in years 11-15 of Strategy 10 dwarf sales in Strategy 12, it is clear that diffusion is being successfully accelerated with a lower subsidy rate (40 percent compared to 60 percent) in Strategy 12, and at a much lower cost. (Subsidy costs in year 15 of Strategy 12 are 28 percent of costs

in Strategy 10.) Still, the average subsidy cost per peak watt drops significantly from \$.82 to \$.60 when the subsidy rate is increased to 60 percent from 40 percent.

It is unlikely that government will allocate \$9.34 billion in funding to photovoltaic subsidy policy, so Strategy 10 in itself is probably not realistic. Nevertheless, an important issue arises in discussing Strategy 10 in relation to Strategy 12: how should government decide what the time path of subsidy rates should look like once demand becomes elastic. The use of high subsidy rates will create large immediate increases in PV sales, but the subsidy spending budget will empty quickly. And as other strategies have demonstrated, once subsidy inoculations cease, PV costs rise and sales fall. It is not clear, however, whether the same subsidy budget, spent more moderately over a longer period of time because of lower subsidy rates, would achieve less or more diffusion. Future analyses of other strategies may help to decide this issue.

The necessity of maintaining a constant or increasing demand for PV, so that PV manufacturers are not periodically driven from the industry when subsidy rates are suddenly dropped, argues for the use of subsidy rates which can be gradually reduced over time to maintain a stable time path of demand. When the subsidy budget runs out the rate should be low enough that a smooth transition in demand can occur. By such time the cost of electricity from utilities will hopefully have increased to a point where a non-subsidized PV price will generate sales on its own.

10. Comparison of Strategies 12 and 13: MD spending in Strategy 13 is expended in the first year. Subsidy rates and TD and ARND spending are the same. Thus, only the time allocation of MD funds varies between

strategies 12 and 13. By accelerating MD expenditures, both subsidy costs and PV sales were increased, while the average subsidy cost per peak watt decreased from \$0.82 to \$0.69. The increase in market penetration is due to the immediate elevation of awareness and technical acceptability supplied by an overdose of MD spending. It appears that \$500 million in year 1 is sufficient to create maintainable awareness and technical acceptability levels since annual PV sales are sustained at high levels for all 15 years of the model. Because costs and penetrations are different, it cannot be concluded that one strategy is superior to the other.

11. Comparison of Strategies 13 and 14: Comparison of market penetration for these strategies illustrates that early subsidization costs money but has little bearing on total diffusion in later years. Referring again to Table 8.1, observe that while cumulative PV sales in Strategies 13 and 14 differ by just 2 percent, Strategy 13 costs 50 percent more (\$1 billion) than Strategy 14 in terms of subsidy expenditures. It is clear that the large early subsidy rates of Strategy 13 cost the government money that could have been saved had the subsidy been delayed.

12. Comparison of Strategies 15 and 12: Aside from all MD funds being allocated to the residential and commercial sectors in Strategy 15, these strategies are identical. The concentration of MD funds in these sectors caused a 67 percent increase in subsidy expenditures in comparison to Strategy 13. Penetration, meanwhile, increased 253 percent. The data strongly suggest that, had subsidy spending been limited in Strategy 15 to that of Strategy 13, the cumulative sales in Strategy 15 would still have been slightly higher. The more important result, however, is that

diffusion occurs fastest in the residential and commercial sectors. A year-by-year comparison of cumulative installed peak kilowatts makes this result apparent.

9. Conclusions, Assessment and Extensions

9.1 Conclusions and Extensions Needed for PV1

The diffusion of the photovoltaic technology will not occur immediately. Yet, government money, spent wisely, can accelerate private sector adoption and shorten the time until the technology becomes viable. Not surprisingly, the analyses of government strategies showed that the cost of PV is the major barrier to PV's successful diffusion: little adoption will occur while PV is a non-competitive energy source. How long it takes for PV to become competitive will in large part be determined by the arrival dates of the second and third stage technologies. Reasonable assumptions were made in the model about the arrival dates of these technologies, but there is certainly no guarantee that they will arrive "on time."

Since the dates of future technology changes are unknown, the PV1 model cannot forecast the time path of diffusion with much certainty. In addition, PV1 penetration forecasts have limited validity, in an absolute sense, because PV1 uses a time-invariant probability-of-purchase as well as a time-invariant aggregate distribution fraction. While the absolute forecast numbers may be off, they are useful because they can be compared relatively between strategies to determine superior allocation policies. Several results with broad implications surfaced in the strategy analyses of Section 8. They are summarized as follows:

- 1) When PV costs are high and far from competitive, subsidy spending is unlikely to help speed diffusion. Instead, subsidy spending is, in such circumstances, essentially wasted money.
- 2) Subsidy spending is very effective once PV costs approach competitive levels.

- 3) MD spending is essential to diffusion. Without it, the public remains unaware and PV is perceived as too risky to chance purchase.
- 4) MD spending is most effective when spent early. Diffusion can be accelerated particularly well in the residential and commercial sectors.

It must be stressed that government spending programs have to be coordinated to achieve maximum impact. The results indicate that, ultimately, a good MD policy coupled with a bad subsidy policy is not much better than no policy at all. The reverse also seems to be true.

Theoretical results on optimal MD spending patterns show that demonstration projects should be concentrated in sectors that show increasing marginal private sales for each additional government installation, but that funds should be spread out once a decline in private marginal PV sales is perceived. The analysis results, however, seemed to suggest that because of low intra-sectoral contact in the smaller-sized sectors, more MD funds should be allocated to the larger sectors.

The theoretical results on subsidy spending advocate a wait period until firm revenues begin to rise (i.e., annual sales begin to increase) before deploying subsidy funds. The position is taken that private purchases should be heavily subsidized initially, followed by a period of gradual reduction in the subsidy rate as the price elasticity of demand begins to decrease. Yet, in the strategy simulations on PV1, subsidy money was expended very rapidly under such a subsidy policy, because as penetration began to catch, price elasticity seemed to increase. A

policy of near complete subsidization in such a situation quickly depletes a fixed budget; a reasonable budget might have been expended before subsidy dollars could make a permanent positive impact on the diffusion rate. The strategy analyses imply that the subsidy rate should be decreased as sales and elasticity increase: this saves subsidy funds for later years when modest spending can promote large sales increases which, because of economies of scale, begin to support a lower PV price level themselves.

The government strategies analyzed here were limited in number: no attempt was made to study the relation of the diffusion rate of PV to the allocation of funds to TD, ARND and advertising. It was also not possible to conclude much about the sensitivity of market penetration to the subsidy allocation strategy because the subsidy budget was not held fixed. The sensitivity of the diffusion rate to exogenous variables such as real annual electricity rate rise is certainly worth exploring through more model simulations.

An important assumption of the PV1 model is that all PV installations will work successfully. Under this assumption, technical screen acceptability will be a continuously increasing function of cumulative installations. The introduction of PV failures, however, could seriously set back the PV program. Work on modeling the failure possibility is currently under way. (See Lilien and Kalish [1980b] for some preliminary analyses.) How long PV diffusion would be delayed by installation failures will be a function of the number of failures, the seriousness of the failures, their visibility, the duration of time until all new installations are successful, and of course, the time it takes to change unfavorable perceptions into favorable ones.

Improvements that are needed to make the PV1 model more realistic include:

- 1) Estimation of region-specific distribution fractions which will increase over time;
- 2) Estimation of probability-of-purchase which may be sector-dependent and probably will change over time;
- 3) Use of a weighted average cost of electricity based on different real annual cost increases of the different fuels in a utility's fuel mix;
- 4) Incorporation of learning curve cost declines into the PV1 cost formulation;
- 5) Development of a distribution of average PV installation sizes for the commercial, industrial, agricultural and government/institutional sectors.
- 6) A breakdown of the residential sector into single family homes, duplexes, apartments, etc.
- 7) Compiling income distribution information so that PV tax credits can be modeled.

By making these changes and extensions to the model the forecast numbers of market penetration will assume increased validity. As the model stands currently, relative comparisons are safest.

9.2 Extensions to Other Technologies

The greatest asset of the PV1 model appears to be its incorporation of a believable model of consumer adoption. PV1 does not rely on an exogenously-defined functional form to derive market penetration forecasts, unlike other major solar penetration models. PV1 is more flexible than these other models because its basic diffusion-model

structure leaves room for a wide range of diffusion phenomena to be added. Other solar diffusion models, which characterize diffusion phenomena with a handful of arbitrary parameters, cannot achieve the realism or the detail of the PV1 model approach.

