THE FEDERAL PHOTOVOLTAICS COMMERCIALIZATION PROGRAM

Thesis by

William Manson Pegram

In Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

California Institute of Technology
Pasadena, California

1989

(Submitted March 8, 1989)

ACKNOWLEDGMENT

I would like to thank my thesis committee--Jeff Dubin, John Ledyard, Rod Kiewiet, and Roger Noll. Jeff Banks, Linda Cohen, and Doug Rivers also made helpful comments. A number of individuals at the Jet Propulsion Laboratory (Mickey Alper, Chet Borden, Bob Chamberlain, Bill Gates, Jeff H. Smith, and Jeff L. Smith) provided useful background and documents, as did Andrew Krantz of the Department of Energy. Peter Cramton provided a technical typing program. The libraries at Caltech and the Congressional Budget Office provided significant assistance.

ABSTRACT

The dissertation presents a political and economic history of the federal government's program to commercialize photovoltaic energy for terrestrial use. Chapter 1 is a detailed history of the program. Chapter 2 is a brief review of the Congressional roll call voting literature. Chapter 3 develops PV benefit measures at the state and Congressional district level necessary for an econometric analysis of PV roll call voting. Chapter 4 presents the econometric analysis.

Because PV power was considerably more expensive than conventional power, the program was designed to make PV a significant power source in the long term, emphasizing research and development, although sizeable amounts have been spent for procurement (direct government purchases and indirectly through tax credits). The decentralized R&D program pursued alternative approaches in parallel, with subsequent funding dependent on earlier progress. Funding rose rapidly in the 1970s before shrinking in the 1980s. Tax credits were introduced in 1978, with the last of the credits due to expire this year.

Major issues in the program have been the appropriate magnitude of demonstrations and government procurement, whether decentralized, residential use or centralized utility generation would first be economic, the role of storage in PV, and the role of PV in a utility's generation mix.

Roll call voting on solar energy (all votes analyzed occurred from 1975-1980) was influenced in a cross-sectional sense by all the influences predicted: party and ideology, local economic benefits of the technology, local PV federal spending and manufacturing, and appropriations committee membership. The cross-sectional results for ideology are consistent with the strongly ideological character of solar energy politics and the timing of funding increases and decreases discussed in Chapter 1. Local PV spending and manufacturing was less significant than ideology or the economic benefits of the technology. Because time series analysis of the votes was not possible, it is not possible to test the role of economic benefits to the nation as a whole.

TABLE OF CONTENTS

Text of Thesis

List of Tables

INTRODUCTION

In response to the Arab oil embargo and resulting quadrupling of world oil prices in 1973-1974, the federal government accelerated research on a wide variety of energy technologies. The work presented below examines the government support of one of these energy technologies--photovoltaics, or the direct production of electricity from sunlight. Of particular interest are the reasons for dramatic funding increases in the 1970s and declines in the 1980s.

One hypothesis is that the level of funding is a function of the likely economic benefits resulting from government support of the technology. These benefits, in turn, depend on whether government involvement is appropriate and on the economic benefits of the technology itself. The threefold economic rationale for government involvement remained relatively constant throughout the period. First, reliance on nonsecure foreign sources of energy imposed security externalities such as effects on U.S. foreign policy toward the Middle East. Increased PV use would reduce these effects, but the benefit of so doing would not be captured by PV producers. Second, reducing dependence on foreign energy required long term research and development projects. If the social discount rate is less than the private discount rate, then government support of R&D can increase research and development to the socially optimal level. Since the effect of this divergence will be greatest for long term R&D, support is especially justified. Third, because the price of world oil since 1973-1974 has been far above cost, the possibility of large price declines could discourage private domestic energy research if protective measures, such as an oil import fee, could not be relied on.

While the rationale for government involvement remained relatively constant, the other key determinant of the economic benefit of government support of the technology, the likely benefits of the technology itself, changed dramatically. The economic benefits of PV are the cost savings resulting from replacing more expensive sources of electricity, the costs of which are highly positively correlated with oil prices. Thus, the large increases in oil prices in 1973-1974 increased the benefits of PV whereas the oil price declines of the 1980s lowered them.

In addition to the economic hypothesis, there are two political hypotheses concerning the funding pattern. The first is that the changing party and ideological composition of the Administration or the Congress affected the level of program funding. There are several strands of evidence for this hypothesis. The sharp change in ideology and party of the Administration and Senate in 1981 occurred just prior to the declines in funding. Furthermore, much of the popular discussion of solar energy in the 1970s had a strong ideological dimension and the Reagan Administration believed in less government involvement. In addition, the initial political justification for involvement was a public, facing gasoline lines and higher energy prices, which clamored for government action in several areas, including government involvement in energy research. In the 1980s, public concern was focused on other matters.

Another political hypothesis is that the level of PV funding was influenced by "pork barrel" effects. Under this hypothesis, the probability of support for a program by a Member or Senator is positively related to the federal dollars from the program going to his or her district or state. Furthermore, programs with strong pork barrel aspects are more likely to be continued (at least for awhile) if other factors, such as economics, take a downward turn.

After a detailed history of the program is presented in Chapter 1, the remainder of the chapters attempt to test these three hypotheses regarding the determinants of the level of PV funding through a cross-sectional econometric analysis of Congressional roll call voting on photovoltaics. In order that this analysis reflect the best practice in the field, a comprehensive survey of previous roll call studies was undertaken, and Chapter 2 reports the findings on the key methodological issues, particularly the appropriate measure to test the ideology hypothesis. Chapter 3 develops the appropriate measures to test my other two hypotheses (economic and pork barrel). Chapter 4 presents the econometric analysis and a brief conclusion. An appendix describes the data used in the econometric analysis.

The cross-sectional analysis indicates that ideology and local economic benefits affect voting in the predicted direction, with the results for ideology most significant. The coefficients of the pork barrel variables are insignificant, although generally of the right sign. Time series analysis was not attempted due to noncomparability of the votes and difficulties in constructing time series for several variables, especially ideology.

Although my results are generally consistent with roll call studies on other issues, three differences should be noted. First, Kalt and Zupan (1984) found that for Senators where the Kalt-Zupan vote model predicted the actual vote incorrectly, the proportion of cases where Senators were voting contrary to ideology was higher where Senators were facing reelection. They interpret their results to mean that ideological "shirking,", i.e. voting one's ideology rather than one's constituency, was less prevalent for Senators facing election than for the rest of the

Senate. Applying their methodology to my data, I find that for Senators whose vote is predicted incorrectly by my vote model, the extent of voting contrary to ideology is the same for those facing election and those not. However, what exactly their methodology is measuring is not clear, for their vote model used to predict votes includes an ideology variable. Using a simpler, more direct approach on my data, I find that the ideology variable is more significant the closer the election, which is the opposite of what one might expect from the Kalt and Zupan results.

Second, previous roll call studies on energy policy (oil and gas deregulation, coal strip mining) have shown the importance of local economic benefits in voting on regulatory programs which have large immediate economic implications for current resource owners and consumers. Local economic benefits have also been hypothesized to be important in voting on distributive programs such as highway construction, categorical grants-in-aid, urban renewal, mass transit, and sewage treatment plants (Weingast, Shepsle, and Johnsen (1981)). The picture is less clear for long term energy technology development programs such as the breeder reactor, synthetic fuels, and PV. Cohen's study of the breeder found that local economic benefits were unimportant, whereas her study of synthetic fuels found an effect (see The Technology Pork Barrel). The lack of an effect in the breeder may be due to the fact that local economic benefits are measured by the presence of nuclear plants, and this presence also motivated opposition by environmental groups. Although my results seem to suggest that local economic benefits are important for a long term program such as the PV R&D program, all of the votes analyzed included funding for programs with short-term economic benefits as well.

Third, with the exception of the correlation analysis of Bernstein and Anthony (1974) and Arnold (1981b), previous published studies have looked for "pork barrel" effects in spending at the entire government level (Peltzman (1985)) or at the agency level for large agencies (the Department of Defense and the Department of Health, Education, and Welfare)--see Kau and Rubin (1979a), Kau, Keenan, and Rubin (1982), and Navarro (1984). Government-wide and agency spending is generally insignificant in these studies. Furthermore, no published regression analysis examines spending at the program level, although a number of studies in draft form find positive effects at the program level--see the studies by Banks, Cohen, and Edelman in The Technology Pork Barrel and Krehbiel and Rivers (1988a). The positive results for PV spending are consistent with the results of these latter studies.

The analysis presented here suggests that ideological, local economic benefit, and "pork barrel" factors are all important in determining the federal support of a program over time. The photovoltaic program employed a decentralized, semi-competitive strategy for the allocation of funds. This meant that the program was unlikely to founder based on the outcome of particular awards and was structured to achieve cost reductions and technological progress. However, it also meant that the program was more likely to be buffeted by the changing winds of ideology or external economics than if a strong pork barrel component had been present. Thus, the strategy that contributes to technological success of the program may also contribute to its political failure. The structure amenable to achieving economic benefits is precisely the one that fails to create a political constituency that lasts long enough, in particular, to sustain development of an innovative, uncertain alternate energy technology.

CHAPTER ONE

HISTORY OF THE PHOTOVOLTAICS COMMERCIALIZATION PROGRAM

Photovoltaic (PV) devices convert sunlight directly into electricity. The first significant use of photovoltaics occurred in the U.S. space program to provide power for satellites, beginning with the Vanguard in 1958.[1] In response to the energy crisis in the early 1970s, the federal government initiated a program, which has continued to the present day, that attempted to commercialize photovoltaics for generation of electricity on earth.[2]

Spending less than a million dollars a year in fiscal years 1972 and 1973, direct federal expenditures (excluding tax credits) on photovoltaics grew to $150 million in FY 1980, before shrinking to less than an average of $50 million per year in the eight Reagan budgets.[3]

The goal of this program was to reduce dramatically the cost of photovoltaic energy. The original cost goals of the program have not been achieved, nor is PV power currently competitive for other than remote applications. However, there have been a number of achievements in photovoltaics. Costs have dropped substantially, and, as shown in Table 1, U.S. photovoltaic module production and domestic use have grown substantially. Although changes in the definition of the categories used

---

[1] Solar Energy Research Institute (1982, p. 8) The SERI book with the same title published in 1984 is an expanded version of this document.

[2] Smith (1981) and Redfield (1981) provide good summaries of the PV program.

[3] Dollars are in current dollars throughout this paper, unless noted.

Table 1
U.S. Photovoltaic Module Manufacturing Activity, 1979-1986
(peak kilowatts)

Year	Shipments by Manufacturers (including exports)	Exports
1979	903[a]	131[a]
1980	2,786	826
1981	2,806	1,195
1982	6,897	1,818
1983	12,620	1,903
1984	9,912	2,153
1985	5,769[b]	1,109
1986	6,333[b]	2,046

Notes:

Shipment figures include imported modules. Figures do not include unencapsulated PV cells.

[a] Last six months only.

[b] Does not include shipments of modules for space satellite applications, which generally account for 5-15 percent of all module shipments.

Sources: 1982-1986 total and 1985-1986 export figures from U.S. Department of Energy (1987b), p. 22. 1983-1984 exports from U.S. Department of Energy (1985c), p. 24. 1981-1982 exports from U.S. Department of Energy (1984b), p. 23. 1981 from U.S. Department of Energy (1984b), p. 23; 1980 from U.S. Department of Energy (1983d), p. 26. 1979 from U.S. Department of Energy (1979c), p. 25.

to collect data on end uses (Table 2) complicates the comparison,[4] the most interesting change is the decline of "central power" from 44-70 percent in 1982-1984 to 9 percent for "utility" in 1985-1986. Since the former category is actually less inclusive than the latter, this indicates a significant decline. Two likely explanations for this are changes in tax credits and less federal support for demonstration projects. Earlier data show substantial growth in utility involvement in photovoltaics (Table 3).

EARLY HISTORY OF THE PROGRAM

Although photovoltaic cells were used extensively in the space program, federal support for all terrestrial applications of solar energy (including other programs as well as photovoltaics) averaged only about $100,000 per year during the 20 year period from 1950-1970.[5] In the early 1970s, the primary federal support for solar technology for terrestrial use came from the National Science Foundation (NSF). In 1975, the program was moved to the Energy Research and Development Administration (ERDA) which in 1977 became part of the Department of Energy (DOE). The budget for PV grew dramatically in the 1970s but shrank considerably in the 1980s (Table 4).

---

[4] The categories were different for 1985-86 than 1982-1984. "Residential" measured less than 5 percent for 1982-84 and 31-32 percent for 1985-1986 (growing in absolute terms from 492 peak kW in 1984 to 1800 in 1985) but the latter category includes nongrid applications, whereas the former does not; thus it is difficult to know how much change has taken place.

[5] Estimate of Dr. John Teem, then Assistant Administrator for Solar, Geothermal, and Advanced Energy Systems, Energy Research and Development Administration (ERDA), in congressional testimony. See Teem (1975), pp. 169-245.

Table 2
PV Modules by End Use

End Use	1985 Shipments (peak kW)	1985 Percent of Total	1986 Shipments (peak kW)	1986 Percent of Total
Water Pumping	545	9.4	591	9.3
Transportation	370	6.4	419	6.6
Communication	1,292	22.4	1,375	21.7
Consumer Goods	244	4.2	294	4.6
Military	112	1.9	101	1.6
Residential	1,800	31.2	2,029	32.0
Industrial/Commercial	826	14.3	895	14.1
Utility	518	9.0	553	8.7
Other	63	1.1	76	1.2
Total	5,769	100.0	6,333	100.0

Residential includes grid and non-grid-connected applications.

End Use	1984 Amount Shipped (peak kW)	1984 Percent of Total	1983 Amount Shipped (peak kW)	1983 Percent of Total	1982 Amount Shipped (peak kW)	1982 Percent of Total
Specialty	470	4.7	242	1.9	88	1.3
Stand-Alone ..	3475	35.1	3334	26.4	3265	47.3
Residential ..	492	5.0	160	1.3	51	0.7
Intermediate .	204	2.1	93	0.7	454	6.6
Central Power	5271	53.2	8791	69.6	3040	44.1
Total	9912	100.0	12,620	100.0	6897	100.0

Stand-alone denotes not grid-connected. Residential and intermediate categories include only grid-connected.

<u>Sources</u>: 1985-1986 figures from U.S. Department of Energy (1987b), p. 24. 1982-1984 figures from U.S. Department of Energy (1985c), pp. 21, 26.

Table 3
Number of Utilities Involved in Photovoltaic Projects, 1975-1983

Year	Number of Utilities	Number of Projects
1975	na	1
1976	5	5
1977	10	12
1978	23	30
1979	24	32
1980	32	48
1981	40	68
1982	41	74
1983	41	74

Source: Photovoltaic Insider's Report, Vol. III, No. 11, November 1984, p. 1

Table 4
Federal Government Expenditures on Terrestrial Photovoltaics
(millions of dollars)

Fiscal Year	Current Dollars	Constant FY 74$
1971	small or none	small or none
1972	.33	.37
1973	.79	.85
1974	2.4	2.4
1975	8.0	7.3
1976	21.6	18.4
1977	64.0	50.1
1978	76.5	57.0
1979	118.8	81.4
1980	150.0	94.6
1981	139.2	80.1
1982	74.0	39.7
1983	58.0	29.9
1984	50.4	25.0
1985	57.0	27.3
1986	40.7	19.0
1987	40.4	18.3
1988	35.0	15.3
1989	35.5	15.1
TOTAL (1971-89)	972.6	582.1

Note: Figures include the effects of supplementals and rescissions. 1976-1989 figures represent appropriations. 1971-1975 figures probably represent costs (approximating outlays). Appropriations figures would be somewhat larger because program is growing at this time. For 1972-88, constant dollars are computed by constructing the fiscal year deflator as the average of the GNP implicit price deflator for the quarters in the fiscal year (the quarterly figures can be found in Survey of Current Business). FY 89 inflation assumed at FY 88 rate (3.1%).

Source: 1971-1975 figures from Herwig (1974, p. 1251), with actual figures for 1971-1974 and estimated for 1975. 1976-1989 figures from Table 21.

Early Assessments of PV

During the NSF period, five key studies assessed the long-term prospects for solar energy and photovoltaics.[6] Four of these studies estimated the contribution that solar energy sources would make in the future. Separate estimates were made for different solar technologies, including photovoltaics. The estimates for photovoltaics are shown in Table 5. This table also shows, for comparison, estimates that were made later, in 1979-1980.

Although these studies reflect varying degrees of optimism regarding solar energy and photovoltaics, they all foresaw a very limited contribution of photovoltaics through at least 1985, with significant penetration of PV by the year 2000. This combination of very limited short-term potential and large long-term potential reflected an assessment that large cost reductions (a hundredfold reduction) were necessary to make PV economic but that these cost reductions were achievable given sufficient time and R&D expenditures.

Table 6 shows various estimates of the federal expenditures required to achieve these cost reductions. These reports attempted to justify these federal expenditures by a rudimentary cost-benefit calculation which compared the total dollar savings in fuel costs resulting from the assumed level of PV use with the federal research and development costs for PV. This comparison was done implicitly in the NSF/NASA report in 1972 which

---

[6] The studies are (1) NSF/NASA (1972), (2) Subpanel IX Report (1973), (3) National Science Foundation (1973, 1974a) and Jet Propulsion Laboratory (1974b), (4) MITRE (1973, 1974), and (5) U.S. Federal Energy Administration (1974).

Table 5
Contribution of Photovoltaics
(10^{15} Btus Per Year--Quadrillion Btus or "Quads")

Study	1980	Year 1985	1990	2000	2020
NSF/NASA (1972)	0	0	-	.45	8.0
Subpanel IX (1973)	0	.03	1.2	3.0	-
MITRE (1973)					
Low	0	0	-	1.6	5.4
High	0	0	.01	5.4	18.0
Solar Energy Task Force (1974)					
Business as Usual	Neg.	.003	.07	1.5	-
Accelerated	Neg.	.01	.3	7.0	-
ERDA (1975)	-	-	-	.9	2.4
National Energy Plan (1979)					
Base	-	-	-	.03	-
Maximum Practical	-	-	-	.3	-
Technical Limit	-	-	-	.75	-
DOE (1980)					
Low Case	-	0	Small	-	-
Best Estimate	-	0	.006	-	-
High Case	-	Small	.012	-	-

Note: a "-" means that no projection for that year was made. 1 KWH = 3412 BTU. Total U.S. energy consumption in 1974 was 72.6 quads.

Sources: NSF/NASA (1972), Table 3, multiplying by factor of 0.3 to get solar energy production equal to the fossil fuel displacement figures given. Subpanel IX (1973), Figure 29, p. 411. MITRE (1973), pp. 178, 180. Solar Energy Task Force from U.S. Federal Energy Administration (1974), pp. I-7, 9. Different figures for these studies were given in a table prepared by a Congressional committee.

Table 6
Estimates of Federal Photovoltaic Program Budget Requirements
(Millions of Dollars[1])

Source	Total Amount Required	Number of Years
Office of Science and Technology (1972)	322	not specified
NSF/NASA (1972)	780	11
Cherry Hill (1973)	560[2]	11
Subpanel IX (1973)	248 373 378	first 5 years first 10 years first 25 years
MITRE (1973)[3]		
Minimum Viable	39.6	first 7 years
Accelerated	72.9	first 7 years
Solar Energy Task Force (1974)	No budget given	
NSF Testimony (1974)	815[4]	10
NSF Report (1974)	816	10

Sources: Office of Science and Technology (1972). Cited in American Institute of Aeronautics and Astronautics (1975), p. 57. NSF/NASA (1972), p. 65. Cherry Hill figures from Wolf (1974), Table 9. Wolf's figures summarize those in the executive report of the conference--Jet Propulsion Laboratory (1974b), pp. 9, 13, 19, 22, 23, 26. Subpanel IX Report (1973), Figure 24, p. 405 in hearing document. MITRE figures from MITRE (1974), pp. 439-441 in hearing document. NSF Testimony from NSF written answers to questions at hearing (Committee on Science and Astronautics, 1974, p. 131). NSF Report from National Solar Energy Program (1974), p. VII-25.

Notes:

1. The reports do not indicate whether figures are in constant or current dollars, or whether these are discounted present values.

2. This estimate does not include estimates for some categories for the final six years of the proposed program. If these were included, the expenditure requirement would probably be about $30 million more.

3. The MITRE report says that this is the amount to conduct all of the research tasks for PV. It is unclear what would be achieved by expenditure of the amounts shown and what support beyond the initial 7 years will be required--especially since elsewhere in the report MITRE predicts that PV will cost from 1 to 4 times as much as conventional energy in the year 2000.

Table 6 (cont.)

4. This is the funding required from public and private sources to establish a market price of about 50 cents per peak watt. It was expected that federal funding would dominate in the 1970s and private funding in the 1980s, if progress continued. This figure appears to conflict with the 816 figure given in the NSF Report in the same year since the latter only estimated federal funding requirements.

showed annual dollar savings in fossil fuel ($750 million in 2000, $16 billion in 2020) with total federal funding required ($780 million). The Solar Energy Task Force Report, done as part of the large Project Independence Blueprint in 1974, made this comparison explicitly, perhaps for the first time.[7] The report states

> . . .photovoltaic conversion systems would be expected to be producing more than 1% of the nation's energy by the year 2000. Estimates indicate that this 1% . . . would require an annual consumption of about 400 million barrels of fuel oil by oil-burning plants. At $11 per barrel, this could mean a saving of over $4 billion worth of fuel oil per year. These anticipated savings for one year are considerably more than the total costs anticipated for the entire PEPS [photovoltaic energy power systems] program.[8]

These forecasts of PV use in the short term, the medium term, and long term emerged from an assessment of the outlook for substantial cost reductions in photovoltaics. Cost goals were first adopted at the Cherry Hill photovoltaics conference in October, 1973.

The consensus of the experts at the conference was the following:[9]

1) A 10-year program to establish the commercial practicability of photovoltaics should be conducted and funded by the federal government.

2) The primary emphasis of this program should be on single-crystal silicon technology, but other systems should also be developed.

---

[7] Dr. John Teem, Assistant Administrator for Solar, Geothermal and Advanced Energy Systems of the Energy Research and Development Administration, reaffirmed this approach in prepared Congressional testimony the next year. Teem (1975), pp. 207-208.

[8] U.S. Federal Energy Administration (1974), p. VII-10. Although the report does not say it, "costs of the PEPS program" refers only to federal costs since the tables on pages VII-4 and 5 of the report indicate that the capital costs of the PEPS in service by the year 2000 will range from $80 to $440 billion.

[9] Jet Propulsion Laboratory (1974b), pp. 1, 2.

3) The participation of electric utilities should be obtained as early as possible.

4) For single-crystal silicon technology, a 50 cents/peak watt cell can be achieved by 1985, with 10 cents per watt by the year 2000.

5) For CdS/CuS_2S, 20 cents per peak watt is a reasonable goal for 1985 with 5 cents possible for 2000.

The conclusion to be drawn from these studies and testimony is that there was a consensus among solar energy experts and advocates in the early 1970s on a number of points:

1) Photovoltaics could generate very little electricity by 1985, but could generate a significant amount of electricity by the year 2000.

2) This could be accomplished by the expenditure of approximately 300 to 800 million dollars by the federal government.

3) This federal expenditure should be undertaken because the savings in fossil fuel costs that would result would be far larger than the federal expenditure required.

4) Costs of the existing technology (flat-plate, single-crystal silicon) could be reduced substantially. However, ultimately other technologies would probably be required to reduce the costs of photovoltaics sufficiently for the widespread use envisioned by the year 2000.

COST-REDUCTION AREAS

As part of the plan to achieve cost reduction, the program very soon defined cost-reduction activities across the entire program. A brief discussion of these areas will illustrate how the cost-reduction problem was disaggregated into several cost-reduction problems:[10]

Existing Technology

The existing technology consisted of single-crystal silicon cells. Five major subactivities were defined to reduce silicon module costs.

Reduce solar-cell-grade silicon from $65 per kilogram to $10.

To make a silicon cell, the starting raw material, quartzite, which is 90 percent or more silica (SiO_2), must be refined and its impurities removed. This involved procedure was quite costly.

Increase efficiency of solar-cell fabrication (over 75 percent of the silicon material was being wasted).

The purified silicon resulting from the above step is polycrystalline. The photovoltaic properties of polycrystalline silicon are less desirable than single-crystal silicon in which silicon atoms are arranged in a perfect lattice, rather than being randomly packed. Single-crystal silicon can be produced from polycrystalline silicon by the Czochralski process, where a cylindrical ingot, typically 7.5 centimeters in diameter, is slowly grown. The next step in the process is to cut the ingots into wafers 0.5 millimeters thick using diamond saws. Because the saws are also about this thickness, this means at least half of the single-crystal silicon material will be lost during slicing.

Improve the ratio of cell to array area (packing factor).

An unfortunate consequence of the cylindrical nature of the Czochralski ingots is that the resulting wafers are circular. Putting

---

[10] U.S. Energy Research and Development Administration (1976), pp. 2-3. The description of solar-cell technology is drawn from Solar Energy Research Institute (1984).

circular cells on an array means that a substantial portion of the array surface will not be covered by cells and thus is of no value for electricity generation. This unused surface area increases the cost of PV electricity due to the fact that the cost of the support structure depends on the surface area of the array.

Develop encapsulation materials to increase array lifetime.

PV arrays ideally have low operating costs. With a high capital cost to operating cost ratio, the cost of PV electricity is critically dependent on the lifetime of the array. Lightweight encapsulation materials are important so as to not to increase the cost of support structures.

Automate production of silicon solar-cell arrays.

Hand fabrication of PV arrays was expensive. Cost targets could only be reached if the process were automated.

Conduct Thin-Film and Novel Materials Research

In addition to reducing the costs of the current technology, the program pursued the use of alternative materials. Thin films using nonsilicon materials offered a number of theoretical advantages to silicon:

a) Different solar-cell materials have different "characteristic energies," the energy required to free electrons, a necessary step to generate electricity. The sun's spectrum consists of a wide variety of energies. To maximize the efficiency of a cell, one wants a material in which the maximum amount of energy in the sun's spectrum is just great enough to free electrons. Silicon is good in this respect, but not ideal.

b) Some other materials are more light-absorbing than silicon. This permits the use of thinner films, saving on material costs, and enhancing the electrical properties of the cell.

However the efficiency of these cells (the ratio of the electrical energy produced to the light energy striking the cell) was low. Lower efficiency means that more cells (costly in themselves) and a larger support structure is required to generate the same amount of electricity.

Develop Concentrators

In addition to exploring alternative materials, the program also pursued different approaches to gathering light. As an alternative to the traditional "flat-plate" approach, mirrors or lenses can be used to "concentrate" light. The reason to do this is that sunlight is relatively diffuse and thus large numbers of cells and large support structures are required to generate large amounts of electricity. The use of lenses or mirrors to concentrate the light provides a way to generate the same amount of electricity but with far fewer cells.

However, concentrators have problems that raise their costs:

Temperature. The efficiency of solar cells varies with temperature. Silicon flat-plate collectors, without the use of concentrators, operate at relatively efficient levels. In the absence of cooling, concentrators could raise the silicon cell temperature so much that the photoelectric effect would disappear. Cooling is therefore essential.

Tracking. Concentrators require tracking the sun. This can be done along one axis or two.

Clouds. Concentrators do not work well with diffuse light, only with sunlight.

R&D MANAGEMENT

The key aspects of R&D management in the PV program were its use of decentralization, coordination, competition, and decision criteria.

Decentralization

Federal R&D programs are typically organized with one, two, or three levels of decision making. An example of a single-level structure is government in-house research and development. A two-level approach is the standard government-contractor form, and the three-level approach is the government-contractor-subcontractor form. The PV program used a three- and four-level form throughout its history. In this structure, the primary management of the program took place in several "Level II" lead centers and "Level III" field centers rather than from Level I headquarters in Washington, D.C. The lead and field centers, in turn, awarded contracts to "Level IV" private contractors.[11]

The "Level I" headquarters of the PV program resided with the Research Applied to National Needs Program in the National Science Foundation until January 1975, when responsibility was shifted to the newly created Energy Research and Development Administration (ERDA).[12]

---

[11] Level I, II, and III terminology does not appear in program documents. The terminology is used in the National Aeronautics and Space Administration (NASA) and is used here for convenience and to draw explicit parallels to current NASA practice.

[12] Responsibility for photovoltaics was transferred to ERDA through three 1974 Acts. ERDA was established by the Energy Reorganization Act of 1974 (P.L. 93-438, October 11, 1974) which transferred the NSF solar heating and cooling and geothermal power development programs to ERDA. The Solar Energy Research, Development, and Demonstration Act of 1974

Responsibility for all ERDA programs, including photovoltaics, shifted to the Department of Energy in October 1977 as a result of the Department of Energy Organization Act (P.L. 95-91, August 4, 1977).[13]

The number of Level II lead centers and their responsibilities changed over time. At the height of the program in 1980, the two lead centers were the Solar Energy Research Institute (SERI) in Golden, Colorado (lead center for Advanced Research and Development) and the Jet Propulsion Laboratory in Pasadena, California (lead center for Technology Development and Applications and the Federal PV Utilization Program). As lead center for technology development and applications, JPL had management responsibility over a number of other "field" centers. These "field" centers which JPL directed as of January 1981, and their responsibilities, are shown in Table 7.[14] In addition to the centers listed in the table, the DOE Albuquerque and Oak Ridge Operations Offices and the Oak Ridge National Laboratory had management responsibility for a number of PV demonstration projects.[15]

Coordination

Private-sector research is usually characterized by duplication among firms. Government R&D typically assigns each contractor or

---

(P.L. 93-473, October 26, 1974) authorized a federal research, development, and demonstration program to commercialize solar energy and provided for these functions to be carried out by ERDA. These responsibilities were further amplified in the Federal Nonnuclear Energy Research and Development Act of 1974 (P.L. 93-577, December 31, 1974).

[13] U.S. Department of Energy (1981), p. 2-1.

[14] U.S. Department of Energy (1981), p. 2-4.

[15] U.S. Department of Energy (1984a), pp. 319-338.

Table 7
Field Centers Directed by JPL as of January 1981

FIELD CENTER	RESPONSIBILITY
Jet Propulsion Laboratory Pasadena, California	Low Cost Solar Array Collectors
Sandia National Laboratories Albuquerque, New Mexico	Systems Design Concentrator Collectors Subsystem Development Intermediate Load Center Applications
MIT Lincoln Laboratory Lexington, Massachusetts	Residential Applications
Aerospace Corporation El Segundo, California	Central Station
MIT Energy Laboratory Cambridge, Massachusetts	Mission and Policy Analysis
Brookhaven National Laboratory Upton, New York	Environmental Health and Safety Requirements
NASA Lewis Research Center Cleveland, Ohio	Remote Stand Alone Applications International Applications

laboratory a specific part of the project to avoid duplication of effort and battles over "turf." For example, in a standard defense contract, one contractor may get the engine contract, another the radar, etc. Because successful completion of all parts is required for success, the program is only as strong as its weakest link.

The PV program used the standard approach of assigning different responsibilities to each organization within a level. The Jet Propulsion Laboratory (JPL), the Solar Energy Research Institute (SERI), and Sandia National Laboratories (Sandia) were the most important centers. Each was assigned responsibility for one of the three major technical alternatives for PV--flat-plate single-crystal silicon (JPL), other materials (SERI), and concentrators (Sandia). Other field centers were assigned different responsibilities. In some cases their responsibilities were complementary. For example, Brookhaven's work on environmental effects complemented the JPL work on reducing the cost of flat-plate single-crystal arrays. In other cases, the tasks assigned to different organizations were substitutes. For example, although exotic materials, concentrators, and flat-plate single-crystal silicon were unique technically, they could potentially serve the same economic function. In either the complementary or competitive case, the element of coordination was that no other organization could undertake <u>technically</u> overlapping work.

<u>Competition</u>

The distinctive aspect of the PV program was that competition existed within the program. As noted above, different Level III organizations had responsibilities for competing technologies. Inevitably therefore the conflict had both a technological and institutional basis--not only was single-plate silicon competing with concentrators and exotic materials, but JPL was competing with Sandia and SERI. The competition was heightened by the fact that the competitive strength of these three technologies was roughly even.

Within each of these technologies, several technical alternatives were pursued. In flat-plate single-crystal silicon arrays, there were several ways to obtain the silicon material and to make the cells. For non-single-crystal silicon arrays, there were polycrystalline and amorphous silicon alternatives, as well as a variety of other materials and cell types. Within the concentrator approach, there were three primary alternatives: parabolic trough, linear point-focus Fresnel lens, and point-focus Fresnel lens.[16]

The program was designed to support multiple concepts in parallel during the initial R&D phases, and as each concept progressed, the menu of alternatives was to be gradually reduced.[17] This approach offered a number of advantages. First, it increased the probability of success. While the outcome of any one approach was uncertain, the chances of a favorable outcome from at least one approach was good as long as the probabilities of success were independent. Second, approaches (and the

---

[16] Maycock and Stirewalt (1985), p. 52.

[17] This approach was described as early as October 1973, the same month as the Cherry Hill conference on photovoltaics discussed above, by Lloyd Herwig, Director of Advanced Solar Energy Research and Technology, Research Applied to National Needs, National Science Foundation, who described the NSF R&D strategy as a "phased program planning approach." Herwig (1974), p. 11. Cited in Gates (1988).

firms undertaking them) would not be funded in later stages if early results were not encouraging. Thus there was a competitive spur to achieve good results. Third, because of budget constraints, pursuing multiple paths meant smaller projects and that smaller firms, groups or individuals could undertake specialized research on a single aspect of the problem.[18] The ability of small organizations to compete was also aided by the decentralized nature of the program, in which the effort was decomposed into numerous specific tasks. The result was that all, or most, research centers and firms in the industry could have a piece of the action, thus minimizing any distributive liabilities from the award process.

The latter point is particularly important because a potential political danger in a parallel contracting approach is that because the process was designed to develop "winners" and discontinue "losers," the losers in the process could have run to their Congressional allies, as happened in the communications satellite program,[19] to prevent the winners from reaping their rewards, one of which would be to alter the relative competitive position of firms in the industry. I did not find any evidence of challenged awards. One likely reason for this is that, unlike the satellite program, no single award was so large as to be pivotal. Another possibility is that new opportunities existed in the program

---

[18] Smith (1981), p. 1478.

[19] Cohen (forthcoming).

because it combined parallel and serial elements.[20]

The evidence regarding the number of contractors during various years of the PV program is interesting in this regard. The data do not show the declines that one might expect from a competitive program where losers are discontinued and which underwent sharp budget cuts (Table 8). There are several likely reasons for this. First, the losers from earlier years could be taking advantage of the new opportunities that were funded in later years. Second, since a number of firms had multiple PV contracts, the cutbacks in the number of contracts implied by the parallel approach would have less of an impact on the number of firms (only if all of a firm's contracts were discontinued would it drop off the list of firms). Third, the funding declines of the 1980s accompanied a shift from constructing production lines and demonstrations and toward basic research, and thus many of the contracts could be much smaller than earlier. Fourth, the data may be inaccurate.[21]

Criteria for Decisions

Decision criteria differ between private and government entities. Government decision makers have political objectives that play little or

---

[20] In an optimally run program, the extent to which alternatives should be pursued in parallel is a function of how much hurry there is to develop the technology. If one has plenty of time, the program should be tilted toward serial development, and conversely.

[21] I counted the number of "current contractors" listed in each year's program summary for the program. A few of these, perhaps 10-20 percent, are not currently receiving funds, but are finishing work that was funded in prior years. Another potential difficulty is that when funding for all contracts listed in the program summaries was totaled, the sums were less than PV spending in those years. Although discrepancies in funding totals probably result for other reasons, these discrepancies cast some doubt on the number of contractors data.

Table 8
Number of Current Contractors in Photovoltaic Program

Fiscal Year	Number of Contractors with Active Contracts
1976	41
1978	106
1979	156
1980	173
1981	176
1982	139
1983	131
1984	135
1985	141
1987	94

Source: Annual program summaries, i.e., Energy Research and Development Administration (1976), U.S. Department of Energy (1978b, 1978e, 1980a, 1981, 1982, 1983b, 1984a, 1985a, 1985d, 1988b) no role in the private sector, and are presumably less informed about the market implications of their activities. Government expenditures sometimes have "pork barrel" characteristics, i.e., funding decisions are made on a political basis, and the key political benefit results from government expenditures, not from whatever benefits flow from successful completion of the project.

Several factors limited pork barrel aspects in the PV R&D program. First, decisions on award of contracts to the private sector were made by the lead and field centers, not NSF, ERDA, or DOE headquarters. The decision makers in these field centers would be less politically attuned or subject to political influence than headquarters personnel and would be more technically competent. Second, in the SERI/JPL/Sandia case discussed above, the competitive nature of the technologies would lead decision makers in these centers to give significant weight to efficiency in decisions since the success of the technology could influence both the future funding of the lab and its prestige.

The program was noteworthy in the development of analytical tools, particularly at JPL, to guide decision making. As noted earlier, tasks were often broken into smaller, complementary pieces. For these subtasks, the program had to decide how to set reasonable goals for each task. It did this through an allocation of the overall module price goal to each of the subtasks, with "equal pain" for each.[22] To assess the progress of research toward these goals, the program developed the Solar Array Manufacturing Industry Costing Standards (SAMICS). Developed by 1978,

---

[22] See U.S. Department of Energy (1980d), pp. 2-30 through 41, for a description of this process.

this permitted a standardized method of cost comparison for different manufacturing processes.[23]

Nevertheless, the assignment of lead and field center responsibilities entirely to government labs may not have been appropriate. JPL, Sandia, and the Midwest Research Institute, which operates SERI, were experienced in government R&D, but not commercialization. Although JPL clearly had experience in the use of PV technology in space, application to terrestrial uses is different in several respects.[24] First, the space technology was designed for one user, the government, whereas adoption of the earth technology would require the separate decisions of many users, each with different circumstances. Second, the space applications were far more tolerant of cost overruns and/or changed economics. There was no substitute product on the shelf for space use that would be used if space PV turned out to be somewhat more costly than anticipated. If the devices worked technically, the project was a success. For earth use, the technology would be successful only if users decided that the new technology had economic advantages over a wide array of alternatives.[25] For these reasons, some use of private firms as lead and/or field centers might have been wise.

---

[23] Callaghan, Henry, and McGuire (1985) describe some of the ways the SAMICS model was employed.

[24] Landsberg (1979), pp. 42-43.

[25] The concept of success for PV will be discussed at greater length at the end of this chapter.

NON-R&D APPROACHES TO COST REDUCTION

The photovoltaics program always has been primarily a research and development effort aimed at bringing down the costs of photovoltaics. A number of different approaches were possible, each with accompanying advantages and disadvantages. The strategy emphasized improving the existing technology (flat-plate single-crystal silicon) while funding longer-term alternative approaches involving other materials and concentrators. In addition to this parallelism among basic approaches, parallelism existed at lower levels, with the funding of multiple options within any one technology.

In addition to this "supply-side" focus, there have been three significant efforts on the demand side: government procurement, utility restrictions, and tax credits. Table 9 summarizes the chronology of these actions.

Government Procurement

The most important issue in the photovoltaic program in the 1970s was the appropriate mix between procurement vs. research and development to achieve cost reductions. ERDA in 1976 had envisioned a program of government purchases as an important means to achieve cost reductions.

There were two reasons advanced for cost reduction through government purchases: economies of scale and the learning curve. The economies of scale argument was that government purchases would provide the industry with a large initial market and thus solar-cell manufacturers would have an incentive to use more automated, lower-cost production techniques.

Table 9
Chronological Summary of Demand Stimulus
Measures Applying to Photovoltaics

Date	Action
Sept. 1977	House approves Tsongas amendment authorizing $28 million for federal purchase of PV systems
Oct. 1977	House approves Tsongas amendment appropriating $12.2 million for federal purchase of PV systems
Feb. 1978	DOE Act of 1978 authorizes $13 million for purchase of cost-effective PV for federal facilities
Nov. 1978	National Energy Act signed into law in 5 Acts.
	--The National Energy Conservation Policy Act authorized $98 million over FY 1979-81 for federal PV purchases
	--The Energy Tax Act of 1978 established a 10 percent business credit which applied to PV; it established a residential tax credit which did not
	--The Powerplant and Industrial Fuel Use Act of 1978 limited oil and gas use in electric utilities.
	--The Public Utility Regulatory Policies Act of 1978 required utilities to buy power from cogenerators and small producers (such at PV) at avoided cost
April 1980	The Crude Oil Windfall Profit Tax of 1980 enacted which
	--raised the residential tax credit to 40 percent of the first $10,000 and applied the credit to PV
	--raised the business tax credit to 15 percent and extended the credit for 3 years
Dec. 1985	Tax credits expire
Oct. 1986	Tax Reform Act of 1986 restores business credits at 15 percent in 86, 12 percent in 1987, and 10 percent in 1988
Nov. 1988	Technical Corrections and Revenue Act of 1988 extends 10 percent credit through 1989

However, the principal argument made for government purchases was the "learning curve" in other technologies, particularly semiconductors, in which unit production costs decline with cumulative firm or industry production. Since semiconductors operate on the same principle as photovoltaic cells, the sharp declines in costs due to learning in semiconductors gave rise to optimism about the cost reductions that would result from government purchases in PV. Furthermore, without government purchases, these cost reductions might happen very slowly because of a lack of intermediate markets with costs between those of remote uses and central-station or residential use. Thus photovoltaic production might be locked in at low levels in the absence of government purchases.

Government procurement plans expanded during the late 1970s. In 1976, ERDA anticipated that purchases by government agencies would reach a cumulative total of 11 MW by FY 1983.[26] In September 1977, Congress adopted an amendment by Representative Paul Tsongas (D. Mass) to authorize $28 million for federal purchases of photovoltaic systems and $10 million for technological development. In October, a Tsongas amendment to appropriate funds for these photovoltaic, wind-energy, and education programs was approved. However, the amounts had been reduced below the level in the authorizing amendment. Only $19 million would be spent on photovoltaics (half the authorized amount) of which $12.2 million would be for government procurement (44 percent of the amount authorized).

The procurement program received additional impetus from two 1978 laws. Section 208 of the Department of Energy Act of 1978 (P.L.95-238, February 25, 1978) authorized $13 million in FY 1978 to purchase

---

[26] U.S. Energy Research and Development Administration (1976), p. 2.

photovoltaic systems for use by Federal agencies in applications that were cost-effective on the basis of life-cycle costs.[27] The National Energy Conservation Policy Act (P.L. 95-619, November 9, 1978) expanded this program. Title 5, Part 4 of this Act established the Federal Photovoltaic Utilization Program (FPUP). This program required the Department of Energy to stimulate photovoltaic energy commercialization though accelerated procurement and installation of photovoltaic solar electric systems. The Act authorized $98 million over a three-year period from October 1, 1978, to September 30, 1981 (FY 79-81) for this purpose.

DOE was required to schedule this procurement to "stimulate the early development of a permanent low-cost private photovoltaic production facility in the United States, and to stimulate the private sector market for photovoltaic power systems."[28] The scheduling requirement was no doubt a response to the argument of opponents that procurement ran the risk of freezing current technology by creating large surges in demand that would result in capacity expansion of the existing technology. Once in place, this capacity would retard the development and introduction of new technology.[29]

Opponents of procurement also argued that the analogy to semiconductors was misleading. Cost reductions in semiconductors had

---

[27] U.S. Department of Energy (1980f), p. 65.

[28] P.L. 95-619, section 565, 567.

[29] On the other hand, one could argue that limited encouragement of manufacturers to expand capacity to serve existing markets or create new ones through lower costs, might be appropriate. Roessner (1982) reports that PV industry officials claimed that investments in plant capacity were not being made because of the fear that if the rapid price reduction goals of the PV R&D program were met, the capacity would rapidly become obsolete.

resulted largely from making things smaller (reducing material requirements) whereas this was not possible in photovoltaics because the output of a photovoltaic cell was proportional to its surface area and its efficiency. Although efficiency gains were possible, thus permitting smaller cells, the theoretical maximum improvement in efficiency was about a factor of three, rather than the orders of magnitude experienced in semiconductors.

Although the proponents of procurement had prevailed in the authorization process in the Congress, the going was more difficult elsewhere. In January, 1979, the American Physical Society released an influential report on photovoltaics which argued that "efforts to stimulate a large-scale, low-cost industry are premature."[30] Appropriations for FPUP were far less than the $98 million authorized. Through FY 1981, purchases of approximately 600 peak kilowatts had been funded under FPUP.[31]

In the 1980s, the Administration sought to eliminate demonstrations, in keeping with its overall philosophy about government support of R&D. This effort was not completely successful. In the 1986 appropriation, Congress earmarked $2 million for the Austin, Texas, residential experimental station and $1 million for the Massachusetts Photovoltaic Center.[32] Far more has been spent recently on central-station projects. In keeping with the program's emphasis on central-station applications since 1983, the primary focus of recent demonstrations has been on

---

[30] American Physical Society (1979), p. 16.

[31] U.S. Department of Energy (1982), p. 1-16.

[32] U.S. House of Representatives (1985), p. 40.

central-station applications. Millions of federal dollars were spent during the Reagan Administration on the SMUD project (originally planned to be 100 MW), the Georgetown University 300 KW National Exemplar, and most recently on the PVUSA project ($4 million in 1987 and $4 million in 1988 for PVUSA). Although the Georgetown project is an on-site use, its large scale and long horizon distinguish it from residential applications.

Despite incomplete implementation of the FPUP program, approximately $121 million in current dollars has been spent to date on federal purchases of PV systems.[33] This represents approximately 12 percent of the total 1971-1989 appropriations of $973 million. Assuming that R&D is a more effective way to reduce costs than procurement, the 12 percent figure is clearly too large for an optimally run PV program. Demonstrations, when required to learn about the technology, can be inexpensive because of the modularity of PV systems. However, given the experience in other programs, the 12 percent figure may have been a reasonable price to pay for Congressional support of an R&D program. PV manufacturers strongly supported government procurement programs, and objected at times to the bulk of the PV money going to research firms.

The major federally supported PV projects (Table 10) reveal three features of the demonstration program. First, most of the projects were uneconomic. Only the remote projects (Mt. Laguna, Natural Bridges, and the Papago Indian village) could possibly be justified economically. Second, only two central-station utility projects received direct federal

---

[33] Personal communication, Andrew Krantz, Department of Energy for non-PVUSA expenditures. PVUSA from Conference Report to accompany H.J. Res. 395, Continuing Appropriations FY 1988, December 22, 1987, p. 751.

Table 10
Major PV Projects Receiving Federal Funds

Contractor	Location	Application	Size (Peak kW)
PVUSA	Davis, CA	Utility	?
Sacramento Municipal Utility District	Sacramento, CA	Utility	1000
Georgetown University International Center	Washington, DC	University building	300
Mississippi County Community College	Blytheville, AR	College	250
Arizona Public Service	Phoenix, AZ	Airport	225
Science Applications	Oklahoma City, OK	Science and art center	150
Lea County Electric Cooperative	Lovington, NM	Shopping center	100
Solar Power Corp.	Beverly, MA	High school	100
Natural Bridges National Monument	Utah	National Monument community	100
Acurex	Kauai, HI	Hospital	60
Mt. Laguna Air Force Base	Mt. Laguna, CA	Radar station	60
BDM	Albuquerque, NM	Office building	47
E-Systems	Dallas, TX	Airport	27
	Mead, NE	Agricultural test facility	25
AM Radio Station	Bryan, Ohio	AM Radio Station	25
New Mexico State	El Paso, TX	Computer at power station	20
Papago Indian village	Schuchuli, AZ	Indian village	3.5
MIT Energy Laboratory	Concord, MA	Northeast Residential Experimental Station	

Table 10 (cont.)

Florida Solar Energy Center	Cape Canaveral, FL	Southeast Residential Experimental Station
New Mexico Solar Energy Institute	Las Cruces, NM	Southwest Residential Experimental Station

Source: Maycock and Stirewalt (1985) except for PVUSA project. List does not include Northwest Mississippi Junior College, a $6.6 million project in Arkansas never completed due to fraud.

assistance. (However these have been two of the largest and the most recent.) All other projects were for intermediate-load-center and residential applications. Third, the projects were geographically dispersed.

Utility Restrictions

Demand for photovoltaics was stimulated through numerous restrictions on conventional power faced by utilities. Fossil fuel use was restricted in a variety of ways.

1) Clean Air Act restrictions, which could be satisfied through scrubbers or low-sulfur coal or oil, increased the cost of coal and oil generation relative to solar technologies whose costs were unaffected because they do not emit pollutants.

2) Direct restrictions on the use of petroleum and natural gas in utilities were adopted. This was first done in 1974 in the Energy Supply and Environmental Coordination Act of 1974 (P.L. 93-319, June 22, 1974), which gave the Federal Energy Administration authority to mandate conversions from oil or gas to coal for utilities that had coal-burning capabilities. Since ESECA mandated switching to coal, no boost was given to solar. The Powerplant and Industrial Fuel Use Act of 1978 (P.L. 95-620, November 9, 1978) restricted oil or gas use in all electric utilities, but without specifying the alternative technology to be used (thus coal or nuclear, as well as renewable technologies, could be used).

3) The Railroad Revitalization and Regulatory Reform Act of 1976 threatened to increase the cost of coal rail transportation (particularly important due to the importance of low-sulfur western coal in meeting

environmental restrictions). Similarly, the Surface Mining Control and Reclamation Act of 1977 could increase the cost of strip-mined coal.

The other major conventional alternative, nuclear, was beset with a variety of problems. Both coal and nuclear plants faced long licensing and construction times, a problem which was heightened by the fact that many states restricted the inclusion of construction work in progress (CWIP) in the rate base.[34]

All of the above provided indirect support for photovoltaics. More direct support was provided by requirements that utilities purchase power from cogenerators or small generators. Section 210 of the Public Utility Regulatory Policies Act of 1978 (P.L. 95-617, November 9, 1978) required electric utilities to purchase power from cogeneration and small power production facilities at "avoided cost," the cost to the electric utility of the electric energy which, but for the purchase of the power from the cogenerator or small power producer, such utility would generate or purchase from another source. The "avoided cost" provision of PURPA has generally been viewed as a stimulus to these alternative power sources.

Tax Credits

In addition to trying to lower the cost of photovoltaics through research and development, federal procurement, and restrictions on electric utilities, the federal government subsidized the private procurement of photovoltaic systems through tax credits and accelerated depreciation for the purchase of photovoltaic systems. Credits were first

---

[34] The relevance of coal transportation, coal strip mining, long licensing lead times for coal and nuclear, and financing is from U.S. Department of Energy (1980h), Section 2.4.1.

enacted in the Energy Tax Act of 1978 (P.L. 95-618, November 9, 1978), expanded in the Crude Oil Windfall Profit Tax Act of 1980 (P.L. 96-223, April 2, 1980), restored in the Tax Reform Act of 1986 (P.L. 99-514, October 22, 1986), and extended in the Technical Corrections and Revenue Act of 1988 (P.L. 100-647, November 10, 1988). Provisions were not enacted solely for PV, but included other renewable technologies. The credits for individuals have been different from those of corporations, and eligible technologies and amount of the credit have changed over time.