In the same way, the model-structure and modeling approach appear applicable to other technologies. The PV1 model is PV specific, but the approach is general:

- (1) Study and understand the likely adoption process for the technology under study.
- (2) Build a behaviorally-based diffusion model, incorporating that understanding of adoption.
- (3) Calibrate the model using as much objective data as possible.
- (4) Study policy alternatives using a combination of quantitative model outputs and theoretical results.

The PV1 approach is adaptive, evolutionary and data based. Further use should demonstrate that it is self-correcting--when it is in error, the source of the error will become apparent and the model will be modified. This same set of model-based concepts should be applicable to a wide range of new technologies, especially in the energy field.

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Appendix 1: PV1 Strategy Comparisons

The tables in this appendix present forecasts of market penetration, costs of PV, and costs of government programs for the 15 strategies run on the PV1 computer model. Market penetration figures are measured in cumulative peak kilowatts and are aggregations of PV sales from the six sectors. Both gross and subsidized cost per peak watt of PV are given for each year of the forecast period. In several instances the subsidized cost is higher than expected, given the subsidy rate. This happens because subsidies are subject to a ceiling limit. The government spending column in each of the tables is an aggregate value of annual MD, TD, ARND, advertising and subsidy spending. Cumulative 15-year totals for each category accompany each table.

Market development spending is allocated equally across the residential, commercial, agricultural, industrial and government/institutional sectors in all strategies except Strategy 15. No MD funds are allocated to the central power sector since preliminary model runs have demonstrated that utilities will not adopt PV unless the subsidy ceiling is raised into the millions. For strategy 15, MD funds are split equally between the residential and commercial sectors.

Although the spending strategies for the MD, TD, ARND and advertising options reflect plausible government actions, the subsidy rates used in several strategies are undoubtedly too high, and lead to some large subsidy expenditures. Government has not yet placed limits on subsidy spending, but it can be assumed that some of the cumulative subsidy figures calculated by the PV1 model exceed a realistic budget. Nevertheless, the use of inflated subsidy rates has the advantage of showing how diffusion occurs once it gets going. In the case of

strategies with only modest subsidization, where PV does not diffuse all that well, this glimpse is not afforded within the 15-year forecast duration.

A vital model assumption on which all results depend is the timing of the Stage 2 and Stage 3 technologies. Clearly, if the time until these technologies arrive is shortened, then diffusion will be speeded up; if it is longer than expected then diffusion will be slowed. Note that, except for the baseline strategy, the allocations of TD and ARND funds, which determine Stage 2 and Stage 3 arrival dates, were kept the same for each strategy (\$400 million for TD, \$700 for ARND). For all models, these funds were spent at double the rate of the most likely annual amount so to hasten the arrivals of the advanced technologies. Had they been spent at a slower rate, some of the more interesting diffusion effects which occur late in the forecasts would have been delayed and missed. Using the terminology of Section 5.4g, the specifications of Stage 2 and Stage 3 arrival dates are as follows.

	<u>Stage 2</u>	<u>Stage 3</u>
t_0	3	6
t_1	6	10
t_2	12	30
t_3	4	7
D_1	50	40

The uninstalled cost per peak watt of PV at Stage 3 was set to the 1986 DOE target of \$.70.

Finally, it is important to remember that deviations in input variables that are held constant in these analyses (e.g., the efficiency of the PV cell, set at 12%) might cause different results. All such

variables were provided with either objective data or best estimate input values.

Table A-1

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	384	15.33	15.33	6.00
2	921	43.44	43.44	6.00
3	1882	32.45	32.45	6.00
4	4121	20.40	20.40	6.00
5	9520	11.93	11.93	6.00
6	17755	8.02	8.02	6.00
7	28386	6.93	6.93	6.00
8	40746	6.52	6.52	6.00
9	54563	6.28	6.28	6.00
10	69560	6.13	6.13	6.00
11	85516	6.03	6.03	6.00
12	103575	2.12	2.12	6.00
13	122339	2.07	2.07	6.00
14	141593	2.07	2.07	6.00
15	161279	2.07	2.07	6.00

Cumulative MD spending (millions) = 75.00

Cumulative government TD spending (millions) = 0.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 0.00

Cumulative subsidy spending (millions) = 0.00

Cumulative advertising spending (millions) = 15.00

Percent of cumulative penetration that is private = 0.9121

Description of Strategy: Strategy 1

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
I-15	5	I-15	0	I-15	0

Year	Subsidy Rate
I-15	0

Electricity rate rise = .03

Table A-2
Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	384	15.33	15.33	206.00
2	921	43.44	43.44	206.00
3	1882	32.45	32.45	206.00
4	4121	20.40	20.40	206.00
5	9765	3.78	3.78	106.00
6	18613	3.61	3.61	106.00
7	29802	3.41	3.41	106.00
8	43455	2.20	2.20	6.00
9	58582	2.15	2.15	6.00
10	74879	2.14	2.14	6.00
11	92147	2.12	2.12	6.00
12	110214	2.10	2.10	6.00
13	128933	2.09	2.09	6.00
14	148186	2.08	2.08	6.00
15	167883	2.07	2.07	6.00

Cumulative MD spending (millions) = 75.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 0.00

Cumulative advertising spending (millions) = 15.00

Percent of cumulative penetration that is private = 0.8691

Description of Strategy: Strategy 2

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
1-15	5	1-4	100	1-7	100
		5-15	0	8-15	0

Year	Subsidy Rate
1-15	0

Electricity rate rise = .03

Table A-3

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	384	12.44	15.33	206.13
2	922	40.50	43.43	206.97
3	1898	29.66	32.40	208.01
4	4359	17.25	20.20	212.42
5	10477	2.26	3.77	113.23
6	19649	2.16	3.60	117.19
7	30879	2.05	3.42	119.34
8	44535	1.32	2.21	16.05
9	59673	1.29	2.15	17.02
10	75976	1.28	2.14	17.92
11	93244	1.27	2.12	18.61
12	111306	1.26	2.10	19.17
13	130015	1.25	2.08	19.61
14	149256	1.25	2.08	19.97
15	168242	1.23	2.05	18.76

Cumulative MD spending (millions) = 75.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 141.61

Cumulative advertising spending (millions) = 15.00

Percent of cumulative penetration that is private = 0.8717

Description of Strategy: Strategy 3

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
I-15	5	I-4	100	I-7	100
		5-15	0	8-15	0

Year	Subsidy Rate
I-15	.40

Electricity rate rise = .03

Table A-4
Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	384	11.39	15.33	206.13
2	922	39.69	43.43	207.01
3	1898	29.03	32.40	208.23
4	4359	16.25	20.20	214.47
5	10477	1.35	3.77	117.69
6	19682	1.24	3.60	124.52
7	31429	1.08	3.42	130.22
8	57263	0.45	2.26	48.73
9	110533	0.40	2.01	87.55
10	215153	0.31	1.54	131.26
11	411848	0.28	1.39	220.98
12	768308	0.25	1.25	359.83
13	1393801	0.23	1.13	567.06
14	2460132	0.20	1.02	868.21
15	4231105	0.18	0.91	1284.69

Cumulative MD spending (millions) = 75.00
 Cumulative government TD spending (millions) = 400.00
 Cumulative private TD spending (millions) = 0.00
 Cumulative ARND spending (millions) = 700.00
 Cumulative subsidy spending (millions) = 3586.58
 Cumulative advertising spending (millions) = 15.00
 Percent of cumulative penetration that is private = 0.9934

Description of Strategy: Strategy 4

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
1-15	5	1-4	100	1-7	100
		5-15	0	8-15	0

Year	Subsidy Rate
1-15	.8

Electricity rate rise = .03

Table A-5

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	384	12.22	15.33	206.13
2	922	40.97	43.43	206.95
3	1864	29.93	32.41	207.84
4	4245	17.89	20.75	212.01
5	11057	0.38	3.92	126.83
6	27823	0.13	3.39	157.47
7	65555	0.07	2.79	205.65
8	146109	0.05	1.60	126.36
9	309509	0.00	1.73	283.34
10	626646	0.00	1.50	475.12
11	666822	0.79	1.32	25.28
12	686930	1.34	2.23	22.01
13	707691	1.28	2.14	21.69
14	728819	1.23	2.06	21.38
15	750242	1.23	2.05	21.56

Cumulative MD spending (millions) = 75.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 1129.62

Cumulative advertising spending (millions) = 15.00

Percent of cumulative penetration that is private = 0.9681

Description of Strategy: Strategy 5

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
1-15	5	1-4	100	1-7	100
		5-15	0	8-15	0