The credits for PV in the Energy Tax Act of 1978 were limited in two important respects. First, the residential credit[35] did not apply to equipment which generated electricity, such as PV. Second, eligibility for the business tax credit[36] did not extend to public utilities,[37] state

---

[35] The credit was for renewable energy source expenditures made in the principal residence of a taxpayer after April 20, 1977, and before January 1, 1986. Taxpayers were entitled to a nonrefundable credit of 30 percent of the first $2000 in expenditures and 20 percent of expenditures of the next $8000, for a maximum total credit of $2200. The credit applied to solar and geothermal energy used to heat, cool, or provide hot water to the dwelling, or to wind energy for residential purposes.

[36] The Act provided a 10-percent refundable energy credit (in addition to the permanent investment tax credit) for business equipment which used solar or wind energy to generate electricity or to provide heating, cooling, or hot water in a structure. The credit was to apply to investment made between October 1, 1978 and December 31, 1982. See U.S. Department of Energy (1980f), p. 296.

[37] Although public utilities are still excluded from the credit by subsequent legislation, central-station activities have received the credit through "third-party" owners, who are neither the supplier/manufacturer of the systems nor the buyers or consumers of the electricity produced. Solar companies have built plants and sold them to parent companies, which then sold the power to electric utilities. In another mechanism, the business credits were marketed to individuals as a tax shelter by United Energy Corporation of Foster City, California. Several megawatt systems were to consist of 2.5 kilowatt modules with each module owned by a specific investor, with the electric power to be sold to electric utilities. See U.S. General Accounting Office (1983), p. 1, and Maycock and Stirewalt (1985), pp. 193-196.

and local governments, most tax-exempt organizations, and holders of federal grants.[38]

The Crude Oil Windfall Profit Tax Act of 1980 expanded the PV credits in several ways. First, the residential credit now applied to electricity generation. Second, the restriction in the 1978 Act that components which served a dual purpose (structural and energy-related) were not eligible for the credit, was eliminated for the residential credit but retained for the business credit.[39] Third, the amount of the credit was increased--the residential credit was increased to 40 percent of the first $10,000 in expenditures and the business credit was increased to 15 percent. Fourth, the business credits were extended until the end of 1985, which was the expiration date of the residential credits as provided for in the 1978 Act.

The Tax Equity and Fiscal Responsibility Act (TEFRA) of 1982 (P.L. 97-248, September 3, 1982), effectively reduced the value of the business energy tax credit by 20 percent. The "basis adjustment" provision in this Act required businesses to reduce the tax basis (and hence allowable

---

Although Maycock and Stirewalt do not explain the reason for the sale to parents, two reasons occur to me. The most likely reason is that the 1980 Act (discussed below) repealed the refundable nature of the business credits under the 1978 Act. Friedmann and Mayer (1980), p. 499. Thus the sale might increase the net present value of the credit, either by providing income from the sale so that the full credit could be taken right away by the subsidiary, or perhaps by allowing the parent to utilize the credit. Another possibility is that if the parent could utilize the credit, the amount of the credit might be determined by the sale amount, which might be larger than the investment made by the subsidiary.

[38] Internal Revenue Code Sections 48(1)(3)(B) and 46(f)(5) and Friedmann and Mayer (1980).

[39] This rule meant that solar panels installed as a roof were not eligible. See Friedmann and Mayer (1980).

depreciation) of any asset acquired after 1982 by half the amount of any energy, investment, or rehabilitation tax credits claimed with respect to the asset.[40]

Efforts to extend the energy tax credits beyond 1985 began in late 1982 but did not succeed till the passage of the mammoth Tax Reform Act of 1986 in October 1986. Although DOE supported extension, Treasury was opposed.[41] Although credits were eventually extended for three more years (two in the case of biofuels), three limitations were adopted. First, the level of the credit was reduced over time from 1986 to 1988 for biofuels, geothermal, PV, and solar thermal (for PV, 15 percent for 1986, 12 percent for 1987, and 10 percent for 1988). Only ocean thermal remained constant at 15 percent. Second, the residential credits and all wind credits were not extended. The wind credits had attracted considerable attention as

---

[40] Moore (1985), p. 19, Code Section 48 (q).

[41] The Treasury position is described in the statement of J. Gregory Ballentine, Deputy Assistant Secretary (Tax Analysis), Hearings on S. 1396 before the Subcommittee on Energy and Agricultural Taxation of the Senate Committee on Finance, June 17, 1983, pp. 17-23. He states,

> In 1978, at the time the energy tax incentives were enacted, price controls and supply allocations were in effect on both crude oil and natural gas and there was substantial resistance to decontrol. Because of price controls, business firms had insufficient incentive to invest in alternative energy sources. Therefore, in the absence of free market prices, an economic rationale existed for energy tax incentives. However, since the enactment of the energy credits, crude oil prices have been decontrolled and natural gas prices are being decontrolled and are approaching, and in some cases exceeding, free market levels. As a result, the tax credits, whatever their original justification, are no longer needed.

Reprinted in Moore (1985), p. 53.

a tax shelter.[42] Third, the affirmative commitment rule of prior law (allows business credit through 1990 if certain steps are taken by certain date) was not provided for in the extension.[43]

Due to expire at the end of 1988, the solar, geothermal, and ocean thermal credits were extended at their 1988 levels in November 1988 for another year by the Technical Corrections and Revenue Act of 1988.[44]

Although the tax credits have received the most attention, other provisions of the Tax Code benefit solar energy. An analysis by the Congressional Research Service (Lazzari and Gravelle (1984)) indicated that the effective tax rates for solar and wind property without the business energy tax credit were still lower than the effective rates for oil, gas, and coal extraction and refining and were much lower than the rates for conventional electric and gas utilities. According to this analysis, these differences arise from the difference in treatment in the Tax Code between equipment and structures and the differing proportion of equipment/structure in these industries. Investment in equipment can be depreciated over 5 years and receives a 10-percent investment credit whereas investment in structures is recovered over 15 years and receives no investment credit. Electric and gas utilities use relatively more structures than oil, gas, and coal extraction and refining, with wind and

---

[42] "Dear Colleague" from Representative Pete Stark; Letter to editor of Sun Up (Energy News Digest) from Rep. Stark, October 1984; DeMott, John S. "Of Windmills, Cattle and Form 1040," Time, March 19, 1984, p. 48; Paris, Ellen "The Great Windmill Tax Dodge," Forbes, March 12, 1984, pp. 39-40; all reprinted in Moore (1985).

[43] This paragraph is based on Moore (1985) and Sissine (1988).

[44] Special Analysis G, The Budget for Fiscal Year 1990, January 1989.

active solar assets using fewer still.[45] Another provision of the Tax Code benefiting solar and wind energy property is that the at-risk limitation for the regular and business energy investment is less stringent than the rules for the regular investment tax credit for ordinary equipment.[46]

In addition to the federal provisions, 28 states had income-tax incentives for solar in 1983. Except in California, New York, and Massachusetts (credits of 55, 55, and 35 percent, respectively), all the state credits could be added to the federal credit. California limited residential credits to $3000, with no limit for commercial. In New York and Massachusetts, only residential was eligible for credits with limits of $2750 and $1000, respectively. In 1983, California reduced the credit to 50 percent and extended it through 1986, with the maximum credit unchanged.[47]

To the best of my knowledge, no data or estimates exist for the dollar cost to the Treasury of the PV credits.[48] However, an order of magnitude and pattern over time can be inferred by examining estimates for

---

[45] Although Section 168(e)(3)(B)(vi)(I) and paragraph 4 of Section 48(l) of the current Internal Revenue Code explicitly provide for 5-year solar depreciation, and Section 168 was completely revised by Section 201(a) of the Tax Reform Act of 1986, and the pre-1986 Section 168 did not mention solar energy, the discussion of 5-year solar depreciation in Lazzari and Gravelle (1984) and Maycock and Stirewalt (1985) clearly indicates that this provision existed prior to 1986.

[46] Lazzari and Gravelle (1984), p. 25.

[47] Godolphin (1983).

[48] This paragraph is based on my examination of the published data I describe, as well as phone conversations with individuals in the Departments of Energy and Treasury, the Internal Revenue Service, and the Joint Tax Committee.

larger aggregates. The cost of tax expenditures is estimated in the special analysis of tax expenditures that annually accompanies the President's budget (see Table 11). As shown in the table, this information is only provided for "supply incentives" and "conservation incentives" for the "residential energy credit" and "alternative, conservation, and new technology credits." PV credits would appear only in the "supply incentives" portion of both.

It is instructive to compare the magnitude of these tax expenditures with direct outlays on renewable energy. The estimated total revenue loss from these "supply incentives" to date (FY 79-90) is $3.81 billion in current dollars. If the FY 79-90 tax expenditures were measured on an outlay equivalent basis (see description in table), they would likely exceed the total current dollar outlay for renewables for FY 73-87 of approximately $4.5 billion.[49] Aside from the obvious implication that total federal "spending" on renewables is approximately twice the outlay number, the magnitude of the tax expenditures means that for renewable programs as a whole, probably at least half of total federal "spending" went for procurement, since the renewable tax credits went entirely for procurement.[50]

For both of these reasons, to determine total "spending" and the relative emphasis between procurement and R&D, it would be desirable to have estimates of PV tax expenditures. Unfortunately, no precise estimates are available. What can be inferred is described below.

---

[49] Outlay figures are from Table 2 in Sissine (1988).

[50] This calculation ignores research and development tax credits and other features of the tax code that are not specific to renewables.

Table 11

Revenue Loss Estimates for Primary Renewable Energy Tax Credits, 1979-90
(millions of current year dollars)

	FISCAL YEAR											
	79	80	81	82	83	84	85	86	87	88	89	90
Residential Energy Credit												
Supply incentives												
Corporations	-	-	-	-	-	-	-	-	-	-	-	-
Individuals	75[a]	55	150	250	325	325	330	315	45	5	-	-
Conservation incentives												
Corporations	-	-	-	-	-	-	-	-	-	-	-	-
Individuals	570[a]	430	425	360	285	270	245	190	*	*	-	-
Alternative, conservation, and new technology credits:												
Supply incentives												
Corporations	100[a]	140	180	205	215	195	175	265	140	80	30	20
Individuals	*	10	b	b	35	25	95	15	10	-	-	-
Conservation incentives												
Corporations	120[a]	190	220	220	45	10	*	*	*	*	*	*
Individuals	*	-	b	b	5	*	*	-	-	-	-	-
Supply Total	175	205	330	455	575	545	600	595	195	85	30	20
Grand Total	865	825	975	1035	910	825	845	785	195	85	30	20

Supply Total (FY 79-90) 3.81 billion; Grand Total 7.40 billion

Footnotes:

a Residential credit of 645 and alternative of 220 not broken out between supply and conservation in special analysis; 1980 ratio used
b Corporate/individual split not available; shown here in corporate
* Less than 2.5 or 5.0 million, depending on year

Source: Annual (FY 81-90) Special Analysis chapter on tax expenditures.

Note: Residential credits expired December 31, 1985. However, FY 86 began October 1, 1985 and unused credits can be carried over to two subsequent taxable years. Moore (1985), p. 39. Beginning with the FY 1983 budget, tax expenditures have been estimated in terms of "revenue losses" and taxable "outlay equivalents." I have used revenue losses in order to provide a consistent series for the 1979-1990 period. Outlay equivalents permit a comparison of the cost of tax expenditure programs with other Federal government expenditures, which are pre-tax magnitudes. Outlay equivalents are often larger than revenue losses (e.g., for 87, total above would be 240). These differences can arise for two reasons. The first, where the tax provision is equivalent to a tax-free grant, does not apply here because the grant is contingent on individuals' consumption decisions, and thus operates as a price reduction, not an increase in the individuals' taxable income. The second is where revenue losses are partially offset by the loss of a tax benefit. Special Analysis G, The Budget for Fiscal Year 1989.

Although no figures are available, one would expect the supply portions of the tax expenditures shown in Table 11 to be dominated by non-PV credits. This conclusion is supported by the data on renewable power facility filings with the Federal Energy Regulatory Commission (Table 12). The largest category, biofuels, was eligible for business credits from September 30, 1978, until the end of 1985.[51] The second largest, small hydro, was made eligible for business credits by the Crude Oil Windfall Profit Tax Act of 1980, with the credit available for 1980 through 1985.[52] The third largest, geothermal, was eligible for residential credits from September 30, 1978, until December 31, 1985, and for business credits from September 30, 1978, through the end of 1989. The fourth largest, wind, was eligible for residential and business credits from September 30, 1978, until December 31, 1985. The fifth largest, solar, includes solar thermal, which has received the same treatment as PV.

In addition to the power generation sources shown in the FERC filings, the tax-credit figures in the "supply incentive" include ocean thermal, cogeneration, and solar heating and cooling. All of this suggests that the PV portion of the estimated $3.81 billion in "supply incentive" tax credits may be relatively small. On the other hand, data from a recent court case suggest that the PV amounts are not inconsequential. Forty-four hundred investors invested a total of $200 million in the United Energy Corporation scheme discussed above. However,

---

[51] This paragraph relies on Friedmann and Mayer (1980), Sissine (1988), and the Conference Report, Crude Oil Windfall Profit Tax Act of 1980, House Report 96-817, March 7, 1980.

[52] The credit was also available for the years 1986-1988 if the application for the project was docketed by the Federal Energy Regulatory Commission before January 1, 1986. Conference Report, pp. 126-128.

Table 12
Renewable Power Facility Filings
(fiscal year, in megawatts)

	80	81	82	83	84	85	86	87	TOTALS
Biofuels	0	284	420	540	708	1,078	1,849	1,107	5,986
Geothermal	76	80	74	119	168	164	1,327	138	2,146
Small Hydro	108	39	62	397	372	305	177	106	3,163
Solar	0	0	0	92	94	42	62	30	320
Wind	76	24	127	325	270	60	298	212	1,936
Totals	260	427	683	1,473	1,612	2,193	5,310	1,593	13,551

Note: These filings are designed to represent year-by-year additions to capacity. However, recent figures suggest that actual installed capacity is substantially lower than suggested by these data. For example, solar installations are currently about 155 MW and wind about 1430 MW.

Source: Sissine (1988, p. CRS-6).

many of the modules were never built, in 1985 the company filed for bankruptcy, and in 1987 a U.S. District court ruled that United Energy was an abusive tax shelter that defrauded the government and the public. The estimated tax loss from this fraud was $90 million.[53]

The difficulty in determining PV credits from Special Analysis estimates occurs in other sources as well. Information on these credits is broken out by income class for individuals and SIC code and size of assets for businesses in the Department of the Treasury's Statistics of Income. Here, as in the annual Special Analysis, the PV credit, for both residential and business, is published only as part of a larger aggregate. For the residential credit, the SOI reporting unit is "residential energy credit." This includes conservation credits as well as "renewable energy source" expenditures. Business energy tax credits are not published in SOI data, but instead are reported in investment tax credits as a whole. In both of these cases, PV is likely to be a small portion of the aggregate, and year-to-year changes in the aggregate cannot be attributed to PV.

In fact, the data problem is more fundamental than Treasury reporting. The tax forms themselves generally do not request that the taxpayer identify the specific technology (such as PV) when claiming a credit, and thus Treasury has no way of knowing the cost of PV credits.

For these reasons, a precise estimate of PV tax expenditures is not available. If the tax loss in United Energy was $90 million, then

---

[53] The Justice Department charged that United Energy ran a Ponzi scheme in which money from new investors was used to pay off previous investors. Wall Street Journal, June 16, 1986, pp. 1, 9; March 5, 1987, p. 43 (Eastern edition).

spending on PV procurement through the tax system likely exceeds the direct federal spending of approximately $121 million on PV procurement. However, because solar heating and cooling use has been greater than PV use, and because of the FERC filing statistics cited earlier, it seems highly unlikely that the PV tax expenditures approach the level of direct outlays, as is the case with renewables as a whole, and thus the program as a whole is still predominantly a research and development program.

ECONOMIC ASSESSMENTS

The economic assessment of photovoltaics changed over the life of the program. Economic assessments throughout the 1970s were generally optimistic, whereas the assessments in the 1980s have become more pessimistic. Accompanying this change has been a decrease in the variance of the assessments.

The precise reasons for changes in assessments are not generally clear for three reasons. First, changes in the economic assessment have occurred due to changes both in assumed values of variables and the methodology for incorporating these variables into the economic assessment. Second, most economic assessments of PV never discuss previous economic assessments. Finally, poor documentation, particularly in the early studies, makes comparison difficult.

This section interprets the assessments during the life of the program in terms of a common conceptual framework. This framework is not taken from any particular study; most of the studies discussed below in fact only use parts of the it. In this framework, a PV economic assessment consists of a number of separate steps: (1) module cost; (2)

system configuration; (3) cost of electricity resulting from this module cost and system configuration; and (4) economic value of PV electricity at this cost.

Module Cost

Module costs in the photovoltaics program have most often been expressed in terms of cents per peak watt. This measure of costs refers to the costs of a PV module in relation to its electrical output under ideal, standardized insolation and weather conditions. Module costs are to be distinguished from system costs, which equal the sum of module costs and "balance of system" costs (e.g., costs of land, support structure, and power conditioning, as well as of batteries for systems not connected to grid power). System costs also have generally been expressed in terms of dollars per peak watt.

The primary emphasis of the program has always been on reducing module costs. Module and balance-of-system costs contribute to system costs in a symmetric fashion, and balance-of-system costs were often estimated to be perhaps 50 percent of system costs. Nevertheless, balance of system costs were viewed as dictated largely by the technology of a mature industry, the construction industry. Consequently, research and development was unlikely to significantly reduce balance-of-system costs.

The PV program always has set goals for the price of modules. These price goals were not expressed as projections or expectations. Congressional testimony or reports sometimes contain qualitative, but never quantitative, statements about the likelihood of attaining these goals. The purpose of the goals was both to set a target for cost reduction and to establish a criterion to be used in judging the progress of the program.

Evolution of Price Goals

The photovoltaics program has operated under two different approaches to formulating module price goals. The first approach chose a module price goal, and then derived the energy cost resulting from this module price. The second approach chose an energy cost, and then derived the module price necessary to produce electricity at the desired cost. The program used the former approach from 1973 to 1979, and the latter approach after 1983. From 1979-1983, the program used a combination of the two approaches. The former approach sets goals in terms of technical possibilities and challenges whereas the latter stresses economic competitiveness and tradeoffs among the variables that affect the energy cost of PV.

The former approach was first used in October 1973 at the Cherry Hill conference, which adopted the goals of 50 cents per peak watt for a single-crystal silicon cell by 1985 and 10 cents per peak watt by the year 2000.[54]

The foundation for these numbers is unknown; however the conference report states:

> Estimates of commercially acceptable prices for arrays have varied from <$0.50/peak W to $0.10/peak W not only because the impacts of the other cost factors, such as land, supporting structure, and maintenance, are difficult to define quantitatively but also because the basis for comparison, the extrapolations of the prices of electricity generated by other

---

[54] 50 cents by 1985 was deemed to be achievable with a suitable development program and 10 cents by 2000 was viewed as possible. Jet Propulsion Laboratory (1974b), p. 1.

> means, are uncertain. Nevertheless, array cost elements have been used as objectives for development programs and as a means for formulating the tasks, milestones, and budgets for these programs. Hence, the economic validity of the utilization of photovoltaic electric power plants rests on the assumption of the range of competitive prices for arrays. . .[55]

The Cherry Hill goals were altered only in minor ways as the scale-up of the federal program proceeded. In June 1974, JPL developed a program plan for a Low Cost Silicon Solar Array Program whose primary goal was "to develop the technological and industrial capability for producing more than 500 MW of single crystal silicon solar photovoltaic arrays per year at a cost of less than $0.50 per peak Watt by 1984."[56] In November 1974, the Solar Energy Task Force Report of Project Independence, prepared under the direction of NSF, proposed an implementation schedule of 50 cents per peak watt in 1985 and 10 cents per peak watt in 1995.[57] After the program was transferred to ERDA, the year of attainment of the 50-cent goal was pushed back to 1986.[58]

The first National Photovoltaics Program Plan was issued in March 1978, and it separated the module price goals into near term (1982), midterm (1985), and far term (1990) goals. It retained the goal of 50 cents per peak watt in 1986, and added the goals of $2 per peak watt in

---

[55] Jet Propulsion Laboratory (1974b), pp. 3-4.

[56] Jet Propulsion Laboratory (1974a), p. 1-1.

[57] U.S. Federal Energy Administration (1974), p. VII-15.

[58] U.S. Energy Research and Development Administration (1976), p. 1. The reason for the change in the year of the goal from the Cherry Hill conference (1973), to the Solar Energy Task Force (1984), to the JPL plan (1984), and finally to the ERDA Program Summary (1986), is not apparent. It may reflect the distinction between a developing of a manufacturing capability in 1984 vs. actual selling prices in 1986, but this is speculation.

1982 and 10 to 30 cents per peak watt in 1990. These goals were specified in 1975$ whereas earlier goal statements had not specified which year dollars were being assumed.[59] Meanwhile, Congress entered the goal-setting process, and shifted the focus to system prices. Section 2 of the Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978 (P.L. 95-590, November 4, 1978) provided that the purpose of the research, development, and demonstration program established by the act would be "to reduce the average cost of installed solar photovoltaic energy systems to $1 per peak watt by fiscal year 1988." Instead of adopting a set of goals for a single year as provided for in the Act, the program documents continued to provide different goals for different years (1982, 1986, and 1990) as provided in the 1978 Program Plan. However, consistent with the Act's emphasis on system prices, the goals were now stated for both arrays and the entire system. The array goals were (all in 1980$)[60] $2.80 per peak watt in 1982, $0.70 in 1986, and $0.15 to $0.40 in 1990. The system goals were $6-13 per watt peak in 1982, $1.60-2.60 in 1986, and $1.10 to 1.30 in 1990.[61]

---

[59] U.S. Department of Energy (1978a), pp. 5, 7.

[60] During 1979, the program recalculated goals in 1980 dollars, which raised the module goal from $0.50 to $0.70 per peak watt and the system goal from $1 to $1.40 per peak watt. U.S. Department of Energy (1980e, Vol. I, p. ES-12; Volume II, p. 12-5). Final data show a 41.3 percent increase in the Gross National Produce Implicit Price Deflator from 1975 to 1980. Economic Report of the President, U.S. Government Printing Office, February 1982.

[61] Program documents in 1979-1980 contain different versions of these goals. Some omit a 1982 goal--e.g., U.S. Department of Energy (1980c), p. 4-4; (1980e), Vol. I, p. ES-12, and Smith (1980b), Vol. 1, pp. 26-27. These three documents also state the 1986 goal as a point estimate (1.60). Finally, the 1990 central station goal appears to have soon been changed to 1.10-1.80. 1.30 is used in Smith (1980b), Vol. 1, p. 27, citing U.S. Department of Energy (1979a), p. 2-3. 1.30 is also used in U.S. Department of Energy (1980c), p. 4-4. 1.80 is used in U.S. Department of

An interesting feature of these new goals was that, for the first time, goals for a particular year were keyed to particular applications: remote in 1982, distributed (grid-connected) in 1986, and central-station in 1990. In addition, the goals were designed to satisfy two constraints simultaneously: the level of prices necessary to compete with conventional sources, and the extent of PV cost reduction believed to be possible.[62] Thus the program operated under the same module price goal enunciated at Cherry Hill and a system price goal, believed to be consistent with the module goal and derived partly from considerations of competitiveness. The 1979-1983 period thus represents a transition between the technological "what is possible to achieve" approach and the cost competitiveness approach.

In 1983, the program goals appeared to become driven entirely by cost competiveness. In the Five Year Research Plan issued in May 1983, the program adopted 15 cents per kilowatt hour (1982$) as a long-term goal for photovoltaic power, based on work done by Roger Taylor of the Electric Power Research Institute.[63] Starting from this energy cost goal, the Five Year Plan derived goals that related module cost targets to conversion efficiency. Modules achieving 13-percent conversion efficiency must cost no more than $40 per square meter, and modules achieving 17-percent efficiency must cost no more than $75 per square meter.[64]

Energy (1980a), p. 9; (1980b), p. 3; (1980d), p. 1-5; and (1981), p. 2-8.

[62] Smith (1980a), pp. 104-105.

[63] U.S. Department of Energy (1983a), pp. 28-29. Taylor (1982), Taylor (1983a,b).