Year	Subsidy Rate
1-10	1.0
11-15	.4

Electricity rate rise = .03

Table A-6

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	3809	15.33	15.33	260.00
2	12098	9.27	9.27	260.00
3	28094	6.83	6.83	260.00
4	47816	6.03	6.03	260.00
5	75963	3.30	3.30	160.00
6	106128	3.17	3.17	160.00
7	136898	3.22	3.22	160.00
8	176704	2.06	2.06	60.00
9	218895	1.94	1.94	60.00
10	260960	1.97	1.97	60.00
11	278619	1.90	1.90	0.00
12	296465	2.16	2.16	0.00
13	314558	2.04	2.04	0.00
14	332876	2.04	2.04	0.00
15	351397	2.03	2.03	0.00

Cumulative MD spending (millions) = 500.00
 Cumulative government TD spending (millions) = 400.00
 Cumulative private TD spending (millions) = 0.00
 Cumulative ARND spending (millions) = 700.00
 Cumulative subsidy spending (millions) = 0.00
 Cumulative advertising spending (millions) = 100.00
 Percent of cumulative penetration that is private = 0.5937

Description of Strategy: Strategy 6

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-15</u>	<u>50</u>	<u>1-4</u>	<u>100</u>	<u>1-7</u>	<u>100</u>
11-15	0	5-15	0	8-15	0

Year	Subsidy Rate
<u>1-15</u>	<u>0</u>

Electricity rate rise = .03

Table A-7

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	3809	12.21	15.33	261.24
2	12619	6.39	9.26	267.68
3	42748	0.97	7.05	420.34
4	126231	0.35	5.19	639.40
5	337386	0.09	2.64	663.16
6	439436	0.58	2.38	308.89
7	487020	0.69	2.94	230.71
8	600585	0.42	2.09	209.69
9	847961	0.32	1.58	332.38
10	1346847	0.24	1.19	496.50
11	1414901	0.70	1.17	31.89
12	1433760	1.26	2.10	15.84
13	1452873	1.27	2.12	16.17
14	1472211	1.22	2.03	15.87
15	1491756	1.22	2.03	15.85

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 2225.44

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.8948

Description of Strategy: Strategy 7

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-10</u>	<u>50</u>	<u>1-4</u>	<u>100</u>	<u>1-7</u>	<u>100</u>
11-15	0	5-11	0	8-15	0

Year	Subsidy Rate
<u>1-5</u>	<u>1.0</u>
6-10	.8
11-15	.4

Electricity rate rise = .03

Table A-8

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	7558	12.20	15.33	322.34
2	41807	1.69	7.42	472.07
3	148570	0.49	5.15	766.87
4	430988	0.20	4.40	1452.99
5	1116762	0.05	2.04	1505.93
6	1274170	0.39	1.89	335.68
7	1306543	0.80	3.05	172.63
8	1373950	0.45	2.27	122.47
9	1508764	0.34	1.70	183.29
10	1768490	0.26	1.29	268.30
11	1805335	0.97	1.61	23.75
12	1824673	1.13	1.89	14.61
13	1844177	1.25	2.09	16.28
14	1863850	1.21	2.02	15.93
15	1883688	1.21	2.02	16.03

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 3989.17

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.9514

Description of Strategy: Strategy 8

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-5</u>	<u>100</u>	<u>1-4</u>	<u>100</u>	<u>1-7</u>	<u>100</u>
6-15	0	5-11	0	8-15	0

Year	Subsidy Rate
<u>1-5</u>	<u>1.0</u>
6-10	.8
11-15	.4

Electricity rate rise = .03

Table A-9

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	3809	12.21	15.33	261.24
2	12619	6.39	9.26	267.68
3	42748	0.97	7.05	420.34
4	126231	0.35	5.19	639.40
5	337386	0.09	2.64	663.16
6	616332	0.47	2.19	602.46
7	969645	0.48	2.28	760.62
8	1724327	0.28	1.39	859.26
9	3248289	0.22	1.10	1365.64
10	5928965	0.16	0.82	1769.85
11	7739385	0.41	0.68	489.17
12	8946924	0.56	0.93	450.12
13	10130729	0.62	1.03	487.92
14	11706740	0.58	0.96	604.50
15	13750316	0.51	0.85	690.88

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 8632.23

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.9862

Description of Strategy: Strategy 9Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-10</u>	<u>50</u>	<u>1-4</u>	<u>100</u>	<u>1-7</u>	<u>100</u>
11-15	0	5-15	0	8-15	0

Year	Subsidy Rate
<u>1-5</u>	<u>1.0</u>
6-10	.8
11-15	.4

Electricity rate rise = .10

Table A-10

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	7558	12.20	15.33	322.34
2	41807	1.69	7.42	472.07
3	148571	0.49	5.15	766.88
4	178661	2.75	5.18	344.20
5	230142	0.85	3.30	274.26
6	332247	0.61	2.87	330.76
7	554209	0.58	2.68	566.60
8	1016365	0.27	1.36	503.70
9	1940686	0.47	1.17	648.17
10	3721425	0.35	0.88	942.79
11	5991147	0.30	0.75	1027.72
12	8341541	0.32	0.79	1120.96
13	10734971	0.34	0.84	1207.17
14	13187432	0.34	0.85	1246.17
15	15685459	0.34	0.85	1267.22

Cumulative MD spending (millions) = 500.00
 Cumulative government TD spending (millions) = 400.00
 Cumulative private TD spending (millions) = 0.00
 Cumulative ARND spending (millions) = 700.00
 Cumulative subsidy spending (millions) = 9341.01
 Cumulative advertising spending (millions) = 100.00
 Percent of cumulative penetration that is private = 0.9944

Description of Strategy: Strategy 10

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
1-5	100	1-4	100	1-7	100
6-15	0	5-15	0	8-15	0

Year	Subsidy Rate
1-3	1.0
4-8	.8
9-15	.6

Electricity rate rise = .10

Table A-11

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	7558	12.20	15.33	322.34
2	41807	1.69	7.42	472.07
3	94214	1.74	5.35	460.00
4	125621	2.73	5.22	349.06
5	179144	0.91	3.36	280.07
6	291184	0.60	2.79	346.18
7	520630	0.57	2.64	574.75
8	787794	0.60	1.20	160.00
9	949392	0.78	1.29	83.58
10	1043363	0.97	1.62	60.87
11	1061636	1.92	1.92	0.00
12	1080036	2.10	2.10	0.00
13	1098833	2.04	2.04	0.00
14	1118095	2.03	2.03	0.00
15	1139410	2.05	2.05	0.00

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 1408.92

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.9235

Description of Strategy: Strategy 11Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-5</u>	<u>100</u>	<u>1-4</u>	<u>100</u>	<u>1-7</u>	<u>100</u>
6-15	0	5-15	0	8-15	0

Year	Subsidy Rate
<u>1-2</u>	<u>1.0</u>
3	.9
4-7	.8
8	.5
9-10	.4
11-15	0

Electricity rate rise = .10

Table A-12

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	7558	12.20	15.33	322.34
2	41807	1.69	7.42	472.07
3	94214	1.74	5.35	460.00
4	125621	2.73	5.22	349.06
5	179144	0.91	3.36	280.07
6	291184	0.60	2.79	346.18
7	520630	0.57	2.64	574.75
8	787794	0.60	1.20	160.00
9	949392	0.78	1.29	83.58
10	1043363	0.97	1.62	60.87
11	1137805	1.07	1.79	67.56
12	1307980	0.97	1.61	109.71
13	1605650	0.84	1.40	167.16
14	2112299	0.69	1.15	233.88
15	2953258	0.62	1.04	349.02

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 2336.25

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.9705

Description of Strategy: Strategy 12

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-5</u>	<u>100</u>	<u>1-4</u>	<u>100</u>	<u>1-7</u>	<u>100</u>
6-15	0	5-15	0	8-15	0

Year	Subsidy Rate
<u>1-2</u>	<u>1.0</u>
3	.9
4-7	.8
8	.5
9-15	.4

Electricity rate rise = .10

Table A-13

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	36314	12.17	15.33	808.39
2	138774	0.06	5.47	754.72
3	215646	0.92	4.56	479.82
4	230162	2.92	5.26	234.09
5	250632	0.94	3.47	151.76
6	297229	0.75	3.28	217.55
7	398525	0.62	2.86	327.26
8	575286	0.64	1.28	112.89
9	731195	0.74	1.24	77.25
10	856018	0.89	1.49	74.27
11	1032592	0.95	1.58	111.70
12	1350759	0.87	1.45	183.90
13	1907299	0.67	1.12	250.11
14	2854557	0.59	0.99	375.47
15	4426856	0.54	0.90	566.02

Cumulative MD spending (millions) = 500.00
 Cumulative government TD spending (millions) = 400.00
 Cumulative private TD spending (millions) = 0.00
 Cumulative ARND spending (millions) = 700.00
 Cumulative subsidy spending (millions) = 3025.21
 Cumulative advertising spending (millions) = 100.00
 Percent of cumulative penetration that is private = 0.9926

Description of Strategy: Strategy 13

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
<u>1-5</u>	500	<u>1-4</u>	100	<u>1-7</u>	100
6-15	0	5-15	0	8-15	0

Year	Subsidy Rate
<u>1-2</u>	1.0
3	.9
4-7	.8
8	.5
9-15	.4

Electricity rate rise = .10

Table A-14

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	36313	15.33	15.33	800.00
2	44743	5.38	5.38	200.00
3	54624	7.17	7.17	200.00
4	66343	6.61	6.61	200.00
5	79692	3.33	3.33	100.00
6	94331	1.00	3.29	133.50
7	112187	0.95	3.32	142.33
8	149367	0.42	2.09	62.26
9	223727	0.38	1.92	114.16
10	330059	0.92	1.54	65.47
11	527919	0.88	1.46	115.54
12	884441	0.75	1.25	178.04
13	1508073	0.67	1.11	276.52
14	2569524	0.59	0.99	419.99
15	4331365	0.54	0.89	628.55

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 1936.64

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.9925

Description of Strategy: Strategy 14

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
1	500	1-4	100	1-7	100
2-15	0	5-15	0	8-15	0

Year	Subsidy Rate
1-5	0
6-9	.8
10-15	.4

Electricity rate rise = .10

Table A-15

Summary of Results

Year	Cumulative Installed Peak KW	Average Cost Per Peak Watt		Government Spending (millions)
		sub	gross	
1	7973	10.97	15.33	323.32
2	44164	0.96	7.04	474.04
3	99397	1.24	5.13	468.86
4	129436	2.15	4.96	342.24
5	192794	0.78	3.26	300.63
6	337021	0.54	2.62	400.53
7	650551	0.48	2.35	684.66
8	1126274	0.54	1.08	257.98
9	1511825	0.63	1.05	161.29
10	1794998	0.74	1.24	140.25
11	2087040	0.80	1.34	156.57
12	2613269	0.76	1.26	265.55
13	3533753	0.60	1.01	370.08
14	5100461	0.52	0.87	546.88
15	7336060	0.48	0.79	710.27

Cumulative MD spending (millions) = 500.00

Cumulative government TD spending (millions) = 400.00

Cumulative private TD spending (millions) = 0.00

Cumulative ARND spending (millions) = 700.00

Cumulative subsidy spending (millions) = 3903.12

Cumulative advertising spending (millions) = 100.00

Percent of cumulative penetration that is private = 0.9874

Description of Strategy: Strategy 15 (Sectoral Concentration)

Annual Spending (millions)

Year	MD	Year	TD	Year	ARND
$\frac{1-5}{2-15}$	$\frac{100}{0}$ *	$\frac{1-4}{5-15}$	$\frac{100}{0}$	$\frac{1-7}{8-15}$	$\frac{100}{0}$

Year	Subsidy Rate
$\frac{1-2}{3}$	$\frac{1.0}{.9}$
4-7	.8
8	.5
9-15	.4

Electricity rate rise = .10

*Funds are allocated equally and totally to the residential and commercial sectors.

**Appendix 2: Questionnaires for
Residential Field Data Collection**

I'll call you back again, in about a week, to answer any questions you may have about the questionnaire.

Our study is based on only a few hundred respondents, and it's very important that we get a representative sample of households. In addition, most people who have already completed the survey have found it to be both interesting and informative. For these reasons I'd really like you to agree to take part. Are there any questions that you might have about the study? Will you participate?

(IF NECESSARY): Of course, any information you will provide will be combined with all the other responses and will be used for statistical analysis only. Your participation will be completely confidential and your name will never be associated with this survey in any way.

Yes _____ No _____ (GO TO DEMOGRAPHICS AND TERMINATE)

Terrific! Let me first take your name and address so that I can mail out the package of information.

Name _____
(9-25)

(PRINT CLEARLY!
SOMEONE HAS TO
COPY THIS OVER!)

Address _____
(26-45)

City _____ State _____ Zip _____
(46-59) (61-62) (64-68)

Telephone Number _____

80-1 Card 2 Duplicate 1-4

You will be receiving the information about solar energy equipment in a week or so. We'd like you to read the material, and to discuss it with your family if you think that would be appropriate. Enclosed with the literature will be some questions about the information presented. We would like you to complete the questionnaire and return it to us in the postage paid return envelope that will accompany it. I will be calling you back in about a week to answer specific questions you might have about the survey. If you don't have any questions, and can complete and mail the survey before I call again, please do so.

INTERVIEWER NAME: _____

TIME START _____

TIME END _____

Now, Mr./Mrs. _____, let me ask you the first set of questions. To start with,

TELEPHONE QUESTIONNAIRE FOR PHOTOVOLTAICS

1. Are you currently using any kind of solar energy system in your home?

Yes _____-1 No _____-2 (SKIP TO Q. 2)

1a. For what purpose are you using your solar energy system?

Water Heating _____-1 (If only water heating, skip to Q. 7)

Space Heating _____-2

Both Water and Space Heating _____-3

Other (specify) _____-4

1b. Do you have an active or a passive solar energy system?

Active _____-1 (SKIP TO Q. 6a)

Passive _____-2 (CONTINUE WITH Q. 2)

Both _____-3 (SKIP TO Q. 6a)

Uncertain _____ (NOTE: IF RESPONDENT IS UNCERTAIN, ASK):
 Could you please describe how your solar
 system works? (Then continue with Q. 2))

2. Other than in a picture, have you ever seen a home equipped with solar collectors or solar panels?

YES _____-1 NO _____-2 NOT SURE _____-3

(IF "PASSIVE" IS CHECKED IN Q. 1b, SKIP TO Q. 6a)

3. Do you know anyone who is now using solar energy for home or water heating?

YES _____-1 NO _____-2 NOT SURE _____-3

4. Have you actually gone looking for information about solar home or water heating equipment from a solar equipment manufacturer or dealer, a builder or an architect?

YES _____-1 NO _____-2

5. Are you likely or unlikely to have an active solar home or water heating system installed in your home in the next year? (AS NECESSARY): Is that very likely/unlikely or somewhat likely/unlikely? And how about within the next 5 years? (AS NECESSARY): Is that very likely/unlikely or somewhat likely/unlikely?

	Next Year	Next 5 Years
Very likely	___-1	___-1
Somewhat likely	___-2	___-2
Unsure	___-3	___-3
Somewhat unlikely	___-4	___-4
Very unlikely	___-5	___-5

(SKIP TO Q. 7)

6a. About what percentage of your total heating needs are supplied by your solar heating system(s)?

_____ %

(IF "BOTH" IS CHECKED IN Q. 1b, ASK 6b. OTHERWISE SKIP TO Q. 7)

6b. And about what percentage of your total heating needs are supplied by the passive portion of your solar heating system alone?

_____ % (NOTE RESPONSE MUST BE SMALLER THAN
RESPONSE TO Q. 6a)

7. Now, I'd like to ask you a few questions about a different kind of solar energy system. This system turns the energy of sunlight into electricity rather than heat. It is usually called a photovoltaic (FOE-TOE-VOLE-TAY'-IC) power system or a PV (PEE-VEE) system for short.

Prior to this survey, had you ever seen or heard anything about the use of PV power systems that generate electricity for use in your home?

Yes ___-1 No ___ -2 (SKIP TO QUESTION 15)

8. In your area can you currently buy photovoltaic power systems?

Yes ___-1 No ___-2 Uncertain ___-3

9. Have you heard of any kinds of government sponsored financial incentives to home owners who install PV power systems?

Yes ___-1 No ___-2 Uncertain ___-3

10. Would you agree or disagree with the statement, "I understand the financial aspects of PV power systems". (AS NECESSARY): Would that be strongly agree/disagree or moderately agree/disagree?

Strongly agree ___-5
 Moderately agree ___-4
 Unsure; don't know ___-3
 Moderately disagree ___-2
 Strongly disagree ___-1

11. And would you agree or disagree with the statement, "I understand how PV power system work." (AS NECESSARY): Would that be strongly agree/disagree or moderately agree/disagree?

Strongly agree	_____	-5
Moderately agree	_____	-4
Unsure , DK	_____	-3
Moderately disagree	_____	-2
Strongly disagree	_____	-1

12. Do you believe that you can or cannot currently obtain reliable and dependable PV power systems for home use? (AS NECESSARY): Is that definitely can/cannot or probably can/cannot?

Definitely can	_____	-5
Probably can	_____	-4
Unsure, DK	_____	-3
Probably cannot	_____	-2
Definitely cannot	_____	-1

13. Do you believe that you can or cannot currently obtain a PV power system that makes economic sense for home use? (AS NECESSARY): Is that definitely can/cannot or probably can/cannot?