[64] Module efficiencies are measured at 28 degrees Centigrade and air mass (AM) 1.5. U.S. Department of Energy (1983c), p. 32. The amount of sunlight hitting the cell is a function of the air mass, or atmosphere,

These are more ambitious module price goals than the 50-cent-per-peak-watt goal that had been used 1973-1983. To see this, one must calculate the module area required to generate 1 kilowatt of AC power. As given in the Five Year Plan, this area (A) is given by:

$$A = 1/(\text{average peak insolation} \times \text{system efficiency})$$

where system efficiency equals the product of balance-of-system efficiency and module efficiency. The Five Year Plan assumes that average peak insolation is 1 kW/m^2 and balance-of-system efficiency is 0.81. With these assumptions, $A = 9.50\ m^2$ for 13-percent modules and $7.26\ m^2$ for 17-percent modules. Multiplying by the module cost goals of the Five Year Plan expressed in dollars per square meter, and dividing by 1.69 to convert to 1975$ gives a cost of 22.5 and 32.2 cents per peak watt (1975$) for 13-percent and 17-percent efficient modules, respectively, compared to the original 50-cent-per-peak-watt goal. This calculation is relatively easy to make, so it is noteworthy that the old and new module goals are not compared in the text of the plan,[65] although graphs in the

---

through which the sunlight must pass. AM_0 is the applicable condition for use of PV in space. AM_1 refers to the air mass under the high-noon sun on a clear day. Higher air-mass figures refer to the "thicker" atmospheres associated with the sun not being directly overhead on such a clear day. In addition to reducing the overall amount of sunlight, the atmosphere selectively absorbs certain wavelengths. Since PV cells made of different materials exhibit differing abilities to absorb various elements of the spectrum, the relative performance of materials made of different cells will depend on the air-mass conditions. See SERI (1984), pp. 5-7, 27.

[65] The draft of the Five Year Plan prepared by JPL indicates in the text that the new goals are more strict than the old goals because "they are aimed at long-term economic viability and at achieving significant levels of energy production from photovoltaics. The change in goals, of course, reflects the change in the program's objective, that is, to conduct long-term, high-risk research with the potential for high payoff." U.S. Department of Energy (1983a), p. 39. This language does not appear in the final Plan released in May.

Five Year Plan imply that 50-cent-per-peak-watt modules cannot attain the 15-cent-per-kilowatt-hour target with the assumptions made concerning other parameters.[66]

Following the issuance of the Five Year Plan, JPL argued that the module goals in the Plan are tighter than needed to attain the goal of 15 cents per kilowatt hour. They felt the following goals would attain the 15-cent-per-kilowatt-hour target:[67]

Module efficiency	Module cost (1982$/$m^2$)
10	36-40
13	68-75
17	110-125

Using these revised module goals and parameters[68] in the above calculation yields module costs of 28.0-31.1, 40.7-44.9, and 50.3-57.1 cents per peak watt (1975$) for 10-, 13-, and 17-percent-efficient modules, respectively.

---

[66] U.S. Department of Energy (1983c), p. 30. Note that the dashed curves represent module costs in 1980$. The 50-cent-per-peak-watt goal expressed in 1980$ is 70 cents.

[67] Efficiency measured at 1000 kWh/m^2/yr. irradiance and 25-degree cell temperature. The lower end of the range is given in Crosetti, Jackson, and Aster (1985), p. 33. The higher end is given in Borden (1984b), p. 2.

[68] A temperature adjustment factor (0.88) x module efficiency x BOS efficiency is used to derive the A factor. See Crosetti, Jackson, and Aster (1985), pp. 7, 11.

Thus the JPL-suggested goals for the Five Year Plan are more strict than the original 50-cent-per-peak-watt goal, except for 17-percent-efficient modules.[69]

The significance of the JPL analysis is best understood in terms of the program's emphasis on single-crystal silicon (conducted at JPL) and more high risk approaches (conducted at SERI). To derive module and efficiency goals from energy price goals, one must assume values for about ten other parameters, some of which are rather uncertain. Thus, a wide range of goals could be justified by seemingly plausible choices of values for other parameters. The JPL analysis implies that the Five Year Plan's choices with respect to these parameters result in overly strict module cost and efficiency goals, which could only be achieved through SERI's high-risk research, rather than JPL's efforts to refine current technology.

A new Five Year Plan, issued by the program in May 1987, tightens the module efficiency and cost goals somewhat.[70] This appears to result

---

[69] The argument that the Five Year Plan goals are more strict than the Cherry Hill goals is made in another form in a recent paper by JPL staff members. Callaghan, Henry, and McGuire (1985). I prefer the comparison I made above. The latter comparison associates with the Cherry Hill module price goal of 50 cents per peak watt, an efficiency goal (10 percent) and lifetime goal (20 years) which do not appear to be part of the original single-crystal silicon goals from Cherry Hill. See Jet Propulsion Laboratory (1974b). Nor were these efficiency and lifetime goals adopted by the program--see, for example, the initial program summaries, U.S. Energy Research and Development Administration (1976) and U.S. Department of Energy (1978b). Since I do not associate efficiency and lifetime goals with the Cherry Hill module goal, I prefer to compare this module price goal to current module price goals, with the same assumptions regarding all other parameters, including efficiency and lifetime.

[70] U.S. Department of Energy (1987a). The goals are actually loosened for concentrators, but for brevity the discussion of the goals throughout this section has been on flat-plate systems.

from a more stringent electricity price target of 5.27 cents per watt compared to the former 6.5 cents per peak watt (both 1982 dollars).[71] A number of assumptions concerning other parameters were also changed. The new goals for flat-plate systems are set forth below:

	Year 2000 Goal (1986$)
Module efficiency	15-20 percent
Module cost	$45-80/m^2$
Balance-of-system costs	
area-related	$50-100/m^2$
power-related	$150/kW
System Life Expectancy	30 yrs.

In addition, the new Plan establishes a set of goals for module efficiency and cost for the early 1990s based on an electricity price twice that of the year 2000 electricity price, a price that may be cost-effective for peaking applications, export markets, and non-grid-connected applications.[72]

---

[71] Levelization divides the total cost of producing electricity over a plant's lifetime by the lifetime, so that the cost per year is the same. Levelization is performed either in current-year dollars or constant-year dollars. The former presents the costs in terms of current-year dollars; the latter in terms of constant dollars. The figure of 15 cents per watt from the 1983 plan was levelized in current-year dollars; levelized in constant 1982$, it was 6.5 cents. The new goal in levelized 1986$ is six cents per watt.

[72] U.S. Department of Energy (1987a), p. 9.

Probability of Attaining Module Price Goals

Congress received numerous assurances during the initial years of the program that the 50-cent-per-peak-watt goal was achievable. For example:

> 1985 appears to be a realistic date in order to achieve 50 cents per watt for the solar arrays.[73]

and

> Thus, in the photovoltaic program, an intermediate ($500 per peak kW) and a long-range objective ($100-$300 per peak kW) were established. It is judged that the silicon array price can be brought down with the lowest risk to the intermediate objective by 1985. [ERDA written response to subcommittee question][74]

In August 1978, JPL published, for the first time, an analysis using a detailed costing methodology of a candidate manufacturing sequence that could meet the goal of manufacturing 50-cent-per-peak-watt flat-plate silicon photovoltaic modules in 1986.[75] With all these assessments generally optimistic and the lack of any quantitative probability assessments, no obvious trend in the assessments existed in the 1973-1978 period. In 1979, two guardedly optimistic assessments appeared:

> . . . flat plate silicon module costs using technology now foreseeable will approach the price range 50-75 cents/peak watt.[76]

and

> Reaching the 1986 program goals and later the objectives of the act will be a difficult challenge . . . Some solar industry officials and scientists doubt that the existing

---

[73] Testimony of John Goldsmith, Group Supervisor, Solar Energy Group, Jet Propulsion Laboratory. Goldsmith (1974), p. 75.

[74] Committee on Science and Technology (1976), p. 269.

[75] Aster (1978).

[76] American Physical Society (1979), p. 6.

> industry can expand that rapidly or reduce array costs by such a large factor. Similarly, during deliberations on the bill H.R. 12874 leading to passage of the "Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978," a number of Congressmen voiced concern relating to the ambitious nature of the objectives set forth. Nevertheless, they generally agreed that the objectives could be met with a well-conceived, carefully planned and executed program of research, development, and demonstration.[77]

By 1982, the prospects for achieving the 1986 goals had dimmed. The General Accounting Office issued a report on the effects of fiscal year 1982 budget reductions on achieving the cost and production goals of the Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978 (P.L. 95-590). The GAO concluded

> Our review showed that the act's goals had little likelihood of being achieved prior to the fiscal year 1982 budget reductions; however, due to these reductions, the goals now have even less likelihood of being reached. Specifically,
>
> --achieving the $1.40 per peak watt system cost goal was unlikely without budget reductions, although there was some optimism that it could have been reached.[78]

As noted in the previous section, in 1983 the Department of Energy abandoned the previous goals and adopted more ambitious cost targets, but set these for the late 1990s, whereas the goals in effect at that time were for 1982, 1986 and 1990. In 1987, these goals were again tightened, and delayed slightly to the year 2000.

The Flat-Plate Solar Array (FSA) Project at JPL was terminated in 1986. Because of the importance and length of this project, several "valedictory" statements have been made that the FSA project essentially achieved the Cherry Hill module price goal. For example, the manager of the FSA Project claimed that the project essentially achieved the Cherry

---

[77] U.S. General Accounting Office (1979), p. 4.

[78] U.S. General Accounting Office (1982), p. 2.

Hill goals with approximately 50.2 percent of the budget recommended by the Cherry Hill conferees.[79] These claims are based on projections using SAMICS (Solar Array Manufacturing Costing Standards), an elaborate costing model developed by JPL for estimating manufacturing costs. SAMICS estimates are based on the best production techniques thought to be available for incorporation during that year, and cover all costs of producing modules, including competitive rates of profit. Table 13 shows SAMICS cost estimates for most of the life of the PV program.

Actual market prices have been higher than SAMICS estimates for three reasons. First, SAMICS produces "technical readiness" estimates. JPL assumed that it would take two to three years to get these techniques into commercial production. Second, the estimates often assume a plant size which captures economies of scale. Actual plant sizes were generally smaller than this, primarily due to the small market for PV at these prices. Third, the prices were FOB plant and excluded the sizable costs of marketing and distribution.

Two time series of actual prices are useful to compare with the SAMICS estimates and to indicate how technical progress was affecting prices. One indicator is the prices in the "block buys" that JPL conducted during the course of the program. Photovoltaic manufacturers submitted PV arrays which were tested by JPL. The decline in average prices for each block buy (see Table 14) provides evidence that costs were being reduced. The measure is imperfect, however, for two related

---

[79] Callaghan, Henry, and McGuire (1985), p. 3. Others argue that FSA funding was only 44.1 percent of funding recommended in the 1978 National Photovoltaics Program Plan, and only 39.4 percent of the funding recommended in the original plan for the project in 1974. See Maycock (1986), Table 3.

Table 13
SAMICS Estimates of Production Costs for Flat-Plate Silicon Modules

Year of Technical Readiness	SAMICS Price Estimate (1980 $/Peak Watt)
1976	16.60
1978	5.54
1980	2.70
1982	2.06
1985	1.12

Source: Jeffrey L. Smith (1980b), Vol. III, p. 32; Henry (1980, 1982); Callaghan, Henry, and McGuire (1985).

Table 14
Module Prices in Block Buys

Year	Price (1980$/Peak Watt)
1975	29.40
1976	19.18
1977	14.56
1983	4.24

Source: Prices for 1975, 1976, and 1977 are for JPL Block Buys 1-3 given in Slonski and Easter (1979). Price for 1983 is for 1MW Sacramento Utility District (SMUD) purchase given in Callaghan, Henry, and McGuire (1985).

reasons. First, these represent prices for relatively small numbers of modules; prices for larger orders could be lower due to greater automation, or higher, if firms were not breaking even on the block buys. Second, firms selling modules might reasonably have concluded that the prices in these buys might affect future Administration or Congressional policy, and this consideration could have affected how firms priced their modules in the block buys. The 1983 price is a better indicator than the block buys since the purchase is larger and there is less reason to suspect that firms might be pricing to influence future Administration policy. However, since the purchase represents only 1 MW of the 100 MW planned for the project, "buying in" behavior can not be ruled out.

A more complete indicator of price is found in the annual Energy Information Administration survey of photovoltaic module manufacturers. The average price of single-crystal silicon modules declined from $5.75 per peak watt in 1985 to $5.19 in 1986.[80]

System Configuration Issues

What type of power system the PV module would be a part of has been an important issue in the PV program. The two most important system configuration issues have been the role of storage and the choice between on-site (distributed) and utility (central-station) applications. The storage issue was resolved in the late 1970s, and on-site vs. central-station by 1983. The later date for the second issue reflects its greater complexity as well as its more contentious politics.

---

[80] U.S. Department of Energy (1987b), p. 22. Although price information was collected in the 1984 survey, EIA did not report the results. U.S. Department of Energy (1985c), p. 33.

Storage. A recurrent problem in the analysis of PV systems is how to treat the fact that the output of the system, unlike conventional sources, is highly variable. PV system output depends on the available light, which varies in a regular way during the day and throughout the year, with additional variation due to weather conditions. Although the NSF staff paper presented at Cherry Hill did not explicitly consider the issue of whether storage should be included as part of a photovoltaic system, most early PV studies assumed that storage was a necessary part of a photovoltaic system. The MITRE study, the Solar Task Force, and the 1979 Resources for the Future energy study all include storage costs, with the latter finding that economical storage "is critical to making solar energy economic on a large scale."[81]

Subsequent analysis of the interaction of PV with electric grids, and of the high costs of storage, reversed this view. The new consensus is that the cost of PV without storage should be compared with the value of the electricity generated, which depends in turn on how the addition of PV affects the optimal generation mix of the utility.[82] The early studies contained an element of truth in the sense that a utility system with PV as a very high percentage of its generation would require a reliable source of power (e.g., storage) for the remainder. But this remainder need not be provided by storage. Thus, including the cost of storage in PV costs is no more appropriate than including it in the costs of other generation options.[83]

---

[81] Landsberg (1979), p. 493.

[82] Smith (1980b), Vol. 1, p. 5.

[83] Metz (1978) provides a good introduction to this issue.

This mistake concerning storage costs probably did not have a major adverse effect on the program. The mistake was recognized early. Moreover, its effect was to make PV look less economic during a period when the program probably was growing too fast under overly optimistic predictions of its success.

On-site vs. Utility Applications. A major issue in the program from 1973-1983 was the relative emphasis to be given to on-site (termed "distributed" by the program) vs. utility (termed "central-station") applications of photovoltaics. The program underwent two shifts in what it viewed as its first significant market (beyond remote applications). Initially the program did not appear to take a definite position regarding the relative economics of distributed vs. central-station applications. In 1978, the program came to view the residential market as the first in which PV would be economic. In 1983, the program reversed itself and declared central-station uses as the first market that would become economic.

Early studies were divided on this issue. The 1973 Subpanel IX Report to the Chairman of the Atomic Energy Commission stated that 50 cents per peak watt in 1985 would be competitive in residences and 10 cents per peak watt in 1990 would be competitive in central-station use.[84] This belief that residential systems would be economic before central-station applications was echoed by the NSF presentation at the Cherry Hill conference, which showed a lower energy cost for residential uses than for central-station, with the same array costs for both (Table 15). On the other hand, a study done for NSF by the Aerospace Corporation in 1975

---

[84] Subpanel IX (1973), pp. 402, 411 in hearings.

Table 15
NSF View of Economics of Photovoltaics at Cherry Hill (1973)

Type/Time	Array Cost $/Wp	System Cost $/W	Operating Cost $/yr	Lifetime years	Power Cost cents/kWh
Residence 1985	$0.50	3	0	20	7
				30	5
Central Station 1990	$0.10	0.7	.01	20	1.8
				30	1.2
Residence	$0.10	1	0	20	1.6
				30	1.0

Note: All figures in original table have been converted to a 1-peak-watt basis. System cost includes array cost but excludes operating cost.
Source: Bleiden (1973), pp. 88, 96.

concluded that "on-site and central station missions are about equally attractive as future (1990) applications for photovoltaic solar energy conversion."[85]

Although the program did not have at this time an official position regarding the relative economics of dispersed vs. central station uses, a number of commentators in the latter half of the 1970s argued that ERDA's approach to solar energy as a whole was too oriented toward solar electricity and centralized systems and that what was needed was a more balanced approach. This criticism was made in a 1975 Office of Technology Assessment review of the 1975 ERDA Plan and Program, as well as in populist magazine articles and books on energy.[86]

This populist criticism reveals an important component of the politics of solar energy. Solar energy is a "soft technology" (small-

---

[85] Aerospace Corporation (1975), p. 112. The basis for this conclusion is not obvious from the report due to the differences in methodology between the residential and central-station analysis. The residential analysis computes a break-even array price to compete with a coal alternative (at an unspecified electricity price). The central-station analysis assumes an array price, and computes an energy cost from that.

[86] Office of Technology Assessment (1975), p. 143, which was a review of U.S. Energy Research and Development Administration (1975a, b). See also Lovins (1976), and Hammond and Metz (1977), p. 197. The case for dispersed PV systems was strongly made by Barry Commoner (1979), p. 44:

> However, unlike conventional energy sources, <u>there is no economy of scale in the acquisition of solar energy</u> . . . a large, centralized solar plant produces energy no more cheaply than a small one (aside from minor savings in maintenance costs). Thus, with transmission costs eliminated or at least greatly reduced, the small plant is by far the most efficient way to deliver the energy.

Commoner's position was attacked in McCracken (1979). The controversy is reviewed in Kidder (1980). Despite the emphasis in the mid-1980s on central stations, some advocates of the populist, distributed position remain. See Maycock and Stirewalt (1985).

scale, distributed, renewable) as opposed to conventional sources which are "hard technologies." The support for soft technologies is philosophical, not based on safety or economics. A dispersed energy system allows individuals greater self-determination, whereas large scale tends to concentrate political and economic power in a few organizations and people. As put by Amory Lovins, the leading proponent of the soft energy path,

> If nuclear power were clean, safe, economic, assured of ample fuel, and socially benign per se, it would be unattractive because of the kind of energy economy it would lock us into.[87]

The "residential-first" position was buttressed by the appearance in the late 1970s of a number of studies which concluded that the photovoltaic residential market would be competitive prior to the central-station market. The first of these was the Aerospace Corporation revision in March 1977 of their 1975 analysis (which had showed on-site and central-station equally attractive) to take into account the differing ownership possibilities in the central-station vs. residential market. This later analysis stated that central-station would be cost-competitive in the U.S. sunbelt in the 1986-2000 period at array prices in the \$100-200/kWp range. Break-even array prices for on-site residential photovoltaic systems were estimated to be \$250-600/kWp if the system was owned by the homeowner, \$100-300/kWp if owned by the utility, largely because the utility company must pay dividends on equity capital and income taxes on revenues generated to pay dividends.[88] As noted in a 1980

---

[87] Lovins (1977), cited in Congressional Research Service (1983), p. 6. The preceding paragraph borrows heavily from the latter.

[88] Leonard et al. (1977), pp. vi and ix. The same financial and tax considerations underlay the conclusion in an August 1978 Aerospace Corporation report that single family uses would be economic before

JPL report, a number of studies reached similar conclusions in 1978-1979, generally due to differences in the financial and tax situation of residential vs. central-station applications.[89]

However, this point of view was not immediately adopted by ERDA or DOE. The annual program summary issued in November 1976 and the National Photovoltaic Program Plan issued in March 1978 do not prioritize applications.[90] The first ERDA or DOE report that implied that residential would be economic before central-station uses was issued in December 1978. It stated that the mid-term goal of 50 cents per peak watt in 1986 would produce energy costs of 5-8 cents/kWh, which would be cost-effective for residential uses. The far-term goal of 10-30 cents per peak watt in 1990 would produce energy costs of 4-6 cents per kilowatt hour and would be cost-effective for utility applications.[91]

The shift in 1978 toward residential programs was reflected in a

---

commercial uses. Leonard et al. (1978), pp. ix, 39.

[89] Smith (1980b), Vol. I, p. 28. Jet Propulsion Laboratory (1980), p. 16, cites Carpenter and Taylor (1978), General Electric Company (1979), and Westinghouse (1978) as the studies which showed higher break-even costs for on-site applications, and thus these applications as more economic.

[90] U.S. Energy Research and Development Administration (1976), U.S. Department of Energy (1978a), p. 5.

[91] U.S. Department of Energy (1978b), p. 5. This position was reflected in the National Energy Plan released in May 1979 which stated that utility applications would be economic at the lower end of the 10-50 cents per peak watt range, and dispersed (residential) applications at the higher end of the range. See U.S. Department of Energy (1979b), p. VI-11.

change in (1) the organization of the solar energy program,[92] (2) electric utility purchase requirements, and perhaps (3) solar tax policy.

(1) <u>Organization of the Solar Energy Program</u>

From 1975 to 1977, the Division of Solar Energy was divided into an office of solar electric applications (which included branches for photovoltaics, ocean thermal, solar thermal, and wind) and an office of direct solar conversion (with branches for solar heating and cooling, agricultural and process heat, and biomass).[93] Thus the organizational structure was neutral with respect to applications of PV. In 1978, the photovoltaics program (along with biomass and wind) became part of the Division of Distributed Solar Technology.[94] In 1980-1981, the photovoltaics division became part of the Office of Solar Applications for Buildings.[95] Both of these organizational structures reflected an emphasis on distributed systems for PV.

(2) <u>Electric Utility Purchase Requirement</u>

The 1978 PURPA utility purchase requirements discussed above aided residential PV by requiring electric utilities to purchase power from small power systems at avoided cost. One such system is a residential PV system which, at some periods during the day, generates power in excess of residential need and sells power back to the utility. This provision

---

[92] Smith (1980b), Vol. I, p. 29, examined the link between program emphasis and organizational structure in 1980. He notes elsewhere that "photovoltaics has been classified by DOE primarily as a distributed option intended for use on buildings." Smith (1980a), Supplement, p. 96. I expand Smith's analysis to other points in the program's history.

[93] Jet Propulsion Laboratory (1975), p. 5 and Buck (1982).

[94] U.S. Department of Energy (1978b), p. iii.

[95] U.S. Department of Energy (1980f), p. 18; (1981), p. 2-3.

provides a strong boost to residential PV since "sellback" revenues reduce the net cost of the PV system.

(3) <u>Solar Tax Provisions</u>

The Energy Tax Act of 1978 provided a larger percentage credit for solar energy residential uses (30 percent of the first $2000 and then 20 percent of the next $8,000, for a maximum credit of $2,200) than for business use (10 percent in addition to the normal investment tax credit), but the residential credit did not apply to PV. Thus, the 1978 act encouraged central-station PV over residential. In 1980 the residential credit was raised to 40 percent for the first $10,000 and the business credit to 15 percent, and the residential credit was extended to PV.

Such a change could have a number of possible effects. First, there are corner situations where the provision would have no effect--e.g., if PV were so uneconomic that the tax provisions were irrelevant, or the before-tax economics and other tax provisions (investment tax credit, ACRS provisions, marginal tax rates, treatment of imputed income, and 1978 PV business credits) were so unequal that the relative after-tax economics of residential vs. central station PV were not affected. Second, since PV systems are modular and since the marginal credit was 0 for residential systems over $10,000, the provisions could encourage the building of residential systems up to $10,000 and encourage the use of PV in utilities for the remainder of residential requirements and other requirements. Since Treasury does not publish data on the utilization of PV credits, it is difficult to know the magnitude of these increases relative to the base amounts, and thus whether the 1980 provisions were a boon to residential or utility PV.

The shift in the photovoltaics program toward distributed systems was not universally welcomed. The critics focused on cost differences between the applications other than purely tax and financial considerations. An Office of Technology Assessment study in September, 1978, discussed the advantages and disadvantages of distributed vs. centralized systems.

(1) Advantages

-Reduced transmission and distribution costs and losses in some cases

-Minimization of the land required

-Increased use of thermal output of collectors

-Reduced interest and inflation during construction due to shorter construction times

-Matching of reliability to local needs

(2) Disadvantages

-Poorly engineered designs

-Inability of organizations other than utilities to raise capital for investments with relatively long payback times

-Uncertainties about maintenance costs

The study concluded that "Given the uncertainties inherent in an analysis of this type, it was simply not possible to establish that there either clearly were or were not economic advantages for small solar systems."[96]

The American Physical Society Study Group Report on photovoltaics concluded that central-station uses would be more economic than on-site

---

[96] Office of Technology Assessment (1978), pp. 12-14. Henry Kelly, technical assistant to the director of OTA, apparently concluded that distributed systems were most economic. See Kelly (1978), p. 642.

applications.[97] The APS Report reached this conclusion through an examination of cost factors other than financial and tax ones. The Jet Propulsion Laboratory's review of the APS Report disagreed with this conclusion, but did not appear to necessarily endorse the opposite view that residential would be more economic.[98] A JPL critic of the emphasis on distributed systems noted in 1980:

> While land area can be conserved through the use of available roof space in distributed applications and structure costs may be reduced, almost all other cost factors work against distributed systems. System installation, maintenance, sales, distribution, power conditioning, safety features, controls and displays, and insurance are all likely to cost more per unit in distributed applications. Building codes, product standards and liability, solar access, zoning restrictions, aesthetics, utility system maintenance, operation, emergency procedures, utility interconnection, PV installer training, and other complications are introduced or exacerbated in distributed applications. Thus it is not at all clear that distributed PV systems are more attractive on a cost/benefit basis than central systems. On the other hand, strong legitimate arguments have been made in support of a distributed emphasis . . . Many would prefer distributed photovoltaics because it could reduce the monopoly power utilities hold over electric generation sources; others would like to reduce the remoteness and impersonality of electricity supply or decrease the economic and political power of utilities and "big business" in general.[99]

The views of the Office of Technology Assessment, the American Physical Society Study Group, and Jeffrey L. Smith of JPL cited above did not prevail in the late 1970s and early 1980s. The emphasis on residential was developed further in 1979 when the program stated its

---

[97] The APS study argued that the major advantage of on-site systems was the opportunity for cogeneration of heat and electricity from a single system, but that only cogeneration systems at large load centers or certain industrial sites would have an economic advantage. American Physical Society (1979), pp. 23-24.