Definitely can	_____	-5
Probably can	_____	-4
Unsure, DK	_____	-3
Probably cannot	_____	-2
Definitely cannot	_____	-1

14. Do you believe that PV power systems will or will not be widely used by homeowners in your area within the next five years? (AS NECESSARY): Is that definitely will/will not or probably will/will not?

Definitely will	_____	-5
Probably will	_____	-4
Unsure , DK	_____	-3
Probably will not	_____	-2
Definitely will not	_____	-1

Next, I have a few questions about your home and home energy usage.

15. How old is your home? (READ LIST)

0 - 5 years	_____ -1	21 - 40 years	_____ -4
6 - 10 years	_____ -2	over 40 years	_____ -5
11 - 20 years	_____ -3	dk/refused	_____ -6

16. a. Does your home have insulation in the ceiling?

Yes	_____ -1	
No	_____ -2) (SKIP TO Q. 16)
Don't know	_____ -3	

b. How much ceiling insulation does your home have? (READ LIST)

1 - 3 inches	_____ -1	10 - 12 inches	_____ -4
4 - 6 inches	_____ -2	over 12 inches	_____ -5
7 - 9 inches	_____ -3	Don't know	_____ -6

17. Does your home have insulation in the walls?

Yes	_____ -1
No	_____ -2
Don't know	_____ -3

18. Does your home have storm windows or the equivalent (therma-pane windows)? (READ LIST)

Yes	²⁵ _____ -1	→ (IF YES:)	²⁶ _____	on all windows?	_____ -1
				on most windows?	_____ -2
				on a few windows?	_____ -3
No	_____ -2				
Don't know	_____ -3				

19. a. Do you have natural gas service available on your street?

Yes	_____ -1	No	_____ -2	Don't know	_____ -3
-----	----------	----	----------	------------	----------

b. Do you have propane delivery service in your neighborhood?

Yes	_____ -1	No	_____ -2	Don't know	_____ -3
-----	----------	----	----------	------------	----------

c. Do you have home heating oil delivery service in your neighborhood?

Yes	_____ -1	No	_____ -2	Don't know	_____ -3
-----	----------	----	----------	------------	----------

20. What fuel do you use for most of your cooking?

Electricity	_____ -1	Gas	_____ -2	Propane	_____ -3
Other (specify)	_____ -4	Do not own	_____ -5		

21a. What is the primary fuel that you use to heat your home? Is it:
(READ LIST) (CHECK ONLY ONE RESPONSE)

Electricity: Is that: with baseboard radiant heat ___-1
with heat pump ___-2

Natural gas ___-3
Propane ___-4
Oil ___-5
Coal ___-6
Wood ___-7
Solar energy ___-8 (IF "Solar" is mentioned, ask Q20b; otherwise, go to Q20c)
something other than these (specify) _____
_____ 9

Do not own ___-10

21b. About how old is your primary heating system? Is it: (READ LIST)

0-5 years ___-1 21-40 years ___-4
6-10 years ___-2 over 40 years ___-5
11-21 years ___-3 dk/refused ___-6

22. What is the primary fuel that you use to heat water for showers and baths, dishwashing, and so on?

Electricity ___-1 Gas ___-2 Oil ___-3 Propane ___-4
Solar ___-5 Other (specify) _____-6 Do not know ___-7

23a. Does your home have a central air conditioning system?

YES ___-1 NO ___-2

23b. Does your home have individual, room air conditioning units?

YES ___-1 NO ___-2

(If YES): How many units? _____

24. Approximately how much do you pay per month for electricity in ...

The summer \$ _____ the winter \$ _____

(If Don't Know, try to have respondent guess)

(READ FOR RESPONDENTS WHO WILL NOT PARTICIPATE):

<p>In order to be certain that we are interviewing a cross section of people I would like to ask you a few statistical questions before we terminate.</p>

Demographics

25. Finally, I would like to get a little more information about you and your household for classification purposes. Please tell me into which of the following age groups you fall? (READ LIST)

under 25	_____	-1
25 - 34	_____	-2
35 - 44	_____	-3
45 - 54	_____	-4
over 55	_____	-5

26. What was the highest level of schooling you completed?
Was it: (READ LIST)

Grammar school	_____	-1
High school	_____	-2
College	_____	-3
Post-graduate work or degree	_____	-4

27. Including yourself, how many people live in your home?

28. How many are: (READ)

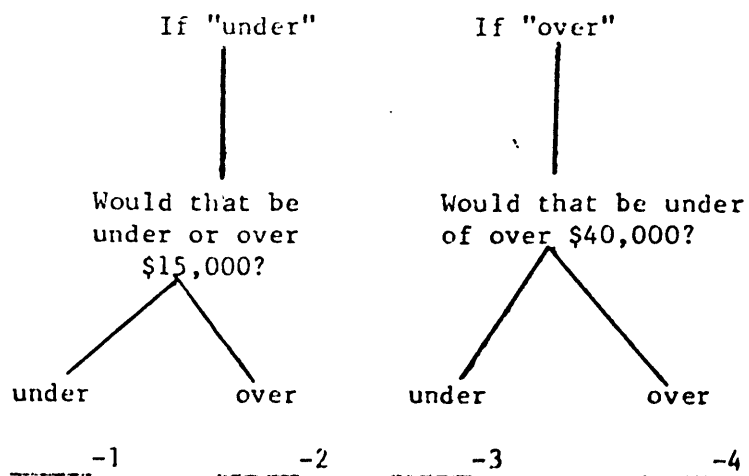
Adults 18 or over	_____
Children under 18	_____

29. Which of the following categories best describes your family's composition?

You have children living at home with the youngest under age 6	_____	-1
You have children living at home with the youngest age 6 to 12	_____	-2
You have children living at home with the youngest age 13 to 18	_____	-3
You have no children living at home under the age of 19	_____	-4

30. How many members of your household, including yourself, work outside the home for 30 hours or more per week?

31. Finally, it would help us a great deal in our statistical analysis if we could get some idea about your income level. Was your total household income for last year, before taxes, under or over \$25,000?



32. (RECORD SEX:) Male _____ -1 Female _____ -2

(IF AGREED TO PARTICIPATE:)

Once again, thank you for agreeing to participate in this study. I'll get the material in the mail soon and you should have it in a week or ten days. I'll talk to you again in about two weeks.

(IF DID NOT AGREE TO PARTICIPATE:)

Thank you very much for your time.

(STAPLE TO SCREENER QUESTIONNAIRE)

(IF REFUSED TO ANSWER QUESTIONS 25, 26 or 31. DO NOT COUNT TOWARD QUOTA)

Interview: At Site _____ -1
 Telephone _____ -2



Massachusetts Institute of Technology
Alfred P. Sloan School of Management
50 Memorial Drive
Cambridge, Massachusetts, 02139

Dear Study Participant:

In this booklet you will find information about photovoltaic (PV) power systems. The description of the system is followed by a series of questions which relate to that particular description. A few of the questions here ask for information about your household energy usage. If you can, please use your records to answer these questions as accurately as possible. If you are unable to determine these answers exactly, please make an estimate. Other questions call for you to guess about the future, or ask for your opinions. On these kinds of questions there are no right or wrong answers, so just try to respond in a way that reflects your beliefs as accurately as possible.

We will be calling you back in a few days to answer specific questions you might have about the survey. If you don't have any questions, and can complete the survey before we call again, please do so.

Thank you very much for your help!

Sincerely,

Gary L. Lilien
Associate Professor of
Management Science.

GLL:dms

PHOTOVOLTAICS SYSTEM FOR HOMES IN THE GREATER BOSTON AREA

The energy of sunlight can be converted into electrical energy for your home by means of a photovoltaic (PV for short) generating system. Such a system is composed of modular panels covered with interconnected "solar cells" and a piece of electrical equipment called a "power inverter." When sunlight strikes the solar cells, an energy reaction takes place because of the special internal structure of the cells. The energy reaction produces electricity which is drawn off through wires attached to the cells, and sent to the power inverter. One of the tasks of the power inverter is then to "invert" the electricity (from DC to AC) so that it can be used in the home.

As long as the sun is shining, the PV system will continue to supply electricity to the home. However, the house still remains connected to the local utility company's power supply. At night, or when the weather is cloudy, the power inverter automatically switches the house over to utility-generated power. On the other hand, when electricity produced by the home's PV system is not being fully utilized (during the daytime or when the family is on vacation), the power inverter sends whatever energy is extra back to the utility company. (See Figure 1.) The home is then credited for energy sold to the company, but at a rate of 60% of the utility company's regular prices because of the cost involved in transferring the surplus power to other areas.

Most homes would need several solar cell panels. The number of panels you would need depends on how much utility-generated electricity you would like to displace. Because the solar cell panels are modular, you can install enough solar cells to provide whatever fraction of your electric power needs you wish. The panels can be mounted on your roof or installed in your yard. For example, you might choose a system that would provide for your home's electric power needs except for hot water, space heating and air conditioning. In that case, any additional electricity needed for those purposes would be provided automatically by the utility company at the normal rate. Of course you could install a larger PV system that would provide for all of your home's electric power needs and reduce your utility bills to zero. If you increase the system size beyond that point you could actually be selling power to the utility company on a regular basis, and would receive payments from the utility.

A photovoltaic system comes with a 5-year manufacturer's warranty. Panels are tested to ensure that they will withstand all possible climate extremes in the area in which they are to be installed. The system has an expected life of 20 years which is comparable to the expected life of typical roofing material. A diagram of a photovoltaic system is shown in Figure 2.

Figure 1: POWER USAGE IN THE AVERAGE HOME (seasonal average)

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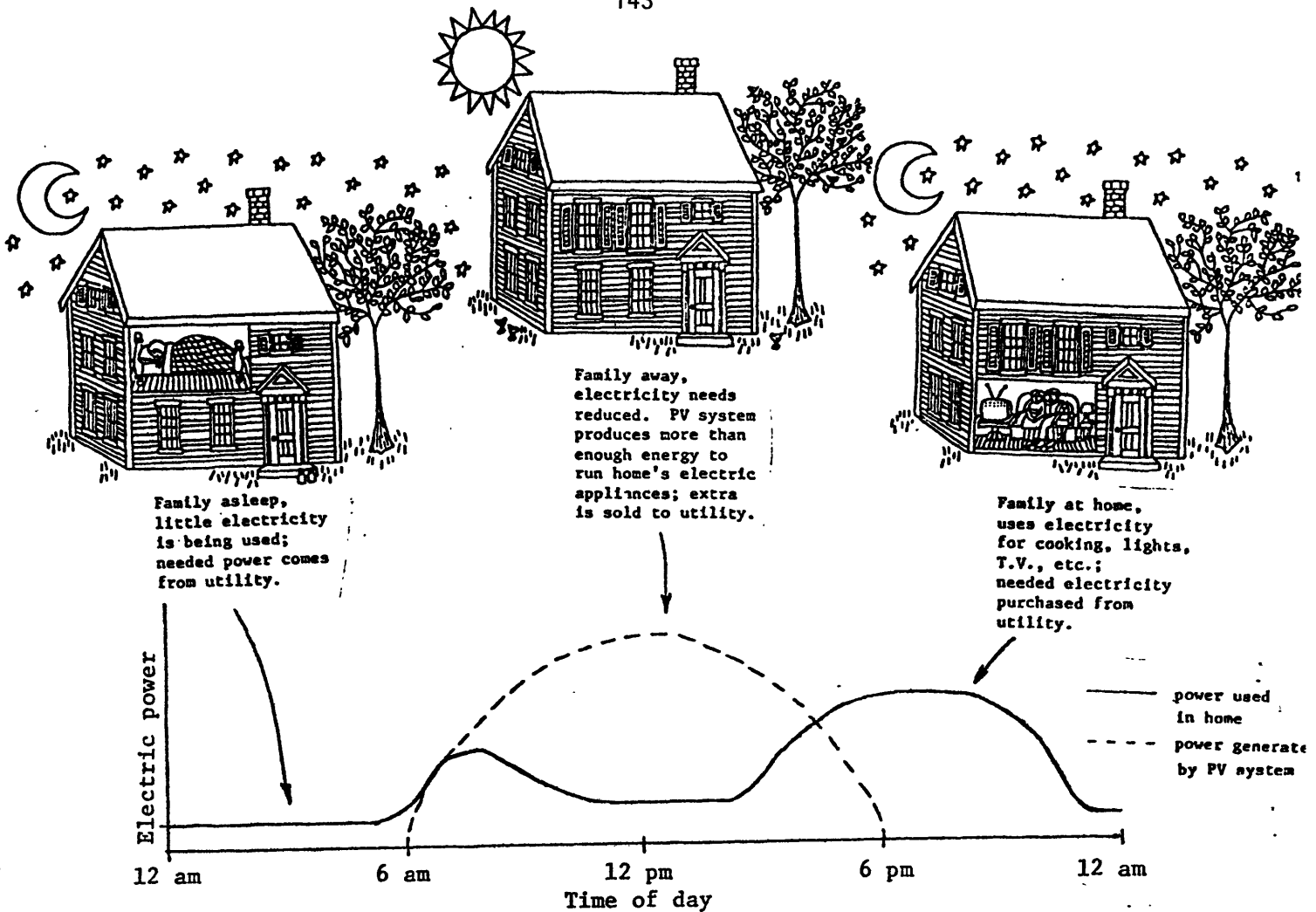
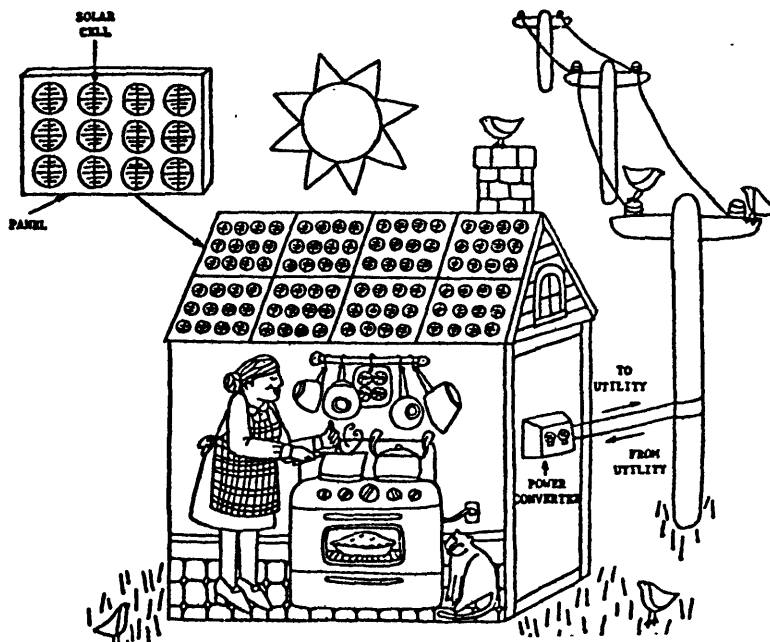


Figure 2: A TYPICAL PHOTOVOLTAIC SYSTEM FOR THE HOME



PHOTOVOLTAIC (PV) POWER SYSTEM FOR MASSACHUSETTS HOMES

A FINANCIAL EXAMPLE

The table on the following page shows financial information associated with owning and operating a PV system. The top row of the table shows various dollar amounts of utility-generated electricity that can be displaced by the system. The second row shows the size of the PV system needed to displace that much electricity. The system that is most appropriate for you thus depends on how much utility-generated electricity you wish to displace, and on the size of the system your property can accommodate. For example, if you wish to displace about \$50/month, you would need a system that measures about 500 ft.². Looking further down in the column, you can see that a system of this size has a gross cost of \$8,600, but you would get a tax rebate of \$4,440, so the actual price of such a system would be \$4,160.

This system saves \$600 the first year after it is installed. Because of expected inflation the system will save more each year, until, in the 5th year, it saves \$875, as the table shows. If you add up the yearly savings for 5½ years, the sum equals the actual price of the system, so the system "pays back" in 5½ years.

PRICE AND TAX REBATES: The gross price of a photovoltaic system for your home would depend on the size of the system as the table shows. The prices shown include materials and installation. However, the federal government and the state of Massachusetts offer refunds, paid to you as lump sums subtracted from your income taxes. (The tax rebate may be spread out over as many years as you need.) The actual cost to you would thus be lower than the gross price. For example, if you purchased a system costing \$10,000 you would be eligible for \$5,000 in tax rebates:

	Gross Price	\$10,000
(minus)	<u>tax rebate</u>	<u>5,000</u>
	Actual Price	\$ 5,000

SAVINGS: Because of inflation, the cost of electricity will increase as the years go by. But since sunshine remains free, the savings from a PV system will grow at the same rate. Over the past 10 years, electric energy costs have increased at a rate of 10% per year. The most likely projections would have the rates of increase over the next years be about the same as over the last 10 years, that is, 10%, so the estimates on the next page use that figure. The system will not add any extra cost for maintenance and upkeep.