[98] Jet Propulsion Laboratory (1980), pp. 15-16.

[99] Smith (1980b), Vol. I, p. 29.

goals in terms of three markets rather than two (residential and central-station). This was first done in June 1979, in the National Photovoltaics Multi-Year Program Plan draft prepared for DOE by JPL. This document proposed system readiness price goals of $1.60 per watt peak in 1986 for residential and selected intermediate load centers and $1.10-1.30 for central-station uses in 1990.[100] These price goals were designed as break-even prices at which the total cost of supplying electricity with photovoltaics is equal to the total cost of supplying the electricity from the best alternative source.[101] Thus, these goals implied that residential and intermediate load centers would be economic at the same PV system price, and would be economic before (and at higher PV prices) than central-station (utility) uses.

Although the 1979 goals remained in force until 1983,[102] the first indication of retreat from the orientation toward distributed uses occurred in 1981. The photovoltaics division was returned to the Office of Solar Electric Technologies,[103] thus returning to the type of organizational structure that existed from 1975 to 1977 and that was neutral with respect to applications. The final act in the drama occurred with the issuance of the Five Year Plan, which has governed the program since 1983. It did not set separate goals for different categories of

---

[100] U.S. Department of Energy (1979a), pp. 2-3, 4. As discussed in note 61, the central-station goal was soon changed to 1.10-1.80.

[101] Smith (1980b), Vol. 1, p. 25.

[102] These goals were repeated in the January 1981 and 1982 annual program summaries. See U.S. Department of Energy (1981), p. 2-8 and U.S. Department of Energy (1982), p. 1-8.

[103] Compare U.S. Department of Energy (1981), p. 2-3; (1982), p. 1-3.

uses, but argued that central-station uses would be the most economic because they had the lowest balance-of-system costs and lowest indirect costs (including marketing and distribution).[104] As is true of other aspects of the plan, this conclusion was based on the work of Roger Taylor at EPRI.[105]

Thus the program went through four phases on the issue of the respective commercialization dates of on-site vs. central-station systems:

1975-1977	Neutral Emphasis in Organization and Goals
1978-1981	On-Site Emphasis in Goals and Organization
1981-1983	Neutral Organization; On-Site Goal Emphasis
After 1983	Neutral Organization; Central-Station Goal Emphasis

Energy Price Goals

The program has always formulated its goals in terms of module or system prices. Since 1983, energy price goals have been the basis for the module price goals, so that the resulting energy price has been known *a priori*. Prior to 1983, the energy price estimates were less prominent. This section will review the evolution of energy price estimates from 1973 to the present.

The first power cost estimates were presented by NSF at the Cherry Hill conference in October 1973. NSF presented power cost estimates derived from 50 cents per peak watt in 1985, and 10 cents per peak watt in 1990 (Table 15 above). In 1973, NSF thus believed that 50-cents-per-peak-watt arrays in 1985 would produce power at about 5-7 cents per kWh,

---

[104] U.S. Department of Energy (1983c), p. 29.

[105] Taylor (1983) and EPRI (1983), p. 2-2.

and that 10-cent arrays in 1990 would produce power for between 1 and 2 cents per kWh. A revised version of this table was presented a year later by the Solar Energy Task Force for Project Independence (Table 16). The Task Force used a 1995 date instead of 1990, higher system costs, higher operating costs for residences, and a lifetime of 25-30 years rather than 20 and 30 years. The Task Force saw 50-cent-per-peak-watt arrays producing power at 4-8 cents per kWh.[106] Because the calculations in both this document and the earlier NSF paper are not possible to follow, the reasons for the differences in energy cost are not clear.

Despite the ambiguities of these tables, they are important in a number of respects. First is the explicit recognition of balance-of-system costs, and the assessment that these might be lower in central-station applications than in residential. Second is the implication that, despite these lower system costs, the costs per kilowatt hour may be higher in central-station applications than residential. The source of this difference is not clear, because if one calculates the power costs for the NSF table using the data indicated, one arrives at exactly the opposite conclusion.

The program made several estimates in 1978-1980 of the energy costs resulting from 50-cent-per-peak-watt arrays. In 1978, the estimate was 5-8 cents/kWh;[107] in 1979, from 3.9 to 9.2 cents/kWh. The latter range reflected differences in location, residential vs. intermediate load

---

[106] U.S. Federal Energy Administration (1974), p. VII-15. The Appendix shows 50-cent arrays producing power for 6.9 to 8.1 cents per kilowatt hour (p. VII-B-3). The discrepancy between this figure and the 4-8 cent figure is not explained.

[107] U.S. Department of Energy (1978a), p. 5; (1978b), p. 5.

Table 16
Cherry Hill Table As Revised by Solar Energy Task Force (1974)

Type/Time	Array $/Wp	System Cost $/W	Operating Cost cents/kWh	Lifetime years	Power Cost cents/kWh
Residence 1985	$0.50	4	0.1 to 0.5	25-30	4.0 to 8.0
Residence 1995	$0.10	2	0.1 to 0.5	25-30	2.0 to 4.6
Central Station 1995	$0.10	1.4	0.1 to 0.2	25-30	2.2 to 4.3

center, and the price at which excess energy would be sold back to the utility.[108] In 1980, the estimate became "approximately 5-9 cents/kWh"[109] and 5.2-8.7 cents/kWh in residential applications and 5.5-9.24 cents/kWh in intermediate load applications.[110]

Thus the estimated energy cost from 50-cent-per-peak-watt arrays changed from 5-7 cents in 1973, to 4-8 cents in 1974, to 5-8 cents in 1978, to 5-9 cents in 1980. In fact, however, the 1979-1980 figures are lower than the earlier estimates when one considers inflation. Because the methodology for the 1973, 1974, and 1978 estimates is not clear, one cannot say for certain, but it is reasonable to assume that these costs are "levelized" in constant 1975$.[111] The 1979-1980 estimates, however, are levelized in constant 1980$.[112] Thus the 5-9 cents/kwh is actually 3.5-6.4 cents/kwh in 1975$.

Energy cost estimates were not published by the program in 1981 and 1982 in the annual program summaries.[113] In 1983, the program adopted the 15 cent per kilowatt hour goal, levelized in current 1982$ dollars, or 6.5

---

[108] Smith (1980b), Vol. 1, pp. 25-27. Intermediate load-centers include all distributed systems other than low-density residential housing (e.g., commercial and industrial buildings, schools, apartments).

[109] U.S. Department of Energy (1980a).

[110] U.S. Department of Energy (1980b), p. 3.

[111] As noted earlier, levelization is a computational procedure which divides the cost of the project so that the cost per year is the same. The cost can either be equal per year in constant dollars or in current dollars. The 1974 estimate appears to be levelized in constant 1974$, based on an array cost of 50 cents per peak watt in 1974$, which is equivalent to levelizing in 1975$ based on a 1975$ array cost. See U.S. Federal Energy Administration (1974), p. VII-B-4.

[112] See U.S. Department of Energy (1980c), p. D-3.

[113] U.S. Department of Energy (1981), p. 2-8; (1982), p. 1-8.

cents per kilowatt hour, levelized in constant 1982$ (equal to 5.1 cents in constant 1980$). The Five Year Plan did not estimate what the cents per kilowatt cost of the 50-cent-per-kilowatt goal would have been, nor have subsequent program documents. However, JPL economists estimated in 1985 that this would be $0.264 per kWh in 1985$, levelized in nominal terms.[114] This is equal to 10.5 cents per kWh levelized in constant 1980$ or 7.4 cents per kWh in constant 1975$.[115]

Table 17 presents the history of energy cost estimates of PV power resulting from attainment of the 50-cent-per-peak-watt goal, with all estimates converted to levelized 1980$. Because the 1973, 1974, 1978, and 1980 estimates are not fully documented, it is not possible to say with certainty what led to the decline in estimates between the early estimates and the 1979-1980 estimates and the later increase in the 1980s. However, the two most likely possibilities are the elimination of storage, and changes in parameter assumptions/methodology.

Economic Value of PV

The economic value of PV depends on the extent to which it replaces higher-cost substitutes, which depends not only on the cost of electricity from PV (examined in the previous section) but on the cost of substitutes. The two most important substitutes are oil and electricity. Oil prices

---

[114] Callaghan, Henry, and McGuire (1985), p. 1.

[115] The conversion to constant 1980$ is accomplished by dividing by 1.30 (the change in the GNP implicit price deflator) to convert to 1980$ levelized in nominal terms and then dividing by 1.93, which is the factor to convert an amount levelized in nominal dollars to an amount levelized in constant dollars, assuming an inflation rate of 8.5 percent, a nominal discount rate of 12.5 percent, and a 20-year lifetime.

Table 17
Energy Cost Estimates For 50-Cent-Per-Peak-Watt Arrays

Year Estimate Made	Application	Energy Cost Estimate Stated Estimate	Energy Cost Estimate Estimate in 1980$
		(cents per kWh, levelized in constant $)	
1973	Residential	5-7	7.2-10.1
1974	Residential	4-8	5.8-11.6
1978	All	5-8	7.2-11.6
1979	Res./Intermediate	3.9-9.2	3.9-9.2
1980	Residential	5-9	5-9
	Intermediate	5.2-8.7	5.2-8.7
1983/85	Central Station	--	10.5

are important in three respects. First, they are the major factor affecting the cost of diesel generation, which is the primary substitute for PV in nongrid applications. Second, they are the major determinant of the cost of oil-fired electricity generation. Third, they (or the gasoline prices resulting) are the most visible energy prices and thus affect public perceptions about energy prices.

The pattern for world oil prices shown in Table 18 is well known; the quadrupling in 1973-1974, followed by an increase in nominal terms but a decline in real terms until 1979, followed by a doubling in 1979-1980, followed by nominal and real declines in the 1980s. However the pattern of electricity prices is quite different, with (in real terms) continual moderate increases until 1983 and moderate declines since then (Table 19).

A model of PV benefits which utilized current oil prices or electricity prices would do so as an indicator of future prices. Cost comparisons between PV systems and grid alternatives must be done for lifetimes that span a number of years; thus future prices dominate the calculation, even after discounting.[116] This is the reason Table 18 uses imported prices; domestic prices were regulated until 1981, and therefore were not a good indicator of prices several years in the future when

---

[116] PV systems have relatively high capital costs but low operating costs, and therefore will only be less costly than alternatives if evaluated over lifetimes of a number of years. Similarly, the alternatives generally have long lifetimes. If prices of conventional energy rise and solar costs decline, PV will clearly be economic to install at some point. The key question is when. JPL in 1980-1981 examined the issue of the optimum time to replace, dubbed the "PV wait" problem.

Table 18
Average Refiner Acquisition Cost of Imported Crude Oil, 1970-1987
(Dollars per Barrel)

Year	Current Dollars	1982 Dollars
1970	2.96	7.05
1971	3.17	7.14
1972	3.22	6.92
1973	4.08	8.24
1974	12.52	23.19
1975	13.93	23.49
1976	13.48	21.36
1977	14.53	21.59
1978	14.57	20.18
1979	21.67	27.57
1980	33.89	39.54
1981	37.05	39.41
1982	33.55	33.55
1983	29.30	28.20
1984	28.88	26.82
1985	26.99	24.27
1986	14.00	12.27
1987	18.15	15.45

Table 19
Average Price of Electricity, 1970-1987
(Cents per Kilowatt-hour)

Year	Current Dollars	1982 Dollars
1970	1.67	3.98
1971	1.77	3.99
1972	1.86	4.00
1973	1.96	3.96
1974	2.49	4.61
1975	2.92	4.92
1976	3.09	4.90
1977	3.42	5.08
1978	3.69	5.11
1979	3.99	5.08
1980	4.73	5.52
1981	5.46	5.81
1982	6.13	6.13
1983	6.29	6.06
1984	6.52	6.05
1985	6.71	6.03
1986	6.70	5.87
1987	6.56	5.58

Source for tables: U.S. Department of Energy (1988a), pp. 141, 209. 1987 figures preliminary.

prices would probably no longer be regulated.[117]

The appropriate price series for electricity prices is less clear-cut. Average prices are relevant for the user deciding whether to replace grid electricity with PV; the effect of regulation is that the user faces the average cost of all generation rather than the marginal price. For the utility deciding whether to install PV, the marginal price (the cost of new generation) is the relevant price. In either case however, the price several years in the future is the "figure of merit". The current marginal price is a better predictor of either than the current average price since the latter reflects the cost of low-cost sources, which either may not exist in the future or will be a smaller proportion of overall generation due to growth in consumption combined with a fixed supply of low-cost sources. However, the current marginal price was not as widely available as the current average price. Chapter 4 will explore whether congressional voting on solar energy is explained better by regional variations in current average prices or agency estimates of future marginal prices.

In addition to the price of substitutes, a number of factors played key roles in determining the economic value of PV:

-At what module price is PV competitive in a given application?

-What level of penetration of PV is predicted for future years?

-What is the economic value of PV at these levels of penetration?

Each of these will be discussed below.

<u>At What Module Price is PV Competitive?</u> The position taken on this

---

[117] If the proportion of price-controlled oil is known, then changes in the average price convey the same information as changes in the cost of uncontrolled oil (e.g., oil imports).

question has been, in almost every case, a function of the position taken on the relative economics of residential vs. central-station use (discussed above on pages 68-78). For example, a number of analyses state that 50 cents per peak watt would be competitive in residential applications whereas a lower price (say 10-20 cents per peak watt) would be competitive in central-station use.[118] Studies which use a figure lower than 50 cents per peak watt as the permissible module price generally focus on central-station use and dismiss residential applications.[119]

<u>What is the Level of Penetration Predicted for Future Years?</u> Table 20 shows the estimated contribution of photovoltaics made by a number of studies. Although the studies at the outset of the program had forecast a photovoltaic contribution in the year 2000 of anywhere from .45 to 7.0 quads, with an average estimate of about 3 quads, the May 1979 Department of Energy National Energy Plan estimated contributions in the year 2000 of 0.03 quads in the base case, 0.3 in the maximum practical, and .75 in the technical limit.[120]

---

[118] For example, Subpanel IX (1973), pp. 402, 411 in hearings; U.S. Department of Energy (1979b), p. VI-11; Henry Kelly of OTA in Committee on Science and Technology (1979), p. 534, plus a number of studies discussed in Section III. Kelly cites a number of studies--i.e., General Electric Corporation (1979), p. 1-7; Westinghouse Electric Corporation (1977), p. 45; Aerospace Corporation (1978); Carpenter and Taylor (1978); and Office of Technology Assessment (1978)--which all conclude, according to Kelly, that 50 cents per peak watt would be competitive.

[119] For example, American Physical Society (1979), p. 4, concluded that the permissible module price in the high-insolation Sunbelt region of the U.S. in the year 2000 would be 10-40 cent/peak watt. As shown earlier, the Five Year Plan, which also dismissed residential uses, chose an energy cost target requirement that generally implies module prices lower than 50 cents per peak watt.

[120] U. S. Department of Energy (1979b), p. V1-4. Fossil energy displacement figures are multiplied by 0.3 to get energy produced.

Table 20
Contribution of Photovoltaics
(10^{15} Btus Per Year--Quadrillion Btus or "Quads")

Study	1980	Year 1985	1990	2000	2020
NSF/NASA (1972)	0	0	-	.45	8.0
Subpanel IX (1973)	0	.03	1.2	3.0	-
MITRE (1973)					
Low	0	0	-	1.6	5.4
High	0	0	.01	5.4	18.0
Solar Energy Task Force (1974)					
Business as Usual	Neg.	.003	.07	1.5	-
Accelerated	Neg.	.01	.3	7.0	-
ERDA (1975)	-	-	-	.9	2.4
National Energy Plan (1979)					
Base	-	-	-	.03	-
Maximum Practical	-	-	-	.3	-
Technical Limit	-	-	-	.75	-
DOE (1980)					
Low Case	-	0	Small	-	-
Best Estimate	-	0	.006	-	-
High Case	-	Small	.012	-	-

Note: This table is identical with Table 5. "-" means that no projection for that year was made. 1 kWh = 3412 BTU. Total U.S. energy consumption in 1974 was 72.6 quads.

Sources: NSF/NASA (1972), Table 3, multiplying by factor of 0.3 to get solar energy production equal to the fossil-fuel displacement figures given. Subpanel IX (1973), Figure 29, p. 411. MITRE (1973), pp. 178, 180. Solar Energy Task Force from U.S. Federal Energy Administration (1974), pp. I-7, 9. Different figures for these studies were given in a table prepared by a Congressional committee.

Estimates of federal funding requirements went up as well. Whereas the original estimates ranged mostly from $300-800 million (see Table 6), in 1980 JPL and the Department of Energy analyzed 7 options, ranging from $1.4 to $5.0 billion in cost, in terms of when they would achieve the price goal of the Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978 (a goal which was viewed as consistent with the original 50-cent-per-peak-watt goal) and the 1978 Domestic Policy Review goal of 1.0-quad displacement by the year 2000. The least expensive option that attained the price goal by 1986 cost $3.0 billion, whereas the $1.4 billion option achieved the goal by 1993.[121]

One might argue however that this increase in cost estimates results not only from a change in expectations, but also from two other sources. First, larger budgets became politically acceptable in the late 1970s as a result of the energy crisis. Second, estimates became more realistic over time; the earlier low estimates could not be rejected as unreasonable at the time due to the great uncertainty involved.[122]

<u>What is the Economic Value of PV at This Level of Penetration?</u> Early economic assessments of photovoltaics were generally attempts to justify the program. In addition to producing optimistic estimates of PV penetration, these early analyses used methodologies which overstated the value of a given level of PV penetration. One source of error was the assumption concerning the type of fuel displaced. Both the 1974 Solar Energy Task Force and 1975 ERDA testimony assumed that 100 percent of the

---

[121] U.S. Department of Energy (1980e), Volume 1, pp. ES-13, F-19, 20.

[122] This point about the interaction of uncertainty and cost estimation in weapon-system cost estimates was made by Terasawa (1984).

fuel displaced would be oil.[123] The opposite conclusion was reached in the 1979 American Physical Society Study Group, which concluded that very little of the displaced fuel would be oil, a conclusion which was challenged by JPL.[124]

The issue of which technologies PV will replace is complex, and requires an accurate assessment of all other new generation options that could compete in an optimized generation mix.[125] If 100 percent was too high a percentage for oil displacement, this would have overstated PV value in two ways. First, energy policy measures during the 1970s were evaluated in large measure in terms of their ability to reduce U.S. dependence on imported petroleum. Second, the value of PV is a combination of fuel and capacity displacement. The value of PV was often measured just in terms of fuel displacement, since it was clear that PV use would reduce fuel use whereas the capacity displacement issue was far more complex.[126] Although assuming only fuel savings from 100 percent oil

---

[123] U.S. Federal Energy Administration (1974), p. VII-10, and Teem (1975), pp. 207-208.

[124] American Physical Society (1979), pp. 45-47, and Jet Propulsion Laboratory (1980), pp. 13-14.

[125] Taylor (1983), p. 4-25. The complexity even extends to the effect of oil price increases on the competitiveness of PV. Some have suggested that oil price increases, and here they must be assuming that no other energy price changes accompany them, have an ambiguous effect on the economics of PV, since although they clearly make PV more economic relative to oil-fired units, oil price increases accelerate the replacement of the oil-fired units. If PV is economic relative to oil at a later date than some other generation option, oil price increases may lead to installation of this other generation option. Once this option is in place, the installation of PV may be delayed since capacity costs for the other option will be sunk.

[126] The assessment of the economic value of PV has always been complicated by the fact that photovoltaics did not fit nicely into the traditional categories of power generation: base load, intermediate load, or peaking. Photovoltaics have a relatively high capital-cost-to-

displacement need not necessarily result in larger estimated benefits than a combination of fuel and capacity savings from other sources, the oil prices used in the analyses (based on the large increases in 1973-1974) would likely lead to larger estimates.

There were at least three other sources of overstatement of the value of the PV program:

1. The dollar value of oil savings was sometimes compared to the R&D costs of the PV program.[127] The relevant comparison is instead to the total cost of the PV systems, of which R&D costs are likely to be a small part.

2. The benefits from PV use (e.g., fuel savings) were sometimes not discounted. Although short construction times for PV systems mean that initial benefits occur within a year or two of the initial costs, other

---

operating-cost ratio (like nuclear and coal-fired plants), so that once constructed, it should be used as much as possible (base load, like coal and nuclear). However, the output of a photovoltaic cell varies with location, and at any one location, varies with the time of day, time of year, and weather. Thus, unlike nuclear and coal-fired plants, the output of photovoltaics is variable and cannot be "counted on" to meet the base load of a system. Nor, because peak demand at a particular location does not necessarily coincide with peak solar energy availability at that location, can photovoltaics be "counted on" to meet peak demand. However, "counted on" is a relative notion since no generation source is 100 percent reliable, and the presence of PV in a system can clearly displace some capacity.

The problem of integrating photovoltaics, or indeed any solar energy source, into a power system becomes more pronounced as the percentage of solar within the system increases. This exacerbates the "capacity displacement" problem, for it is inherently a long run problem for which existing experience with photovoltaics in the 1970s provided little guide. The results of a number of studies concerning the economic value of PV in terms of capacity, fuel, and operations and maintenance savings are summarized in Smith (1980b), Vol. II, pp. 20-25.

[127] This is done implicitly in NSF/NASA (1972), Tables 3 and 4, and explicitly in U.S. Federal Energy Administration (1974), p. VII-10, and 1975 ERDA Testimony (Teem (1975), pp. 207-208)).

factors (a high ratio of capital costs to operating costs, and the 20-30 year lifetime, i.e., stream of benefits, required to make PV economic) make the failure to discount serious.

3. The benefits of the federal government's PV research and development program were sometimes confused with the benefits of PV use. The benefits of a federal R&D program, by contrast, are a function of the benefits of PV use occurring earlier than they otherwise would.[128]

In addition, there was one error which could have led to either overstatement or understatement of the potential of PV relative to other technologies. The benefits of PV use are the cost savings, which are a function of the quantity of PV used and the unit cost difference. The benefits of various technologies, including PV, were sometimes evaluated by comparing the conventional energy production displaced by the technology with the federal funds devoted to the technology,[129] or sometimes by just looking at the energy production figure.

In each aspect reviewed above, the changes over time would lead an observer to a lower assessment of PV value. First, oil and electricity prices did not increase as expected. Second, the attractiveness of residential systems decreased due to a recognition of difficulties. Third, the penetration estimates also declined from the early 1973-1975 estimates to the DOE estimates in 1979-1980. Finally, the assessment of

---

[128] This point is made clear in Hamilton (1981) in which the proper approach is developed. The question of PV value has been virtually ignored since this paper.

[129] For example, the response of the Policy and Evaluation group in the Department of Energy to a request from Senator Bennett Johnston--Inside DOE, May 18, 1979, or the suggested approach in Schmalensee (1980), p. 18.

the economic value of a given level of PV use decreased as a number of methodological errors in the early assessments were gradually eliminated from analyses.

The principal conclusion to be drawn from studying the wealth of analyses of the prospects for PV is that the economic benefits of the program were generally overestimated due to a combination of optimistic estimates and faulty methodology. The early studies, undertaken largely by advocates, were the worst in this regard. As the program progressed, the studies became more pessimistic, primarily because of the general decline of forecast energy prices and demand, and the realization that the focus on distributed systems had been misplaced.

BUDGETARY HISTORY

Although the budgetary fortunes of PV and all solar energy programs rose and fell together, PV's share of the total solar budget has risen steadily, from 19 percent in fiscal year 1976 to 39 percent in 1989. Table 21 shows appropriations for photovoltaics whereas Table 22 shows solar appropriations.[130] Table 23 shows that PV has always fared a little

---

[130] Whatever their importance in the Congressional funding process as a whole, authorizations have played a rather minor role in photovoltaics, especially in recent years. This is due to the fact that during the 1979-1985 period, for example, Congress failed to pass the relevant energy authorization bill for fiscal years 1979-1981 and 1985, and for 1983-1984 set authorizations in terms of a formula based on the previous year's appropriation plus 10 percent. Such a rule is not likely to be binding during a period of program contraction (as occurred in this period). Furthermore, this rule appears to apply at the level of the appropriation account, i.e., "operating expenses--energy supply, research and development activities" and photovoltaics is but a small portion of this account. See U.S. Senate (1980), p. 9; (1981), p. 6. Thus the authorization process did not seem to provide guidance to the appropriations committees regarding photovoltaics funding in some years of the program.

Table 21
Photovoltaics Appropriations, 1976-1989
(Operating Expenses, Capital Equipment, and Construction)

Fiscal Year	Admin. Request	House Comm.	House	Senate Comm.	Senate	Conference/ Final
1976[1]	10.0	12.0[2]	29.5	10.7[2]	na[3]	21.6[2]
1977	32.8	34.7	68.8	49.6	na4	64.0
1978	57.5	57.5	57.5	57.5	57.5	57.5
Supplem.	57.5	57.5	76.5	76.5	76.5	76.5
1979	76.1	125.3	125.3	106.1	106.1	118.8
1980	130.0	157.0	157.0	152.0	152.0	157.0
Rescission[5]		na	na	na	na	150.0
1981	160.2	149.0	160.2	152.2	156.0[6]	160.2
Rescission		139.2	139.2	139.2	139.2	139.2
1982	62.9	84.0	84.0	78.0	78.0	74.0[7]
1983	27.0	47.0	na[8]	58.0	na[8]	58.0
1984	32.7	46.7	46.7	55.7	55.7	50.4[9]
1985	47.5	57.0	57.0	56.5	56.5	57.0
1986	44.8	45.8	45.8	49.0	49.0	40.7[10]
1987	20.6	35.6	35.6	40.6	40.6	40.4
1988	20.4	35.0	35.0	39.0	39.0	35.0
1989	24.2	24.2	24.2[11]	37.0	37.0	35.5

Notes:

The final amount for the prior year, and the Administration request and House committee amount for the current year are from the report from the House Appropriations Committee accompanying the appropriation bill. The House amount and Senate committee amount are from the corresponding report of the Senate appropriation committee. The Senate amount is difficult to ascertain; the Congressional Record often does not provide this information for floor amendments. The Department of Energy Budget Request documents were also used at various points. The revised budget request of the incoming President is used in fiscal years 1978 and 1982. The revised budget request in 1979 of $106.1 million is not used since there was no change in Administration.