QUESTIONS ABOUT PHOTOVOLTAIC SYSTEMS

1. Have you seriously considered an alternative system for meeting your electric power needs?

yes _____ no _____

2. Approximately how much was your electric bill for an average month last year? If you do not know please look it up, or as a last resort, guess. How much do you expect to pay for electricity per month next year? How much do you think you will have to pay per month five years from now (in 1985)?

last year \$ _____/month next year \$ _____/month in 1985 \$ _____/month
(guess) (guess)

3. Assume for a moment that you are going to buy a PV system for your home. Look back at the table in the preceding page, and think about what size system you would be most likely to have installed. (You might want to consider the amount of utility-generated electricity you'd like to displace, displace, the cost of the system and the space you have available to put it.) Approximately what size PV system would you buy?

200 sq. ft. _____	500 sq. ft. _____	800 sq. ft. _____
300 sq. ft. _____	600 sq. ft. _____	900 sq. ft. _____
400 sq. ft. _____	700 sq. ft. _____	1000 sq. ft. _____

4. Taking into consideration your family's electric power needs and what you know about PV system prices, government incentives, and your own situation, how much would you expect a system of the size you indicated in Q. 3 would cost you, if you were to buy one? Please check the number that comes closest to your estimate.

Actual price to you,	\$1,000 _____	\$6,000 _____	\$11,000 _____
<u>after applicable</u>	\$2,000 _____	\$7,000 _____	\$12,000 _____
<u>tax rebates:</u>	\$3,000 _____	\$8,000 _____	\$13,000 _____
	\$4,000 _____	\$9,000 _____	\$14,000 _____
	\$5,000 _____	\$10,000 _____	\$15,000 _____
			over \$15,000 _____

5. If you were to install a photovoltaic system in your home now, for the price you indicated in Question 4, about how much less would you spend on electric power this year than you would spend using the utility company? Please check the number that comes closest to your estimate.

less than \$240 _____	about \$720 (\$60/month) _____
about \$240 (\$20/month) _____	\$780 (\$65/month) _____
\$300 (\$25/month) _____	\$840 (\$70/month) _____
\$360 (\$30/month) _____	\$900 (\$75/month) _____
\$420 (\$35/month) _____	\$960 (\$80/month) _____
\$480 (\$40/month) _____	\$1020 (\$85/month) _____
\$540 (\$45/month) _____	\$1080 (\$90/month) _____
\$600 (\$50/month) _____	\$1140 (\$95/month) _____
\$660 (\$55/month) _____	\$1200 (\$100/month) _____
	Over \$1200 _____

PV SYSTEM SAVINGS

Dollars per Month of
Utility-Generated Electricity Displaced

	<u>\$20</u>	<u>\$30</u>	<u>\$40</u>	<u>\$50</u>	<u>\$60</u>	<u>\$70</u>	<u>\$80</u>	<u>\$90</u>	<u>\$100</u>
<u>Approximate Size System Required</u> (in square feet)	200	300	400	500	600	700	800	900	1000
<u>Approximate Cost</u>									
Gross Price	\$5,100	\$6,300	\$7,200	\$8,600	\$10,000	\$11,400	\$12,800	\$14,100	\$15,500
<u>Tax Rebate</u>	<u>3,040</u>	<u>3,520</u>	<u>3,880</u>	<u>4,440</u>	<u>5,000</u>	<u>5,560</u>	<u>6,120</u>	<u>6,640</u>	<u>7,210</u>
Actual Price	<u>\$2,060</u>	<u>\$2,780</u>	<u>\$3,320</u>	<u>\$4,160</u>	<u>\$5,000</u>	<u>\$5,840</u>	<u>\$ 6,680</u>	<u>\$ 7,460</u>	<u>\$ 8,290</u>
<u>Estimated Savings</u>									
First Month	\$ 20	\$ 30	\$ 40	\$ 50	\$ 60	\$ 70	\$ 80	\$ 90	\$ 100
First Year	\$ 240	\$ 360	\$ 480	\$ 600	\$ 720	840	960	1,080	1,200
Fifth Year	\$ 350	\$ 525	\$ 700	\$ 875	\$1,050	\$1,230	\$ 1,406	\$ 1,575	\$ 1,750
<u>Years to Payback*</u>	6 1/2	6	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5

* When sum of yearly savings equals actual price.

Please copy your "Actual Price" from Question 4 here:

This is your BASE PRICE: \$ _____ BASE PRICE

Please copy your annual savings estimate from Question 5

here. This is your BASE SAVINGS: \$ _____ BASE SAVINGS

6a. Please look at your BASE PRICE and BASE SAVINGS above. Thinking about your base figures, how likely would you be to buy a photovoltaic system for your home in the next year? Please check the appropriate space:

- Certain, practically certain (99 in 100) _____
- Almost sure (9 in 10) _____
- Very probable (8 in 10) _____
- Probable (7 in 10) _____
- Good possibility (6 in 10) _____
- Fairly good possibility (5 in 10) _____
- Fair possibility (4 in 10) _____
- Some possibility (3 in 10) _____
- Slight possibility (2 in 10) _____
- Very slight possibility (1 in 10) _____
- No chance, almost no chance (0 in 10) _____

6b. Prices for photovoltaic systems may go down. Keeping your BASE SAVINGS (from above) in mind, suppose you could buy a system for 25% less than your BASE PRICE. (The new price of the system would then be 3/4 of your BASE PRICE.) How likely would you be to buy a system in the next year? Please check the appropriate space:

- Certain, practically certain (99 in 100) _____
- Almost sure (9 in 10) _____
- Very probable (8 in 10) _____
- Probable (7 in 10) _____
- Good possibility (6 in 10) _____
- Fairly good possibility (5 in 10) _____
- Fair possibility (4 in 10) _____
- Some possibility (3 in 10) _____
- Slight possibility (2 in 10) _____
- Very slight possibility (1 in 10) _____
- No chance, almost no chance (0 in 10) _____

6c. Again using your BASE SAVINGS from above, suppose that you could buy a PV system for half of your BASE PRICE. How likely would you be to buy a system in the next year? Please check the appropriate space:

- Certain, practically certain (99 in 100) _____
- Almost sure (9 in 10) _____
- Very probable (8 in 10) _____
- Probable (7 in 10) _____
- Good possibility (6 in 10) _____
- Fairly good possibility (5 in 10) _____
- Fair possibility (4 in 10) _____
- Some possibility (3 in 10) _____
- Slight possibility (2 in 10) _____
- Very slight possibility (1 in 10) _____
- No chance, almost no chance (0 in 10) _____

6d. Electricity prices may rise faster than we now expect. Go back to your BASE PRICE from above, but now suppose that your savings are 50% more than your estimated BASE SAVINGS. How likely would you be to buy a system in the next year, if you could get these increased savings? Please check the appropriate space:

- Certain, practically certain (99 in 100) _____
- Almost sure (9 in 10) _____
- Very probable (8 in 10) _____
- Probable (7 in 10) _____
- Good possibility (6 in 10) _____
- Fairly good possibility (5 in 10) _____
- Fair possibility (4 in 10) _____
- Some possibility (3 in 10) _____
- Slight possibility (2 in 10) _____
- Very slight possibility (1 in 10) _____
- No chance, almost no chance (0 in 10) _____

6e. Assuming an improved technology in photovoltaics, suppose that the PV system originally described could also satisfy the power demand for heating in winter and air conditioning in summer, as well as year-'round water heating, at your BASE PRICE. How likely would you be to buy a system in the next year? Please check the appropriate space:

- Certain, practically certain (99 in 100) _____
- Almost sure (9 in 10) _____
- Very probable (8 in 10) _____
- Probable (7 in 10) _____
- Good possibility (6 in 10) _____
- Fairly good possibility (5 in 10) _____
- Fair possibility (4 in 10) _____
- Some possibility (3 in 10) _____
- Slight possibility (2 in 10) _____
- Very slight possibility (1 in 10) _____
- No chance, almost no chance (0 in 10) _____

7. Now think about the original PV system as it is available today -- at your BASE PRICE and with BASE SAVINGS -- and consider how likely you would be to purchase such a system in the next year. (This is the answer you gave to Question 6a.)

a. If the manufacturer changed the warranty from 5 years to 20 years, how much more likely would you be to purchase a system in the next year?

- Almost certain to buy _____
- Much more likely _____
- A little more likely _____
- Wouldn't change my likelihood _____

b. If the PV system were to come with the original 5-year warranty, but this time the federal government were to back it, how much more likely would you be to purchase a system in the next year?

- Almost certain to buy _____
- Much more likely _____
- A little more likely _____
- Wouldn't change my likelihood _____

c. Now, imagine that the PV system could be reduced in size, through technological changes, so that only half the original number of panels would give you your BASE SAVINGS (again at your BASE PRICE). How much more likely would you be to purchase such a system in the next year?