1. All 1976 appropriation figures shown represent costs (approximating

Table 21 (cont.)

outlays) except for the final figure (obligations) and the House floor figure (unknown whether it is costs or obligations). This is why the final 1976 figure (21.6) is larger than the conference committee total (16.0). The 1976 appropriation figures also do not include $8.2 million for solar research in the 1976 NSF budget. See Congressional Record, December 5, 1975, p. S38926.

2. These figures do not include capital equipment funds, which were not allocated among the solar energy accounts. Including these would probably increase the PV amounts by less than $1 million.

3. The Glenn amendment, to increase solar appropriations by $30 million, did not specify the increase for photovoltaics.

4. The Hart amendment, to increase solar appropriations by $16.4 million, did not specify the increase for photovoltaics.

5. Precise PV totals in the rescission bill are not clear from House and Senate reports.

6. Description of the Tsongas amendment in the Congressional Record appears to leave PV funding unchanged, with only the Dole amendment increasing the PV total.

7. Although the conference total was $78.0 million, a general reduction taken by the Administration reduced this to $74.0 million. See Department of Energy FY 1983 Congressional Budget Request, Vol. 2, p. 24.

8. Neither the House nor the Senate took action on the 1983 appropriations bill, so funds were provided through the 1983 continuing appropriations resolution, which did not specify amounts for PV.

9. Although the conference total was $51.2 million, a general reduction taken by the Administration reduced the PV total to $50.4 million.

10. The conference total of $49.0 million was reduced by $6.5 million by "management initiatives" and $1.1 million by Gramm-Rudman-Hollings reductions. See Department of Energy FY 1987 Congressional Budget Request, Vol. 2, p. 25.

11. The $20 million increase in solar from the Brown amendment is only listed in the Senate report as a "general increase"; it is not allocated among the solar accounts.

Table 22
Solar Appropriations, 1976-1989
(Operating Expenses, Capital Equipment, and Construction)

Fiscal Year	Admin. Request	House Comm.	House	Senate Comm.	Senate	Conference/ Final
1976	57.1	75.0	84.7	71.7	107.1	114.7
1977	160.0	213.7	304.8	261.9	278.3	290.4
1978	320.0	368.2	368.2	358.5	364.0	368.3
Supplem.	368.3	368.3	392.3	392.3	392.3	389.3
1979	372.1	526.3	526.3	450.1	455.1	485.3
1980	563.8	561.0	561.0	569.9	569.9	577.7
Rescission		549.2	549.2	517.2	553.7	552.7
1981	613.2	553.1	602.1	564.9	574.6	596.4
Rescission	505.6	500.0	500.0	503.6	503.6	500.0
1982	193.2	304.4	304.4	253.4	253.4	268.2
1983	72.2	180.4	N/A	187.9	N/A	201.9
1984	86.4	180.0	180.0	176.0	176.0	181.7
1985	163.6	174.5	174.5	183.0	183.0	179.4
1986	148.0	147.0	147.0	161.7	161.7	144.6
1987	72.3	113.4	113.4	125.8	123.5	123.5
1988	71.2	101.2	101.2	105.1	105.1	96.9
1989	80.4	80.9	100.9	98.8	92.2	92.2

Note: As in Table 21, the 1976 figures represent a mixture of costs and obligations. The original budget requests for 1976 and 1979 are shown, since no change in Administration took place. In 1978 and 1982, where there was a change in Administration, the request of the incoming President is shown. For 1986, the conference figure of $157.2 million was reduced by management initiatives of $6.5 million (solely in PV), Gramm-Rudman-Hollings reductions of $5.9 million, and other adjustments of $0.2 million.

Table 23
Percentage Increase in Appropriations for PV and Solar

	Average Annual Increase 1976-80	81 Resc. over Prev. 81 Level	82 over 81 Resc.	83 over 82	84 over 83	86 over 84	89 over 86
PV	74.4	-13.1	-46.8	-21.6	-13.1	-19.2	-12.8
Solar	56.4	-16.2	-46.4	-24.3	-10.0	-20.4	-36.2

better than solar programs in general, with a significant difference since 1986.

The budgetary history of solar energy shows that the entire program was driven primarily by congressional enthusiasm. In every year except 1980 and 1986, the solar amount appropriated by Congress equaled or exceeded the President's request. For PV, the Congressional amount was larger in every year except 1981 and 1986. The 1986 final figures for solar and PV are below the budget request due to Gramm-Rudman-Hollings reductions. The average percentage increase each year in appropriations over the President's proposed budget was virtually identical for PV and the entire solar budget--50 and 49 percent, respectively (Table 24).

Congressional enthusiasm for solar energy was not confined to its authorizations and appropriations oversight committees. Neither the House nor the Senate ever even voted on an amendment to reduce funds below the amounts proposed by their appropriations and authorizations committees. During the period of growth in the 1970s, proposals to increase funds above committee proposals were often offered and passed. Moreover, with few exceptions proposals to increase spending on PV were packaged with increases in all or most other solar energy activities. During the harder times of the 1980s, appropriations committee requests were always accepted without amendment, and were always higher than the administration had requested, with two exceptions. First, for fiscal year 1989, the House accepted an amendment to increase funding solar by $20 million. Second, for fiscal year 1986, the House committee recommended a level $1 million dollars below the Administration request for PV and solar.

If one assumes that the program managers, executive branch budget

Table 24
Percentage Increase of Final Appropriations over Administration Request

Year	PV	Solar
1976	116.0	100.9
1977	95.1	81.5
1978	0	15.1
1979	56.1	30.4
1980	20.8	2.5
1981	0	-2.7
1982	17.6	38.8
1983	114.8	179.6
1984	54.1	110.3
1985	20.0	9.7
1986	-9.2	-2.3
1987	97.1	70.8
1988	71.6	36.1
1989	46.7	14.7
Average Increase	50.1	49.0

Note: Table does not show supplementals or rescissions.

officials, and members of the oversight committees generally possessed more expertise about the program than did Congress in general, the implication of these figures is that the PV and solar programs grew too fast in the 1970s. If so, the incremental dollars would have been spent on activities with relatively low productivity. Moreover, because of the long-term character of the program from the outset, one would expect that the program would have had a better chance for success if the boom and bust pattern of the last 15 years had been replaced by a much smoother, more even path of expenditures.

THE POLITICS OF SOLAR ENERGY

The dramatic rise of the budgets for solar energy during the Carter presidency and the equally dramatic decline during the Reagan years, suggest that strictly political factors--differences in support constituencies and ideologies--were an important factor in the life of the program. For purposes of analysis, the forces affecting the political survival of solar programs can be usefully separated into three categories: ideology and party; distributive politics; and program performance. Whereas it is clear that the demise of solar energy programs began with the election of Ronald Reagan, the question remains whether the Reagan Administration's opposition to the program reflected fundamental ideological and policy differences with the Carter Administration, a simultaneous change in the long-term prospects of the solar energy program, or differences between Republicans and Democrats with respect to the constituencies that they seek to woo with targeted federal expenditures.

Party and Ideology

The policy differences between the two Administrations on the issue of solar energy were abundantly clear. The Carter Administration advocated a broad-based, research-oriented energy program, and specifically solar energy. In addition to the increases in budget requests shown in Table 21 and 22, the November 1978 National Energy Act, consisting of five pieces of legislation, provided for government procurement, tax credits, and utility fuel-use restrictions. The Solar Photovoltaic Energy Research, Development, and Demonstration Act (P.L. 95-590, November 4, 1978) represents the only legislative enactment of photovoltaic goals during the history of the program. The Act set forth a fiscal year 1988 production goal of 2 million peak kilowatts and a 1988 price goal of $1 per peak watt for installed systems. It contemplated that the 10-year program to attain this goal would require a federal expenditure of $1.5 billion. Earlier that year, on Sun Day, May 3, 1978, President Carter instituted the Domestic Policy Review of Solar Energy. Following that review, President Carter, on June 20, 1979, proposed a national goal of meeting 20 percent of our energy needs with solar and renewable resources by the end of this century, and outlined a comprehensive program involving a number of government agencies to accelerate the use of solar energy.[131] In contrast, President Reagan soon after taking office, proposed shifting "the Department of Energy's solar activities away from costly near-term development, demonstration, and commercialization efforts and into longer-range research and development projects that are too risky for private firms to undertake." Accompanying

---

[131] U.S. House of Representatives (1979).

this redirection was a proposed reduction of DOE solar spending by more than 60 percent in 1982, with cumulative savings of nearly $1.9 billion by the end of 1986.[132]

Accompanying this shift in party and ideology of the Administration was a shift in party, and consequently ideology,[133] in the Congress, shown in Table 25. Thus shifts in party and ideology in the Administration and Congress immediately preceded major funding increases in the 70s and reductions in the 80s for solar and photovoltaics.

---

[132] U.S. House of Representatives (1981, pp. 4-16).

[133] A time series for ideology is more difficult to obtain. Although there is no theoretical reason why average ACA score should provide a good time series, the actual numbers dash any hopes that this would be the case. The ACA scores increased with the arrival of the "class of 74" (one would have expected a decrease), and the differences in ACA scores within any one Congress are too large relative to the shifts across Congresses.

YEAR	AVERAGE ACA SCORE IN HOUSE	YEAR	AVERAGE ACA SCORE
1970	48.3	1977	43.0
1971	50.8	1978	48.3
1972	49.6	1979	44.3
1973	46.3	1980	46.1
1974	42.9	1981	49.6
1975	45.2	1982	48.6
1976	40.9		

With respect to ADA scores, Kau and Rubin (1979b) claim that the ADA picks votes so that the average rating is about .5 and thus such ratings are not suitable for a time-series study.

One procedure that has been used is to average the score for different years of each member, and then compute the average score of each Congress using these averages for each member. This procedure assumes that the liberal-conservative positions of each member are constant over time and the variation over time in the liberal-conservative nature of the Congress is due to changes in membership.

Table 25
Party in the U.S. Congress

	House	Senate
Year	% Democratic	% Democratic
1971	58.5	55.1
1973	55.5	57.1
1975	66.9	61.9
1977	67.1	61.6
1979	63.7	58.6
1981	55.9	46.5
1983	62.0	46.0
1985	58.1	47.0
1987	59.4	54.0

Note: Percentages are calculated as Dem./(Dem. + Rep.) and thus independents are ignored.

Source: U.S. Department of Commerce (1986, p. 235) for 1971-1985. U.S. Government Printing Office (1987) for 1987.

Distributive Politics

The importance of distributive politics arises from the nature of representation of the citizenry in Congress. One can expect legislators to evaluate programs based in part on the effects of the program on their constituents. In the solar energy program, these effects are the stimulative effect of federal expenditures and the benefits of solar energy.

Several distributive aspects of the solar energy program are likely to have had similar effects on all or most solar technologies. Sunlight, for example, is important to both solar thermal and PV technologies, although less important for wind. Another common factor is the price of conventional and other energy sources, which also varies geographically. All solar technologies will be more attractive in areas where, all else being equal, conventional and other energy sources are more expensive.[134] Still another factor is overlapping technology. For example, solar thermal and PV both use concentrators, so that advances in concentrator technology would benefit both. Moreover, the presence of technical commonalities could lead to geographic concentration of solar R&D across a spectrum of technologies. In fact, many firms and government labs worked simultaneously on several solar technologies.

These factors all suggest that the appropriate focus of a political analysis is the entire solar energy program, not one of its components such as PV. Moreover, because solar energy apparently did constitute a

---

[134] Although different solar technologies may substitute for different fuels, there is enough commonality in fuel type as well as correlation between the prices of these substitutes, to lead to common distributive effects.

politically relevant ideological category of policies, even in the absence of technical and economic commonalities it would still be an ideal basis on which to build a political coalition or to orchestrate a logroll. Hence, separating the distributive effects of each solar energy program is likely to be very difficult and perhaps impossible.

Some distributive factors are useful only for explaining differences among politicians in their support for a program, rather than changes in the fortunes of a program over time. For example, the geographic distribution of sunlight does not vary over time, and so cannot explain the rise and fall in the fortunes of the solar energy program. In the case of PV, changes in the distributive politics of solar energy could affect its long-term fortunes in the following ways. First, if any one of the solar energy technologies appeared to be losing the competition with PV, the entire solar energy coalition could fall apart. Second, a group of firms in the PV industry might develop that was not receiving federal support. Continuation of the program would be seen by them as unfair, and their representatives could come to regard the distributive aspects of the program as undesirable. Third, changes in the political composition of the government could reflect important changes in the relevant political constituencies in assessing distributive effects. Specifically, groups threatened by solar energy (such as the nuclear power industry or, with respect to distributed systems, electric utilities) might become better represented as time progressed, while solar interests simultaneously enjoyed fewer supporters in Congress. This effect, of course, is all but impossible to disentangle from the effects of party and ideology.

The distributive benefits of PV were quite uncertain along three dimensions: when PV would work, who it would work for, and who would receive federal money. The first uncertainty arose out of uncertainties internal (supply-side) and external to the program (demand-side). The uncertainty about who PV would work for arose because of the complicated nature of PV economics, in which the competitiveness of PV in a region would depend on a number of factors such as latitude, weather, load pattern, environmental constraints, the need for new capacity, and the cost of alternative sources. Whether the primary market for PV was dispersed residential use or central-station utility generators was also uncertain for the first 10 years of the program.

Who would receive federal money was uncertain for a number of reasons. The program was not targeted from the beginning, such as a dam or harbor would be. Also, there was uncertainty about program direction: an R&D program implied a different set of beneficiaries than a program of demand stimulus achieved through a combination of government procurement, tax credits, and forced utility purchases. Within the context of an R&D program, there were additional sources of uncertainty. First, the contract award process was decentralized and thus less subject to political influence. Second, who got the larger contracts that characterize the later stages of R&D would depend on technical success in earlier stages, and this was highly uncertain. Finally, the approach to demonstrations was to not fund a single project, unlike the solar thermal project at Barstow, California, or the Clinch River breeder reactor. Demonstration projects were funded, but they were of a smaller scale, and hence less predictable.

The next two chapters will examine the distributive benefits of PV in more detail. Chapter 3 develops a model of the benefits of PV technology. Chapter 4 uses this model in an econometric analysis of PV roll call voting.

EVALUATION OF PROGRAM

There are a variety of ways to evaluate the photovoltaics program. Among these are the following:

-Did the program achieve its goals?

-Were the goals of the program sensible?

-Did the program make the right strategic decisions?

-Were the budgetary levels appropriate?

-Was the form of government involvement the right one?

-Was the management structure appropriate?

These issues will be addressed in this section.

Did the Program Achieve Its Goals?

Evaluating the PV program in terms of its outcome has three major deficiencies. First, both cost reductions in PV and the external environment in which the product must compete are subject to substantial uncertainty. One should not confuse a bad outcome with a bad decision. Perhaps the program was likely to produce commercial adoption but a bad draw from nature resulted in an uneconomic outcome. Second, even if adoption of the technology is unlikely, proceeding with the technology may be wise, particularly if one is risk-averse, to provide insurance against future events that may not transpire, but that would be very costly if they did and no plans had been made to cope with them. Third, the existence of a new energy technology, even if never adopted, can constrain the cost of other energy sources with which it could compete.

These three considerations suggest that evaluating the desirability of the PV program in terms of whether it accomplished its original price goal is unduly harsh. Lack of adoption of the technology could be a result of "unlucky outcomes" (e.g., some foreseen technology cost reductions that did not happen, or the decline in world oil prices beginning in 1981). Similarly, solar technology could be valuable insurance against the possibility that nuclear or fossil fuel alternatives do not work out.[135] Also, the demonstration of a "backstop" technology such as solar, even if not available for many years, could significantly depress current oil prices due to the fact that energy producers, as a result of the demonstration of the technology, will produce more oil and sell it at lower prices until the backstop technology becomes available.

Neither the Administration nor the Congress justified the program as either insurance or as a backstop technology. The justification for the program was that achievement of the program's goals, which were considered feasible, would result in commercial adoption of the technology.

Were the Goals of the Program Sensible?

Primary emphasis on a cent-per-watt cost goal for modules for most of the program's history (1973-1983) raises the possibility of mismanagement of program resources. A major argument in favor of this

---

[135] Landsberg (1979), p. 468.

goal is that a stable goal, even if not ideal, is preferable to a shifting target based on changes in energy prices, financial parameters, etc. A second advantage was its orientation toward costs rather than technical accomplishment. The disadvantages were the neglect of balance-of-system costs in the module goal and the lack of a direct tie to economic viability.

Did the Program Make the Right Strategic Choices?

Several key strategic choices were made during the life of the program. Probably the most important was the balance between research and development and government procurement. Although the 12 percent of program funds spent on demonstration programs was too large, it means that the program remained throughout primarily a research and development program.[136] Furthermore, 12 percent compares favorably with other energy programs, such as the solar thermal or breeder reactor programs. Both of the latter included a single major demonstration project which consumed a large portion of the program budget. By contrast, the PV demonstration projects remained relatively small, entirely in keeping with the notion that PV was a modular technology and hence that there were not risks in extrapolating results to large units.[137]

The program underwent several shifts in its thinking regarding system configuration, specifically the role of storage and the role of distributed vs. central-station PV systems. Analytical issues that are

---

[136] As noted earlier, the solar tax credits are similar to government procurement and are not included in the 12 percent figure.

[137] This characteristic of PV is noted in Maycock (1985), p. 140.

clear in hindsight are often muddled at the time, and it is reasonable to regard some program expenditures as necessary for learning. The inclusion of storage costs appears to be a simple analytical mistake that did not have major long-term consequences (inclusion made batteries seem more important than their obvious use in remote applications). The emphasis on distributed systems in the late 1970s reflected political and social factors. On the analytical side, the resolution of the issue depended on the appropriate balancing of financial and tax considerations favoring residential use vs. cost factors that favored central-station use. The cost differences between distributed and central-station systems were not accurately assessed in the late 1970s. Some errors were obvious--e.g., the view that residential maintenance costs were zero (since they do it themselves). Another error which could have been avoided without any detailed research was the failure to perceive the large marketing and distribution costs of distributed systems, and complications such as utility interconnection and PV installer training that are exacerbated in distributed applications.[138]

This misplaced emphasis on distributed systems could have had a number of effects that could have retarded progress in central-station applications. The specific problem areas might have been the following: too little emphasis on concentrators and sun-tracking systems; too much emphasis on residential institutional issues such as building codes and engineering, legal, and economic issues relating to the interconnection

---

[138] There may also be a safety issue. I was told by a former lawyer for the nuclear industry of an estimate that extrapolated from the accident experience of homeowners with rooftop antennas to conclude that accidents from rooftop PV could be sizable.

of dispersed PV systems to the grid, primarily relating to the sell-back of electricity to the grid; and, among demonstration projects, too much emphasis on residential and not enough on utility applications. However, this distributed bias would have had little effect on much of the research effort, since much of the technology would be the same under either focus.

Another potential difficulty was distortions introduced by the difference in PV tax credits for residential and business use, and the exclusion of utilities from the credit. The actual effect of these provisions is difficult to determine given the lack of data on utilization of the PV credits.

Were the Budgetary Levels Appropriate?

The program grew rapidly in the 1970s and shrank dramatically in the 1980s. Whether this growth and subsequent cuts were justified is a complicated question. One place to begin is with the shape of the budget path, given that the program was designed to payoff 10-25 years after its inception. Growth of a program from $2 million in 1974 to $76.5 and $150 million four and six years later incurs some waste. This must be balanced against the perceived urgency in the 1970s concerning the development of energy alternatives. Similarly, rapid reductions incur inefficiencies as research and demonstration programs are terminated prior to fruition. This in turn must be balanced against the decreasing need for alternative energy sources with falling oil prices. The decline of world oil prices beginning in 1981 reduced the expected benefits of PV, so an optimal program would have been cut back. But this does not answer the question of whether the pre-1981 levels were too high or low, or whether the magnitude of the cutback was correct. The growth appears to have been too rapid and the subsequent cuts too severe, given the steady progress of the program, but this judgment is difficult if not impossible to prove.

Was the Form of Government Involvement the Right One?

There are at least two alternatives to the form of government involvement utilized in PV. One is to let the private sector make the R&D decisions. This is the approach recommended by Nelson (1982) and Gates (1988) except for special cases, such as where there is a well-defined government procurement interest. To ensure that the private sector undertakes the R&D, there are "carrot" and "stick" approaches. The "carrot" approach is tax credits, either on the supply side supporting research and development, or on the demand side supporting purchases, which indirectly spurs R&D. The "stick" approach is regulatory. For example, little government R&D money has gone into pollution abatement or increased gasoline mileage, two issues that the government has deemed (via the regulatory process) to be of national importance. In both of these cases, the strategy has been to mandate performance goals or the adoption of certain technologies. The analogy in photovoltaics might have been to mandate that electric utilities utilize photovoltaics.

The approach the government followed was different. On the supply side, the policy was more specific than a tax or regulatory approach because the government made specific choices on the supply side among competing technologies, whereas these other approaches would have only required that the research be in a category, such as PV, solar, or energy, and thus would not discriminate among PV approaches. On the demand side, it supported adoption of these technologies by government procurement, tax credits, and fuel-use restrictions as in the "carrot" and "stick" approaches. The fuel-use restrictions, however, only required that utilities meet environmental standards and restrictions on oil and gas use, and that they buy solar power at their avoided costs. Thus if the environmental/fuel-use restrictions could be met in other ways, and the solar resulting from the government program was more costly than other sources, they had no need to adopt solar energy.

This is not to suggest that legislative and/or regulatory mandates for photovoltaic use by electric utilities would have been a wise policy. These provisions prejudge highly uncertain economic outcomes and may result in substantial inefficiency. However they have the advantage that potential users guide the application of applied and research and development funds.[139]

Given that "technology-forcing" approaches have been used elsewhere, it is worth considering why this approach was not used in photovoltaics. One reason may have been that homeowners were foreseen at the outset as the initial users. Thus failure to perceive that the utility market would dominate (as shown in Table 3) may have precluded the use of alternate strategies for photovoltaics development.

One difficulty in either the PV approach to R&D management or leaving it up to the private sector is that the resulting R&D is not coordinated. In government-managed R&D, it is difficult for the government to know what private R&D is occurring and thus how to integrate

---

[139] See the final chapter of Nelson (1982) for a discussion of this point.

its R&D with that occurring in the private sector. The photovoltaic program did not appear to develop special mechanisms to deal with this problem.[140]

An alternative is centralized control, which was recommended by Ouchi (1984) in his criticism of the PV program. In his view, excessive program fragmentation caused contract awards to unqualified organizations and poor coordination of the research. The former point, if true, is also consistent with the view that the program simply grew too fast or made awards for political reasons. The latter is not by itself a conclusive argument, for less coordination is a necessary cost of decentralization and competition that may or may not provide offsetting benefits. That there were offsetting benefits appears plausible.

The program throughout was characterized by a great deal of uncertainty for reasons internal (supply-side) and external (demand-side) to the program. To cope with the technical uncertainties, multiple approaches were supported in a competitive environment. On the demand side, the program devoted a great deal of analytical effort to understanding how PV might become competitive in different uses. Government procurement, tax credits, and utility restrictions were used to assure at least some market for PV.

Conclusion

The fortunes of the photovoltaic program rose and fell with the energy crisis, and with the changes in party and ideology in the Congress

---

[140] This problem has been raised regarding R&D in general by Nelson (1982), p. 5, and with respect to energy R&D by Landsberg (1979), p. 550, and Gates (1988).

and the Administration, first in 1975/77 and then in 1981. One reason for this may have been that, with the exception of a few demonstration programs, the PV program imposed on itself, through the decentralized award of contracts to technical "winners," an inability to reward Congressmen for previous political support. In addition to sustaining a preeminent role for party and ideology in determining program support, this may have had an effect on the economic performance of the program. The allocation of resources within the program was less subject to Congressional control, either directly or indirectly through attempts of program administrators to maintain political support for the program by awarding contracts to particular districts.[141] This freedom from "pork barrel" aspects may have improved program performance.

It is instructive to compare the photovoltaics program with the breeder program.[142] Both were long-term electricity supply options, with essentially infinite energy supplies, but that were too costly for current use. Proponents of both programs argued that the programs were valuable as insurance, even if too costly now or in the immediate future. Solar advocates often argued for more funds for solar based on the funds received by the breeder.[143]

---

[141] Arnold (1979) documents Congressional influence through the actions of program administrators designed to affect Congressional support.

[142] Chapter 9, Cohen and Noll, forthcoming.

[143] "If only a part of the $2 billion of federal funds slated for the Clinch River breeder reactor were directed instead to photovoltaic purchases, the $1000 per-peak-kilowatt could be achieved very soon--compared to a $5000 per-peak-kilowatt estimated cost at Clinch River." Maidique (1979), p. 210, cited in Maycock and Stirewalt (1985), p. 17f.

The conclusion in Cohen and Noll with respect to the breeder that

> results from the R&D program itself play virtually no role in the overall assessment of the program, in part because the program proceeded slowly, but mainly because the external shifts were far more dramatic in their implications than the technical progress of the program

overstates the case for PV, but is basically correct. Changes in the overall energy situation affected both programs, although the decline in electricity demand growth rates impacted the breeder program more severely, through its dependence on the demand for light-water reactors. For photovoltaics, the shifts in external economic conditions were important, but the shifts in the attitude of the federal government toward solar energy were far more important.

CHAPTER TWO

STATISTICAL ANALYSES OF CONGRESSIONAL ROLL CALL VOTING

This chapter briefly surveys statistical analyses of congressional roll call voting that were published in the 1970s and the 1980s. Beginning the survey in 1970 means that the historical context for the early studies is undeveloped, but one has to begin somewhere. Issues addressed below include general statistical methodology and the use of explanatory variables concerning party and ideology, constituency, and campaign contributions.

STATISTICAL METHODOLOGY

The approach in all these statistical studies has been to examine the relationship between voting behavior and other variables. Where regression analysis has been used, votes on bills have been the dependent variable, and variables representing party, ideology, constituent interests, contributions, etc. have been "right-hand-side" independent variables.

Early studies used correlations and ordinary least squares, often in conjunction. Correlations were used by Markus (1974), Bernstein and Anthony (1974), Dunlap and Allen (1976), Kenski and Kenski (1980), Bernstein and Horn (1981), and Wayman (1985). Ordinary least squares was used by Jackson (1971), Markus (1974), Bernstein and Horn (1981), Chappell (1981a), Riddlesperger and King (1982), Peltzman (1985), Wayman (1985), and Wayman and Kutler (1985). Since the mid-1970s, because of the 0-1 nature of the dependent variable (yes-no vote on a bill), most studies have employed either probit or logit, mostly in single-equation form, but in a few instances employed simultaneous models. Probit was used by Davis and Jackson (1974), Silberman and Durden (1976), Abrams (1977), Danielsen and Rubin (1977), Kau and Rubin (1978), Kau and Rubin (1979a), Chappell (1981a), Chappell (1982), Welch (1982), and Coughlin (1985). Logit was used by Kau and Rubin (1979b), Chappell (1981b), Kalt (1981, 1982), Kau, Keenan, and Rubin (1982), Crandall (1983), Weingast and Moran (1983), Navarro (1984), Feldstein and Melnick (1984), Peltzman (1984), Kalt and Zupan (1984), Pashigian (1985), Wright (1985), Nivola (1986), Fowler and Shaiko (1987), and Krehbiel and Rivers (1988a). Probit appeared to be more popular in the earlier studies and logit more recently, but these studies in general do not address the rationale for choosing one over the other.

The studies have attempted to explain samples ranging from a few votes to large numbers of votes. One of two approaches has generally been taken. The first is to estimate one equation for each vote. The second is to estimate one equation, where the dependent variable is a voting index constructed from the individual votes. In either case, the number of observations is the number of members voting (when indices are constructed, these studies generally use members who have voted on all the bills or compute a score for a member assuming his or her votes on the other bills would follow the same pattern as the available votes). Estimation of separate equations for each vote was done by Kau and Rubin (1979a), Chappell (1981b), Wright (1985), and Nivola (1986), among others. Scales were used in Jackson (1971), Markus (1974), Bernstein and Anthony (1974), Davis and Jackson (1974), Dunlap and Allen (1976), Silberman and

Durden (1976), Lopreato and Smoller (1978), Bernstein and Horn, Kalt (1981, 1982), Crandall (1983), and Kalt and Zupan (1984). A third approach is to combine votes by pooling the data. This was done in Weingast and Moran (1983) and Pashigian (1985).

PARTY AND IDEOLOGY

Party and ideology have been used as explanatory variables in many studies. Although no objection has been raised to the use of party, the ideology issue is unquestionably the most controversial issue in roll call analyses. A wide variety of ideology measures have been used. The most commonly used have been the ratings of the Americans for Constitutional Action (ACA) and the Americans For Democratic Action (ADA). Every year each organization selects a set of votes in each House in that year and computes an index (from 0 to 100) for each member, based on those votes. For the years 1975-77 and 1980 (the years utilized in Chapter 4), ACA selected 24-28 votes in each House and ADA selected 18-20. The ACA score for a member is based only on votes that member actually casts, whereas ADA scores treat failures to vote as a vote contrary to the ADA position. Kalt (1981) used a special ADA index which avoided this problem.

Ratings by interest groups are highly correlated and thus the choice of the rating is unlikely to affect the results. ADA scores were used in Mitchell (1977, 1979), Bernstein and Horn (1981), Carson and Oppenheimer (1984), Kau and Rubin (1978, 1979b), Peltzman (1984, 1985), Weingast and Moran (1983), Coughlin (1985), Wright (1985), and Wayman (1985). ACA scores were used by Lopreato and Smoller (1978), Chappell (1981a, b), Welch (1982), and the studies in The Technology Pork Barrel (forthcoming).

Other indices, such as COPE or the League of Conservation Voters, have occasionally been used.

The problem with the use of ideology as an RHS variable in a roll call regression is that if one believes that other variables influence the vote in question (e.g., one includes variables such as party and constituency interest as RHS variables), then it is reasonable to believe that these same variables, or similar ones, influence some of the votes used to create the ideology index (Fiorina (1979)). The coefficients in the roll call regression therefore become difficult to interpret. To confront this difficulty, a number of studies regress the ideology variable on the other variables, and then include the residual ideology variable in the main equation to eliminate multicollinearity between the ideology variable and other variables (Kau and Rubin (1979b), Carson and Oppenheimer (1984), Kalt and Zupan (1984)). This approach has been criticized by Bernstein (1985), Morgan (1985), Sanders (1985), and Poole (1988) on several grounds. First, because the economic interests of the constituents, the member's party, and the member's ideology are highly correlated, it is misleading to define the residuals as "personal" ideology. Second, the Carson and Oppenheimer results using this procedure do not correspond with our normal concepts of who is liberal and who is conservative in the Senate.

Another approach is to utilize ideology measures unrelated to the issue at hand--e.g., Kalt (1981), in examining votes on oil-price control, uses an ADA score on nonenergy issues, and Kalt and Zupan (1984), to examine coal strip-mining voting, use four different substitutes for ideology: a Social Issue Index based on 12 non-Panama Canal issues, a

Panama Canal Index based on 25 votes on the Panama Canal, a single vote on communist immigration, and a single vote on the death penalty. In the latter study, these measures do not do as well as the League of Conservation Voters index, but still result in a considerable increase in explanatory power over the model without ideology.

Another approach is to "explain away" ideology by the inclusion of sufficient numbers of economic variables so that the addition of the ideology variable does not add anything (Peltzman (1984), Coughlin (1985)). Although there has been some success in such an effort[1], it has not been shown that the set of variables from one "success" can be applied to other votes, which of course is one of the strengths of ideology scores, or that Peltzman's results can be extended to the House or to voting on a single issue.[2] More importantly, in comparing votes on one issue to those on others, it is essential that the list of economic variables be relatively compact to facilitate comparison--another strength of ideology scores. Finally, the Peltzman (1984) results suggest that the constituency variables must include those relating to supporters, not just the district or statewide averages, and this significantly adds to the effort involved.

Virtually all studies have found ideology to be significant in roll call regressions, and in some it is the most significant variable, even

---

[1] Peltzman (1984) studied 331 Senate votes in 1979-1980 and found that the inclusion of better voter and contributor interest variables would decrease the explanatory power of the ideology variable. Of course one could take the approach of beginning with ideology, and seeing how much economic variables would add--Poole (1988) believes it would be little.

[2] I strongly disagree with the interpretation of the ideology findings in Coughlin's study of House voting on one issue.

when other constituency variables are included. The significance of an ideology variable in a regression containing economic interest variables could be due to a number of factors. First, as suggested by the Peltzman (1984) results, it may be due to faulty choice of economic interest variables--certainly a number of studies have made odd choices for variables. Second, as suggested by Kalt and Zupan (1984), it may indicate "shirking" by legislators; instead of representing their constituents or supporters,[3] they are voting their own preferences. Third, they are directly representing constituent or supporter ideology, as opposed to economic interest. A few studies have attempted to include measures of constituency ideology, e.g., Kalt (1981, 1982) used the percentage of the state vote going to McGovern in 1972, Kau, Keenan, and Rubin (1982) used percent voting for Ford in 1976, Kalt and Zupan used state membership in environmental organizations, Wright (1985) used percent voting for Reagan in 1980, and Wayman and Kutler (1985) use a public opinion measure of the liberal/conservative nature of the district. Votes for President appear to be problematic as representing voter ideology, since they presumably are a function of judgments about the character of individual candidates and economic interests, as well as voter ideology.

---

[3] The supporter qualification is important in two respects. First, campaign contributions and other support come, to some extent, from outside the House member's district, or the senator's state, and thus variables that refer only to the district and state may not explain votes. Second, members may be influenced more by their supporters within the district/state (which has been termed their "reelection constituency") than those in the district/state not supporting them, and thus constituency variables which refer to the district/state as a whole may not be the whole story. Markus (1974) found that the electoral coalition had a higher explanatory variable than state characteristics.

CONSTITUENCY VARIABLES

Constituency variables included in these studies have been of three types--general, Census-type demographic variables; variables relating specifically to the economics of the issue being voted on; and program expenditure variables. Not surprisingly, studies examining votes on a wide variety of issues use demographic variables almost exclusively, e.g., percent urban, percent nonwhite, percent in agriculture, percent in manufacturing, etc., whereas those in particular areas tend to use variables relating to the issue at hand, either by themselves or in conjunction with demographic variables. The interesting issue in this area is therefore whether the studies addressing votes in particular areas use demographic variables. Those using general demographic variables include Davis and Jackson (1974) in votes on negative income tax, Dunlap and Allen (1976) on environmental issues, Silberman and Durden (1976) and Krehbiel and Rivers (1988b) on minimum wage, Abrams (1977) on NOW accounts, Mitchell (1977, 1979) on natural gas deregulation, Lopreato and Smoller on energy (1978), Kau and Rubin (1978) on minimum wage, Kau and Rubin (1979a) on gas guzzlers and the SST, Kau and Rubin (1979b) on a wide variety of issues, Chappell (1981b) on mortgage disclosure for lenders, air pollution control requirements, and tax rebates for oil companies, Kalt (1981, 1982) on oil price control, and Wright (1985) on an FTC used-car rule, a highway bill, the Gramm-Latta budget proposal, the exemption of professionals from FTC regulation, and the withholding of interest from bank accounts. Those using only specific economic variables include Danielsen and Rubin (1977) on energy, Bernstein and Horn (1981) on energy, Chappell (1981a) on maritime legislation, Riddlesperger and King (1982) on energy, Welch (1982) on milk price supports, Kalt and Zupan (1984) on strip mining, Feldstein and Melnick (1984) on hospital cost containment, Wayman (1985) on defense, Wayman and Kutler (1985) on oil decontrol, and Nivola (1986) on energy conservation.[4]

Thus practice with regard to the inclusion of demographic variables in the analysis has been mixed. Recent studies, or those dealing with energy, tend not to use general demographic variables, although not universally. Kalt (1981, 1982) is included in the list including demographic variables, but the focus there was to determine whether the ideology variable could be explained by the use of demographic variables.

A more surprising pattern is evident in the third type of constituency variable, that relating to government spending. Until recently, the few studies in this area used either a government-wide spend/tax variable (Peltzman (1985)) or spending by the largest of agencies (DOD or HEW--Kau and Rubin (1979b), Kau, Keenan, and Rubin (1982), Navarro (1984), and Wayman (1985)). The lack of significant positive results in these studies is surprising. More recently, a number of draft studies (logit regression studies of the Space Shuttle, Clinch River, and SST in <u>The Technology Pork Barrel</u> and Krehbiel and Rivers (1988a) on federal school spending) have examined spending at the program level, and the results here have been more encouraging. The only published studies using program spending (Bernstein and Anthony (1974) and Arnold (1979b)) have been correlation analyses.

---

[4] In one analysis, of gasoline taxes, Nivola uses a percent urban variable.

CAMPAIGN CONTRIBUTIONS

The post-Watergate campaign financing reforms probably led to the use of campaign contributions as RHS explanatory variables in roll call analyses in two different ways. First, the reforms made the data more available. Second, they are generally credited with increasing the importance of Political Action Committees (PACs). PAC contributions are far better to use as an RHS variable than contributions from individuals, since the issues associated with a PAC contribution are more clearly identified than those associated with an individual's contribution. Studies employing campaign contributions have included Silberman and Durden (1976); Chappell (1981a); Chappell (1982); Kau, Keenan, and Rubin (1982); Welch (1982); Feldstein and Melnick (1984); Wright (1985); Wayman and Kutler (1985); and Schroedel (1986).

These studies suggest that the use of contributions in the analysis of solar energy voting is inadvisable. First, these studies have generally either found insignificant effects or, where significant, effects which were the least significant of the variables examined. Second, these studies examined issues such as the minimum wage, milk price supports, the exemption of professionals from FTC regulation, and others which affected PACs which were generally viewed as the most powerful. There is certainly no solar energy PAC in this league. Finally, the inclusion of contributions generally has complicated the analysis, through the use of simultaneous models to deal with the endogenous nature of contributions.

CHAPTER THREE

BENEFITS OF PV

There are three difficulties in assessing PV benefits. In order of increasing difficulty, they are as follows. First, there are different types of benefits, different markets, all of which must be considered. Second, the nature of the proposals being voted on, to increase spending on PV over the level recommended by the authorization or appropriation committee, means that the benefits of a PV proposal may be different from the benefits of PV. Third, determination of benefits in grid-connected markets is complicated for any generation source, but is made more so by the intermittent nature of PV generation. These difficulties are addressed in the next three sections.

Following the discussion of these three difficulties, two issues of how this benefit information should be used in a roll call analysis are discussed. These issues apply to virtually all roll call analyses. First, what is the appropriate base case and the role of costs? Second, should benefits be represented by a single benefits variable corresponding to consumer surplus or by several "indicator" variables that are in some way related to the benefit variable?

Finally, based on the above, several options for PV roll call analysis are described in detail and a preferred option chosen.

TYPES OF BENEFITS

As discussed in Arnold (1981a, b), public policies in general offer (and Congressmen evaluate) three classes of benefits. <u>General</u> benefits of a policy accrue to everyone, group benefits accrue to particular segments or groups in society, and local benefits flow to specific geographic areas. As he states, "When general benefits are substantial and the support for them is widespread, programs survive and prosper without having to allocate local benefits carefully to maintain a congressional coalition."[1]

I will also classify benefits along another dimension into two or three categories. Expenditure benefits will refer to the stimulus effect of federal program expenditures, whereas I term all other benefits nonexpenditure. In many government programs such as those relating to technology development, nonexpenditure benefits can be further subdivided into production benefits (e.g., stimulus resulting from production of PV systems) and consumption benefits (e.g., cost savings from using these systems to produce electricity). The relative importance of these categories in a cross-sectional context will vary depending on the program. In defense, expenditure and production benefits will dominate because defense is a "public good" and therefore the consumption benefits do not differ across districts.[2] Because defense is entirely federally procured, expenditure and production benefits are identical. By contrast, nonexpenditure effects will dominate in regulatory programs. Solar energy programs are interesting because all three types of benefits (expenditure,

---

[1] Arnold (1981a), p. 528.

[2] Throughout this chapter, references to "district" should always be interpreted as references to districts or states to account for the different unit of representation in the House and Senate and the fact that even though data are desired on a district basis for analysis of House votes, they are sometimes only available on a state basis. References to Representatives likewise include Senators.

production, and consumption) are distinguishable and could be important. Nonexpenditure effects might dominate if federal expenditures were low relative to classic "pork barrel" projects. On the other hand, if PV were seen as a "loser" which would not become economic, then expenditure benefits might dominate.

These two dimensions (general/group/local and expenditure/production/consumption) produce a 3x3 matrix classification of benefits. However, not all cells of this matrix will be important for our analysis of PV.

General Benefits of PV

PV provides three types of general benefits: reduced dependence on foreign oil, a backstop technology which constrains price increases in other energy sources[3], and reduced pollution.[4] Oil savings received far more attention than the other two types of general benefits in PV analyses. In fact, it was viewed as a major benefit of the program. Because general benefits do not vary by district, it is not possible in a cross-sectional analysis to determine whether one type of general benefit was more important than others. In a time series analysis, the relative importance of different types of general benefits can be

---

[3] PV as a backstop technology benefits all consumers of the alternatives to PV, not just those who end up consuming PV, and is therefore a general benefit.

[4] Reduced pollution from PV replacing use of fossil fuels has both local and general benefits. Local effects of fossil fuel generation are important, both at the site of generation and in some more distant areas as a result of acid rain. The primary general effects are global warming as well as lowered "option" value (lowering the utility one receives from knowing that other areas, even if one will not live there, have low pollution).

determined if the levels of these change over time. Unfortunately, as explained in Chapter 4, a time series analysis of roll call votes is not feasible for photovoltaics because of the lack of comparable votes which could be pooled. Hence the subsequent discussion will be limited to cross-sectional analysis and will ignore general benefits.[5]

Group Benefits of PV

Group benefits of PV would go to various classes of users (e.g., homeowners, utility companies and their customers, the DOD, etc.) and PV system producers and installers. As with group benefits in any program, group benefits of PV are similar to local benefits. The difference lies in the fact that benefits going outside the district of a member of Congress matter to the member if they flow to members of an identifiable group which may be the source of campaign contributions or may increase the support given to the member from group members inside the district.

Neither of these conditions for the salience of group benefits applies to PV. As discussed in Chapter 2, there is no reason to believe that campaign contributions were important for PV. With respect to the second condition, one should examine the three groups that might especially benefit from PV: electric utilities, PV manufacturers, and PV

---

[5] General benefits could be added in to all districts if one were concerned about whether members voted for PV even when total net benefits for their district were negative, or vice versa. However, determination of the sign of total net benefits for each district is very difficult given the uncertainty regarding future PV and conventional electricity prices, the need to assess insurance benefits at PV and conventional electricity prices different from the expected values, and other complications (explained later in this chapter) in assessment of PV benefits. For these reasons, I will not be interested in whether benefits in a district are positive or negative, but only how they compare to benefits in other districts.

research firms. During the period of the votes (1975-1980), electric utilities were very lukewarm toward PV and were not lobbying for its support. PV manufacturers, which did strongly support the federal PV program, were competitors. A member with a PV manufacturer in his district would not want PV manufacturers in other districts to prosper. PV research firms were competing for federal dollars and thus their situation was similar to PV manufacturers. These considerations suggest that group benefits for PV should not be analyzed separately from local benefits.

With general and group benefits excluded, the analysis reduces to the analysis of the expenditure, production, and consumption aspects of local PV benefits. Expenditure aspects are measured by PV funding going to individual districts, and are addressed in more detail in Chapter 4. Production benefits in PV occur both where the PV module is produced and also where it is used, since some local labor and materials will generally be used for the latter (e.g., installation, operations and maintenance, etc.). Production benefits depend on the "flow" of PV module production and installation, whereas consumption benefits depend on the "stock" of PV installed (as well as on other factors). Because of these differences, the regional pattern of production benefits at the point of use may be somewhat different than the pattern of consumption benefits. However, they are obviously correlated. Furthermore, the district pattern of production benefits at the point of use of PV is obviously correlated with the corresponding pattern of benefits at the point of use of whatever PV replaces. For these reasons, production benefits of PV at the point of use will be ignored.

The production benefits at the point of PV module manufacture will be represented by a dummy variable which indicates whether the district contained a PV manufacturer. Further details on this measure are contained in Chapter 4. The rest of this chapter will be devoted to local consumption benefits, with the exception of generic issues relating to roll call analyses.

PV Markets and Resulting Consumption Benefits

Assessment of the local nonexpenditure benefits of PV requires an assessment of several markets and the types of benefits in each market. The PV market can be divided into five markets: foreign, U.S. specialty (calculators, watches, etc.), U.S. government, U.S. nongrid, and U.S. grid-connected applications. Upper-bound estimates made in the late 1970s of the size of these markets are shown in Table 26.

The analysis of nonexpenditure benefits will differ by market. All markets result in U.S. "production" and "consumption" benefits except the foreign market, which only confers production benefits to the U.S. The local consumption benefits of PV are cost savings and reduced pollution as a result of installation of the technology, and insurance against price increases in other electricity sources. Insurance benefits result from potential cost savings from utilization of PV and therefore are local in nature in contrast to the backstop nature of PV, which provides benefits to those who do not utilize PV. Because insurance benefits are potential cost savings (that would be realized if the conventional price, PV price, or other factors are different than expected), they are perfectly

Table 26
Initial Breakeven Prices (1977) and Market Potential

Market	System Breakeven Price ($/Wp)	Market Size (MW)
U.S. Private Nongrid:		
Communications	20	2.5-2.7
Shallow-Well Cathodic	35	0.5-1.6
Deep-Well Cathodic	11	.18-6.5
Outdoor Lighting	1.5	10-300
Government:		
DOD	4.3	4-86
Non-DOD	6-8	.6-6
Consumer:	4-20	1-3
Grid:		
Sunbelt	1.05	390
Non-Sunbelt	.63	2145
Foreign:		
Communications	10-27.5	1.7-10
Pumping: Low-Lift	3.5-4.25	10-75
Pumping: Medium-Lift	4-9	5-200
Deep Well Cathodic	15-50	.1-4.6
Remote Power	4-12	1-40

Notes:

These estimates are based on a panel review of existing studies. Market size is the upper bound on potential sales and reflects the size of the market for which photovoltaics could compete. The consumer category includes watches, toys, calculators, etc.

Source: Solar Energy Research Institute (1978), Vol. I, p. 51.

correlated with cost savings and thus need not be analyzed separately.[6] The analysis below will therefore focus only on cost savings. Pollution benefits will be ignored here because the program never attempted to make much of the pollution benefits of PV on either a national or local basis.

The consumption benefits of various PV markets are outlined below:

1) U.S. specialty use can be ignored in a cross-sectional analysis; regional variations in consumption are likely to be small. Furthermore, this market was never the focus of the Administration or the Congress.

2) U.S. government use could result in cost savings to the nation as a whole (which are translated into benefits of other programs, tax reductions, or reduced deficits) as well as conceivably permitting applications which would not be practicable without PV. For DOD uses, which dominate U.S. government uses, the latter would generally result in benefits to the nation as a whole, rather than to residents at the location of use.

3) Non-grid-connected and grid-connected benefits clearly vary by district.

Thus, in a cross-sectional analysis of nonexpenditure benefits, non-grid-connected and grid-connected consumption benefits deserve the most attention.

Nongrid Consumption Benefits. As is clear from the system break-even prices and sizes in Table 26, the relative importance of U.S. non-grid and grid markets was subject to some uncertainty during the period of the votes. The grid-connected market was seen as much larger but

---

[6] Again the fact that only relative magnitudes among districts is of interest, means that insurance benefits do not have to be added in.

economic only at lower PV prices. As long as PV prices remained high, the nongrid market would constitute the PV market. When prices dropped, the grid-connected market would dwarf the nongrid market. Therefore the benefits from each market would depend on the rate of price decrease and the discount rate.

The evaluation by the program of the relative importance of these two markets can partially be inferred through examination of the price goals set by the program. The 1973 Cherry Hill goals of 50 and 10 cents per peak watt, discussed in Chapter 1, were grid-connected goals. Not until 1978 was a higher intermediate goal of $2 per peak watt set. The influential American Physical Society report, issued in 1979, focused on grid-connected applications, dismissing nongrid applications based on the small size of the market relative to grid applications.[7] Thus, in program planning, the benefits of grid-connected applications were the primary focus.

Because of the program's evaluation that the longer-term grid-connected market was the appropriate framework for evaluation, and because the non-grid-connected market dominated in the near term, PV provides a test of the Cohen and Noll (1984) hypothesis that the implicit discount rate in the legislative process is higher than in the private sector. The importance of nongrid applications in PV roll call votes would support this hypothesis since analyses tended to dismiss the nongrid market. However, the Tsongas amendment must be treated separately. It was aimed primarily at increased federal purchases of PV systems. In the year after

---

[7] American Physical Society (1979), p. 23. The conclusions were based on the SERI report, which is the basis for Table 26.

the Tsongas vote, an elaborate, market-by-market analysis of the net economic benefit of such a federal procurement initiative showed that (1) the proposal would result in a negative net economic benefit and (2) virtually all of the benefits would occur in the non-grid-connected market because the price reduction effects are sufficient to increase benefits in the nongrid market but not enough to materially alter benefits in the grid-connected market.[8] This has two implications. First, if the nongrid variable is significant in the Tsongas vote, one cannot use this as evidence to support the Cohen-Noll hypothesis, since the agency analysis saw the bulk of the benefits going to the nongrid sector. Second, if the Congressional evaluations were similar to the agency analysis, then one would expect that nongrid applications would be more important in the Tsongas vote than in other votes.

These considerations concerning discount rate and the difference between an R&D program and a procurement program suggest that the role of nongrid applications is an important one to test empirically.

Grid-Connected Consumption Benefits. The special problems involved in assessing PV benefits in this market are described later.