- Almost certain to buy _____
- Much more likely _____
- A little more likely _____
- Wouldn't change my likelihood _____

8. Again think back to your BASE PRICE estimate. (This is the answer you gave to Question 4).

a. Did you choose this BASE PRICE system to displace a portion of your home's electrical power needs including heating and air conditioning or to displace all of those needs?

a portion of my home's needs _____ (please answer Q. 8b)

all of my home's needs _____ (please skip to Q. 8c)

b. About how much more than your BASE PRICE would you be willing to pay for a PV system that would displace all of your home's electrical power needs, including heating and air condition?

- | | | |
|--------------------|--------------------|-------------------|
| \$0 _____ | up to \$3000 _____ | over \$5000 _____ |
| up to \$1000 _____ | up to \$4000 _____ | |
| up to \$2000 _____ | up to \$5000 _____ | |

- c. Now assume that you could buy a PV system that would allow you to be entirely independent of the utility company. You would need some storage capacity for electricity (batteries) and a back-up diesel generator. You would neither buy electricity from nor sell electricity to the utility. In fact the power lines would be removed. Your home would run as a "stand-alone" unit. Would you be interested in this kind of "stand-alone" capability for your home?

yes Please answer Q. 8d.

no Please skip to Q. 9.

- d. About how much more than your BASE PRICE would you be willing to pay for a PV system that would give you "stand-alone" capability -- that is, total independence from the utility company?

\$0	<input type="checkbox"/>	up to \$3000	<input type="checkbox"/>	
up to \$1000	<input type="checkbox"/>	up to \$4000	<input type="checkbox"/>	over \$5000 <input type="checkbox"/>
up to \$2000	<input type="checkbox"/>	up to \$5000	<input type="checkbox"/>	

9. Please answer the following questions about the use of photovoltaic power systems.

- a. Do you believe that you can currently obtain a reliable and dependable photovoltaic system for home use?

Definitely can
 Probably can
 Unsure
 Probably can not
 Definitely can not
 Don't know

- b. Do you believe that you can currently obtain a photovoltaic system that makes economic sense for home use?

Definitely can
 Probably can
 Unsure
 Probably can not
 Definitely can not
 Don't know

- c. Do you believe that photovoltaic systems will or will not be widely used by homeowners in your area within the next five years?

Definitely will
 Probably will
 Unsure
 Probably will not
 Definitely will not
 Don't know

10. Please indicate, by circling a number on the scale, how strongly you agree or disagree with each of the following statements about photovoltaic (PV) systems:

	<u>Strongly</u> <u>Agree</u>	<u>Agree</u>	<u>Neither</u> <u>Agree nor</u> <u>Disagree</u>	<u>Disagree</u>	<u>Strongly</u> <u>Disagree</u>	<u>Don'</u> <u>Know</u> <u>(Chec</u>
a. I understand the financial aspects of PV systems.	1	2	3	4	5	_____
b. I understand how PV systems work.	1	2	3	4	5	_____
c. PV systems can provide protection from future energy shortages	1	2	3	4	5	_____
d. A PV system will increase the resale value of my home.	1	2	3	4	5	_____
e. If a PV system that I had installed failed and needed major repairs or replacement, it would mean a financial disaster for my family.	1	2	3	4	5	_____
f. PV collector panels will be unattractive on my house.	1	2	3	4	5	_____
g. It is very easy to take a loan to buy a PV system.	1	2	3	4	5	_____
h. To me, initial cost is much more important than expected savings in deciding whether or not to purchase a PV system.	1	2	3	4	5	_____
i. If a PV system that I have installed gave less savings than I had expected, it would mean a financial disaster for my family.	1	2	3	4	5	_____
j. A PV system will protect me from increasing energy costs.	1	2	3	4	5	_____
k. I would vote for zoning restrictions to ban PV collector panels from the front of houses in my neighborhood.	1	2	3	4	5	_____

10. (continued)

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Don't Know (check)
l. Manufacturers of PV systems are mostly small, unstable companies.	1	2	3	4	5	_____
m. A PV system will need lots of attention and maintenance.	1	2	3	4	5	_____
n. I would admire a neighbor who installed a PV system.	1	2	3	4	5	_____
o. Technological advances will soon make currently available PV systems outdated.	1	2	3	4	5	_____
p. To me, expected savings is much more important than initial cost in deciding whether or not to purchase a PV system.	1	2	3	4	5	_____
q. Electricity is too small a part of my total energy usage for me to consider a PV system.	1	2	3	4	5	_____
r. A PV system that malfunctioned might damage my home, or cause danger to my family.	1	2	3	4	5	_____

11. a. How likely are you to look for more information about PV systems, within the next few months?

- Very likely _____
- Somewhat likely _____
- Unsure _____
- Somewhat unlikely _____
- Very unlikely _____

b. How likely would you be to visit a government sponsored open house showing a PV system in operation, if it were located in your town? In Springfield, MA?

<u>In your town</u>	<u>In Springfield, MA</u>
Very likely _____	Very likely _____
Somewhat likely _____	Somewhat likely _____
Unsure _____	Unsure _____
Somewhat unlikely _____	Somewhat unlikely _____
Very unlikely _____	Very unlikely _____

c. How likely are you to visit a PV dealer to look at the PV systems that are available, in the next few months? In the next 2 years?

<u>Next few months</u>	<u>Next 2 years</u>
Very likely _____	Very likely _____
Somewhat likely _____	Somewhat likely _____
Unsure _____	Unsure _____
Somewhat unlikely _____	Somewhat unlikely _____
Very unlikely _____	Very unlikely _____

11. d. How likely are you to have a photovoltaic system installed in your home within the next 5 years?

Very likely _____
 Somewhat likely _____
 Unsure _____
 Somewhat unlikely _____
 Very unlikely _____

12. Please read each of the following statements. Then circle the number on the scale that shows how much more likely you would be to purchase a PV system under the conditions of the statement.

	<u>Almost certain</u>	<u>Much more likely</u>	<u>A little more likely</u>	<u>No more likely</u>
a. If a PV system would protect me from future energy shortages, I'd be _____ to buy one.	1	2	3	4
b. If a PV system would increase the resale value of my home, I'd be _____ to buy one.	1	2	3	4
c. If it were easy to take a loan to buy a PV system, I'd be _____ to buy one.	1	2	3	4
d. If a PV system would protect me from increasing energy costs, I'd be _____ to buy one.	1	2	3	4
e. If PV systems had a proven safety record, I'd be _____ to buy one.	1	2	3	4

13. Note that the scale changes for the next few statements. Please circle the number on each of these scales that shows how much less likely you would be to purchase a PV system under the conditions of the statement.

	<u>Almost certain not</u>	<u>Much less likely</u>	<u>A little less likely</u>	<u>No less likely</u>
a. If a PV system would be unattractive on my house, I'd be _____ to buy one.	1	2	3	4
b. If PV manufacturers were small, unstable companies, I'd be _____ to buy one.	1	2	3	4
c. If a PV system needed lots of attention and maintenance, I'd be _____ to buy one.	1	2	3	4
d. If technological advances will eventually make currently available PV systems outdated, I'd be _____ to buy one.	1	2	3	4

14. If you were to purchase a photovoltaic system, how would you be most likely to pay for it?

- Personal savings _____
- Included in mortgage _____
- Second mortgage _____
- Separate bank or credit union loan _____
- Other (please specify) _____

15. Do you intend to look for additional information about any kind of solar energy systems within the next two or three months?

Yes _____ No _____ (If "No", please skip to Q. 18)

16. About what kinds of solar energy systems will you look for information?

- Solar water heating _____
- Solar-assisted heat pump _____
- Solar home heating _____
- Photovoltaic power systems _____
- Other (please specify) _____

17. Approximately how much does a gallon of unleaded, regular gasoline cost in your area?

- | | | | |
|----------------|-------|----------------|-------|
| \$1.20 or less | _____ | \$1.35 | _____ |
| \$1.25 | _____ | \$1.40 | _____ |
| \$1.30 | _____ | \$1.45 or more | _____ |

18. How much do you think a gallon of unleaded, regular gasoline will cost five years from now (in 1985)?

\$ _____ /gallon

19. Which of the following products have you bought for your own or your family's use?

- | | | | |
|---------------------------|-------|--------------------------------|-------|
| Microwave oven | _____ | Waterbed | _____ |
| Home table-top computer | _____ | Quartz room heater | _____ |
| Videotape player/recorder | _____ | Digital watch | _____ |
| Food processor | _____ | Whirlpool bath, spa or hot tub | _____ |

If you write to us at the return address, in several months, after the study is over we will send you a summary of the results.

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