BENEFITS OF A PV FUNDING AMENDMENT

The nature of the proposals being voted on, to increase federal funding for PV by a certain amount, presents two difficulties for evaluation of the benefits of these proposals. First, the benefits of the proposals reflect the benefits of the federal program, not the benefits of the PV technology. Second, the proposals are to increase federal

---

[8] Solar Energy Research Institute (1978).

funding, not up-or-down votes on the entire federal program. These two issues are examined below.

The Benefits of a Federal PV Program

Since the available roll call votes concern funding increases for the PV program, it is important to examine whether the consumption benefits of the federal PV program are different than the consumption benefits of PV. These are identical only if the federal program is necessary for PV, i.e., without a federal program, PV would never be economic. Otherwise, the consumption benefits of the federal program are to accelerate the point at which PV is economic in various applications.[9] To make this more precise, we will develop expressions for the consumption benefits of PV and of the federal PV program.

We shall assume that PV is installed at the optimum time (as defined below) and instantaneously replaces all grid electricity of "type" i. "Type" would refer to different fuel sources (coal, nuclear, oil, gas, etc.) as well as differences in base load, intermediate, and peaking capacity. To relax the assumption of instantaneous replacement of a category, "type" could also refer to parts of each category so that the entire category could be replaced over time. For simplicity, we shall also assume that the installation of PV does not affect the quantity of

---

[9] Only Hamilton (1981) seems to correctly formulate the possibility that the benefit of the program is to accelerate the adoption of the technology rather than be an essential prerequisite for the adoption of the technology. The benefit analysis in Solar Energy Research Institute (1978) considers the change in price and quantity resulting from a federal procurement initiative. Because this initiative is only part of the federal program, the question of whether a market may exist without a federal program is never addressed.

electricity consumed (thus we are neglecting the "welfare triangle" from increased consumption of electricity at lower prices of electricity brought about by PV)[10] and that all cost savings are passed along to the consumer. Let

$U_i(t)$ = total cost[11] of grid electricity of type i at time t

$C(t,s_i)$ = cost of PV (cash flow) at time t given installation at time s to replace grid electricity of type i

The optimum time, T_i, to install PV to replace grid electricity type i, is found by minimizing the following expression:[12]

$$NPV(T) = \int_0^{T_i} U_i(t)\, e^{-kt} dt + \int_{T_i}^{\infty} C(t,T_i)\, e^{-kt} dt \qquad (1)$$

where k is the discount rate. Since PV would probably replace different types of grid electricity at different times, the benefits of PV are therefore

$$\sum_{i \in R} \left[\int_0^{\infty} U_i(t) e^{-kt} dt - \int_0^{T_i} U_i(t) e^{-kt} dt - \int_{T_i}^{\infty} C(t,T_i) e^{-kt} dt \right] \qquad (2)$$

where R is the set of electricity types that are replaced by PV. This reduces to

---

[10] In accounting for increased consumption, the supply curve that shifts is the curve for all electricity (not just PV electricity) due to the fact that the cost of PV is "averaged in" with other cost sources to produce an electricity price.

[11] The cost of energy could include environmental pollution, occupational accidents, and dependence on foreign oil.

[12] This is a generalization to account for multiple conventional sources of the formulation in Orren and Chamberlain (1981) of the optimal time to install PV (the "PV wait" problem).

$$\sum_{i\in R} \int_{T_i}^{\infty} [U_i(t)-C(t,T_i)]e^{-kt}dt \tag{3}$$

These expressions assume that the benefits are under certainty (no insurance benefits) and that the cost of grid-electricity is not affected by PV (no price-constraining effect).

Assuming that PV is installed optimally according to (1) both in the case of a program and the case of no program, the consumption benefits of the program, if they exist, occur in one of two cases:

(1) Without the program, PV would be adopted ΔT_i years later, or

(2) Without the program, PV would never be adopted (Case 1 with an infinite ΔT_i).

Only for case two are the consumption benefits of the program equal to the consumption benefits of PV (derived above). The consumption benefits of the program, B, for case one (assuming that PV is installed at time T_i with the program and ΔT_i years later without the program) are as follows (neglecting benefits such as reduced dependence on foreign oil, reduced pollution, price-constraining effects, or insurance):

$$B = \sum_{i\in R} \left[\int_0^{T_i+\Delta T_i} U_i(t)e^{-kt}dt + \int_{T_i+\Delta T_i}^{\infty} C_{np}(t,T_i+\Delta T_i)\, e^{-kt}dt - \left[\int_0^{T_i} U_i(t)e^{-kt}dt + \int_{T_i}^{\infty} C_p(t,T_i)\, e^{-kt}dt \right] \right] \tag{4}$$

where

$C_p(\cdot,\cdot)$ = cost of PV with a federal PV program

$C_{np}(\cdot,\cdot)$ = cost of PV without a federal PV program

For case two, this expression reduces to our previous expression (equation 3) for the benefits of PV. This expression reduces to

$$B = \sum_{i \in R} \left[\int_{T_i}^{T_i+\Delta T_i} [U_i(t)-C_p(t,T_i)]e^{-kt}dt + \int_{T_i+\Delta T_i}^{\infty} [C_{np}(t,T_i)-C_p(t,T_i)]e^{-kt}dt \right] \qquad (5)$$

The two integrals represent the two potential consumption benefits of the PV program. The first term represents the reduction in electricity costs from replacing conventional sources by PV from the time of replacement of grid source i by PV with the program (time T_i) to the replacement of grid source i by PV without the program (time $T_i+\Delta T_i$). The second term represents the reduction due to the PV program of the costs of PV for the years beyond when grid type i would be replaced by PV without the program.[13]

The Benefits of a PV Funding Amendment

All the roll call votes examined in Chapter 4 are votes on funding amendments rather than yes-no votes on the total program. The analysis of the consumption benefits of the entire program however is applicable as long as one assumes that the consumption benefits of the amendment are perfectly correlated with the benefits of the program. This is a reasonable assumption in general since the precise targeting of funds was either not specified in the amendments or was generally in accord with the baseline distribution of funds. However, as noted above, in at least one

---

[13] Hamilton implicitly assumes, as I have done explicitly, that the quantity consumed is unaffected by the introduction of PV. He also assumes only one electricity generation type and that PV costs are constant over time.

case, the Tsongas amendment, the distribution of consumption benefits would be different since the federal procurement program provided for in this amendment would result in a larger percentage of consumption benefits going to nongrid applications than would be the case under the research and development emphasis of the program without the amendment.

CONSUMPTION BENEFITS IN GRID-CONNECTED MARKETS

The expressions in the previous section require assessment of the cost difference between conventional power and the PV which replaces it. This is in accord with our intuition that the cost-reduction benefit of PV in grid-connected applications would be to replace more expensive electricity. The difficulty lies in the fact that even though power is a homogeneous good, when one replaces power from one generation source with power from another type of generation, one cannot simply compare the costs per kilowatt or kilowatt hour of each generation source. The good supplied by each generation source is not homogeneous, but instead power with a certain probability, that depends on the lead time, the need for repair, and other factors (such as weather, in the case of PV).

This difficulty does not invalidate any of the mathematics presented in this chapter. An optimal planning process would determine the cost, and quantity, of PV that would replace a given amount of conventional electricity, and this is implied by defining C(t,s) in terms of what would replace U(t). Because of the modular nature of PV, PV can be sized to replace prespecified amounts of capacity (e.g., an entire generating unit). However, in other contexts, one will specify the PV capacity and calculate the conventional capacity replaced. Regardless of which variable is fixed, the assessment process is the same.

The cost savings from the alternative technology are assessed by comparing the difference in costs between two cases: (1) the cost of conventional generation assuming that no alternative technology is considered, and (2) the cost of conventional generation assuming that the alternative generation is considered.[14] This requires modelling of the utility load curve and the characteristics of the generation sources involved.

To apply this methodology to PV, one recognizes that because the costs of PV are almost entirely capital costs, PV will always be used when available. Therefore the output of the PV device is subtracted from demand; PV is a negative load. The simplest assumption is that the output of the PV device is known in advance with certainty. To determine the cost of conventional generation with PV, a level of PV capacity is assumed and the output of this capacity is simulated on an hourly basis and subtracted from demand, and then the resulting demand is served by conventional generation. The costs of conventional generation with and without PV present are calculated assuming the utility is optimizing, holding variables like reliability constant. Cost changes are computed for capital, fuel, and operations and maintenance categories. Cost savings are calculated by subtracting the cost of PV from the difference in conventional generation costs.

The assumption of known PV output becomes somewhat unrealistic in the context of short-term load-following by the utility, i.e., the process

---

[14] This methodology is described in Jeffrey L. Smith (1980b), pp. 7-8, and Flaim (1985). The former reviews a number of studies of the savings in conventional energy costs from the use of PV.

of managing demand and supply by putting various types of generation capacity on or off line as required and increasing or decreasing the load on the on-line units. As Flaim (1985) notes, a utility might have to commit additional spinning reserve capacity (capacity that can be brought on-line quickly) to cover the sudden loss of some of the intermittent generation (e.g., PV). At small penetrations of intermittent generation, this is unlikely to matter much. At larger penetrations, this effect would be more important and thus the level of cost savings per unit of PV is likely to decline as the level of PV capacity is increased, although the additional sites from larger penetration would result in greater spatial diversity and thus reduce the correlation in output across sites and thus reduce the impact of intermittent generation on load-following requirements.[15]

Because of the complexities involved in the substitution of any power source for another, and the particular difficulties resulting from the intermittent nature of PV generation, assessment of cost savings from PV in grid-connected applications will be difficult.

GENERIC ISSUES IN USE OF BENEFIT INFORMATION IN ROLL CALL ANALYSES

The two issues discussed in this section are the relevance of other alternatives and costs, and how benefit information is represented.

---

[15] As Flaim notes, the studies she describes showing that larger penetrations of intermittent capacity lead to decreases in percentage of capacity displaced as a percent of PV capacity are based on single-site resource data and thus do not capture the effects of spatial diversity.

The Relevance of Other Alternatives and Costs

Roll call studies have generally not assessed the benefits of the program relative to other proposals.[16] On the cost side, in the few roll call studies which assess expenditure benefits, the practice with regard to whether expenditures are gross or net (of tax) is mixed. Kau and Rubin (1979b), Kau, Keenan, and Rubin (1982), and the other studies in The Technology Pork Barrel use gross expenditures. Peltzman (1985) and Krehbiel and Rivers (1988a) include the tax side as well.[17] Only Wayman (1985) considers both gross and net-of-tax specifications. Net expenditures performed better in a bivariate sense, but there was no noticeable difference in a multivariate setting.

To determine the correct course for PV, one begins with general principles of policy evaluation. Policy evaluation should always consider net benefits, benefits minus costs, and benefits and costs should always be evaluated relative to some base case. There are three polar cases with respect to the base case for policy proposals before Congress. The first is that overall government expenditures and revenues are fixed, and thus

---

[16] Although many roll call studies assess nonexpenditure benefits, they do so by what I will term "indicator" variables rather than "benefit" variables (see next section). The indicators chosen do not attempt to represents benefits relative to another proposal. With respect to expenditure benefits, Krehbiel and Rivers (1988a) examine voting on several alternative school funding proposals. Whether expenditure benefits are assessed relative to other proposals is not clear in the paper.

[17] The latter compute a benefit-cost ratio, which is odd given that benefits minus costs rather than the B/C ratio is the appropriate decision criterion for a decision maker choosing among mutually exclusive projects. Even though the three alternative funding schemes being analyzed there have different aggregate spending levels (and thus preferences over the total level of funding would be relevant as well as the benefit-cost relationship), the use of ratios is questionable.

the program is being funded at the expense of something else. In this event, the tax cost is the same under both proposals and thus can be ignored whereas the benefit measure is the difference in benefits between the two proposals. The second possibility is that total government expenditures and revenue collections are increased by the amount of the proposal. In this case, one looks only at the benefits minus costs of the proposal. The third possibility is deficit financing: tax revenues are fixed, but government expenditures increase by the amount of the proposal. The benefit measure is the benefit of the proposal minus the cost of the deficit financing.

A number of facts are relevant in deciding among these interpretations. First, most spending proposals, including all the solar energy amendments we are considering, are not self-financing; they do not raise taxes. Taxes are raised in separate proposals. Second, during the period of the votes, general revenue tax increases occurred through "bracket creep" without any explicit action of the Congress. Third, Congress is required to set overall spending and revenue levels in budget resolutions. Subsequent authorization and appropriation actions to fund specific programs are supposed to fit within these levels. Fourth, the solar energy funding amendments proposed changes in funding that are minuscule compared to overall federal budget levels. Fifth, the differences among the states in taxes paid per capita are not huge (in 1976 they ranged from a high of $1995 in Connecticut to a low of $945 per capita in Mississippi).[18]

Based on these considerations, inclusion of tax costs in a roll call

---

[18] U.S. Department of Commerce (1978), p. 267.

analysis seems merited only if special circumstances exist. The most important of these is if the proposal explicitly raises taxes. Other criteria would be if the geographic allocation of funds is determined by formula or if the program were particularly large. Allocation of formula invites a comparison to geographic tax share. Furthermore, allocation by formula often results in a more even distribution of funds than in an award process (such as utilized by PV). Subtraction of taxes paid thus is likely to have a greater effect on the relative ranking of geographic areas for programs funded by allocation rather than awards. In a large program, there is a greater payoff from the inclusion of factors (such as tax share) which may not be worth the bother in smaller programs.[19]

Of course tax costs can be ignored where the program is being funded at the expense of something else. In some cases, the proposal does this explicitly (of the solar roll call votes discussed in Chapter 4, only the Brown amendment did this--solar electric at the expense of solar heating and cooling). In cases where the alternative is not explicit, one could implement this interpretation by using the pattern of benefits of government programs as a whole or in the particular budget area. This approach is practical for expenditure benefits (information on total and budget category per capita government expenditures by state is published in Statistical Abstract of the United States), but not for nonexpenditure benefits since it would be impossible to estimate nonexpenditure benefits for all government programs taken as a whole. The interstate expenditure

---

[19] One or another of these two latter special factors were present in each case in the literature where tax costs were considered. Krehbiel and Rivers (1988a) examined school funding (allocation formula) whereas Wayman (1985) examined defense programs as a whole and Peltzman (1985) focused on the entire federal government as a whole.

pattern is considerably different than the geographic pattern for tax share.[20]

Finally, under the interpretation of deficit financing one would determine the geographic incidence of the costs of deficit financing, which of course is quite unclear.

Based on the above, except for the special cases which have been described, inclusion of benefits of alternative programs or the costs of tax and deficit financing costs does not appear warranted. Given the uncertainty as to which formulation is best (e.g., does one use the tax or the expenditure pattern for all programs), assuming that Congressmen would ignore these corrections is attractive. Furthermore, the expenditures from the program are visible, the tax share less so and the benefits from other programs uncertain. However, one could test whether other specifications outperform this simple form in the case of PV expenditures. One would want to test the two alternative specifications: gross expenditures minus tax burden and gross expenditures minus expenditure share in other programs. One could also test specifications using ratios as in Krehbiel and Rivers (1988a).

The Representation of Benefits in Roll Call Studies

The proposition that the degree to which Representatives support a program is influenced by the benefits of the program (to the nation as a whole or their district) can be tested in roll call studies in which one or more RHS variables represent benefits. But what do we mean by represent? The approach used in the roll call literature has been

---

[20] U.S. Department of Commerce (1978), p. 267.

somewhat different for expenditure and nonexpenditure benefits. For expenditure benefits, roll call studies have always used a variable representing the dollar amount going to the district from the agency or program, with the exception of some of the studies done for The Technology Pork Barrel which used dummy variables,[21] and Krehbiel and Rivers (1988a), which used a dollar funding/tax ratio. For nonexpenditure benefits, every roll call study (of which I am aware) has used variables which are indicators of benefits, rather than variables that directly measure benefits in the sense of consumer surplus or net present value.

The approach for nonexpenditure benefits has been to use demographic variables, nonpopulation variables, or both. Examples of nonpopulation variables include electricity price, per capita oil production or consumption, percent increase in medical prices, etc. Although the use of demographic variables is generally as indicators of nonexpenditure benefits, such use is subject to alternative interpretations. For example, demographic variables may be correlated with constituent ideology, and thus the significance of a demographic variable in an analysis could mean that a representative was voting constituent ideological, as opposed to economic, interest. As noted in Chapter 2, recent studies tend to use nonpopulation variables that relate specifically to the issue at hand, rather than demographic variables. The specialized nonpopulation variables may avoid this interpretation problem

---

[21] Banks in his space shuttle study used a dummy variable to indicate whether the district contained a large shuttle contractor or one of the principal NASA Centers for the shuttle. Edelman on the SST and Cohen on Clinch River use a dummy variable because a continuous representation was viewed as too fine a measure for mirroring Congressional behavior and because they believed the responsiveness to funding would be nonlinear.

because they are more uniquely related to constituent economic interest.

Benefit Variables. The potential for the use of benefit variables can be illustrated by examining the issue most studied in roll call analyses: energy deregulation. Instead of using several indicator variables such as oil production and the cost of crude oil in the state, one could calculate a benefits variable and use this instead of the indicator variables in the analysis. Two energy studies by Kalt are the only roll call studies on any topic that even make an attempt in this direction. Kalt (1981, 1982) uses a variable to represent producer interest equal to the product of state crude oil production and the difference between the price of foreign oil and the state's average price of crude oil. Kalt and Zupan (1984) uses a variable which apparently measures the agriculture/timber revenue yield of acres affected by strip mining. These studies use indicator variables to represent other interests.

Use of a benefits variable in roll call analyses has a number of appealing features. First, it provides a straightforward test of the proposition that the degree to which Representatives support a program is influenced by the benefits of the program to their district. Second, estimates of nonexpenditure benefits are often available at the time of the vote, generated by agency analysts, by economic groups with substantial stakes in the outcome, and other groups. These results would be communicated, in a variety of ways, to Congressmen. Third, use of a benefits variable permits the roll call analyst to test a variety of precise ways of integrating the effect of the relevant variables. For example, do the votes suggest that Congressmen are voting the benefits of

PV or the benefits of the program (see above), what escalation or discount rates are being assumed, etc.

Advantages of Indicator Variables. On the other hand, there are several reasons why the use of indicator variables may be more appropriate, and thus why studies to date have used the indicator approach rather than attempt to calculate benefits. The most important of these is that, while it is true that estimates of nonexpenditure "benefits" are often available at the time of votes, this information is not of the form implied by a benefits approach to roll call voting. First, most policy analyses generate impacts on price and quantity variables of interest rather than calculating economic benefit measures such as net present values or consumer surplus. For example, energy deregulation studies featured impacts on gasoline prices or inflation, or oil imports and production, rather than net economic benefit. Second, where studies generate both price/quantity impact and benefit information, the former receives more attention. Third, legislative proposals, in contrast to agency decisions, are often at a level of generality which makes precise determination of nonexpenditure benefits difficult. This is in contrast to the district expenditure benefits of legislation which are sometimes clear either from the legislation itself or from studies produced by the relevant agency indicating funding totals by district. Fourth, most analyses are national in nature, with far fewer addressing regional impacts, and fewer still impacts on a district basis. Perhaps as a result of all these reasons, no study of which I am aware, on any subject, calculates net economic benefit (as an economist would define it) on a district basis.[22]

The other principal argument against a benefits approach is the nature of Congressmen, the decisions facing them, and the voting public. Congressmen are not economists or analytically minded, they must make decisions on a wide variety of topics, and they have limited staff support and limited time for decisions. Reliance on benefits analysis produced by agencies makes the Congressmen more susceptible to manipulation by agency analysts.[23] Indicators represent easily available and noncontroversial data whereas a benefits formula may require data or estimates that are not readily available or which are controversial. Finally, although interest groups may respond to detailed benefits calculations, voters at large would more likely judge nonexpenditure benefits in terms of indicators. Another (but weaker) argument for an indicator approach is that it is obviously easier for the analyst of roll call voting to implement and report. Precisely because the way the indicators combine into a single benefits measure is not spelled out, the roll call analyst can avoid issues that are irrelevant for the purpose at hand.

Conclusion. Although the issue of multiple indicators vs. a single benefits variable may be resolved for some by these general arguments, for others it will depend on the issue at hand. Two key issues are the

---

[22] The statements in this paragraph are based on the author's eight years of work experience in both the executive and legislative branches of the federal government in the areas of the environment, energy, aerospace, and agriculture, as well as familiarity with analyses conducted in PV. However such a study probably exists or agencies might have prepared special computer runs with such information at the request of Congressmen.

[23] Roger Noll to author, June 10, 1987.

following: (1) Were estimates of a benefit variable produced, as were, for example, the estimates of agriculture/timber revenue yield of acres affected by strip mining in Kalt and Zupan (1984), and (2) Do the indicators which relate to benefits and for which there are data or estimates combine in a natural way, as did oil production and the difference in the costs of imported and domestic oil in Kalt (1981, 1982)? These questions are addressed in the next section.

In cases where use of a single benefits variable appears desirable, the best research strategy may be to use an indicator approach first before using a single benefits variable because the risk of misspecification leading to insignificant results would be greater with the benefits variable.

LOCAL CONSUMPTION BENEFITS OF PV: ANALYSES EXISTING AT TIME OF VOTE

The preceding sections have suggested that a complete analysis of the benefits of a PV funding increase proposal would be quite complicated. The program or other groups never produced estimates on a regional or local basis of the benefits of a PV funding amendment, of the PV program, or of PV itself. A complete analysis of such is beyond the capabilities of this paper. Even if it were feasible to conduct one now, there is a philosophical question as to whether such an analysis would provide a good understanding of how Congress voted, since the results were not available to those voting. It is therefore worthwhile to consider what analyses were conducted at the time.

The early studies of PV focus on the national potential of PV and do not carefully examine how the potential of PV differs by region. The first published quantitative regional assessment I found was a 1977 Aerospace Corporation report for the Department of Energy which computed PV energy costs for utilities in five cities. In order of ascending PV costs, they were (1) Inyokern, California, (2) Miami, Florida, (3) Sterling, Virginia, (4) Cleveland, Ohio, and (5) Seattle, Washington.[24] Of course a ranking based on PV energy cost alone does not consider many factors that might determine the potential of PV in different regions.

Beginning in 1978, a number of studies broadened the analysis by calculating PV module break-even prices in grid-connected applications for a small number (often 3-6) of representative sites around the country. The rationale for using PV module or system break-even prices was that PV module and system prices were coming down as the technology progressed. The break-even price indicated how far they had to decline before being competitive and thus was a good way to set cost targets. Areas with the highest PV module break-even price would be the first in which PV was competitive. PV module break-even prices included both PV energy costs and the costs of alternatives. The break-even prices were generally computed for small, but significant PV penetration levels--e.g., 4-16 percent.[25]

Areas with higher break-even prices would tend to have larger benefits from PV for two reasons. First, higher break-even prices mean earlier use and thus earlier cost-reduction benefits. Earlier benefits translate to larger benefits because discount rates are generally assumed

---

[24] Aerospace Corporation (1977), p. 43.

[25] This is the range of the studies summarized in Jeffrey L. Smith (1980b), p. 23.

to be positive. Second, as PV module prices decline past the break-even point, benefits are larger in areas with higher break-even points. The same result holds even if PV prices never reach the break-even point--the higher the break-even point, the greater the insurance value of PV because it provides cost-reduction benefits over a bigger range of PV module prices.

However, these statements ignore the quantity of PV used, which affects PV benefits. The quantity used is equal to the PV penetration percentage times the electricity usage in the region. Two pathologies exist regarding PV penetration percentage. First, if one is comparing break-even prices for two areas, and the higher break-even price is calculated based on a lower PV penetration percentage, then one cannot tell in which of the two areas PV penetration level (and benefits) will be highest for any given module price. Second, if the actual PV module price is below the two break-even prices, one cannot be sure about which area will have the larger PV penetration percentage (a break-even price tells us about the conventional electricity supply curve at one point only).

The degree of electricity usage in the region is independent of the attractiveness of PV, and thus may result in a different pattern of regional benefits of PV than indicated by break-even prices alone. The degree of electricity usage is a relevant issue for a determination of regional benefits, but not to set technology goals or determine where PV will first be used, and therefore was not highlighted in these studies.

The studies showing PV break-even prices for different areas are reviewed below. Most, if not all, of these were sponsored by the solar program in DOE. Although quantitative estimates of break-even prices for each site were produced in each case, I have only shown the relative ordering of sites/regions by break-even price.

-The MIT Energy Laboratory in 1978 examined break-even prices in three different settings: (1) single family residences; (2) institutional buildings (such as a school), and (3) utilities. The residential and institutional analysis chose 5 cities to represent 5 different regions: Miami (South), Omaha (Northcentral), Boston (Northeast), Southwest (Phoenix), and Fort Worth (Texas). The utility analysis was conducted for four synthetic utilities developed by the Electric Power Research Institute (EPRI). The ordering of regions (Table 27) depends on the application considered and the assumptions concerning penetration level and type of capacity displaced.

-General Electric in 1978 computed break-even prices for three utilities. Break-even prices were highest for Arizona Public Service (Salt River Project), followed by New England Electric System, and then Florida Power and Light.[26]

-Stone and Webster in 1979-80 examined three utilities in the Southwest and two in the Southeast. Combining the results of these studies, break-even prices were (from highest to lowest): Salt River Project, Southern California Edison, Florida Power and Light, Baltimore

---

[26] "Requirements Assessment of Photovoltaic Power Plants in Electric Utility Systems," General Electric Company, Volume 2, ER-685, June 1978, Section H, as reported in Jeffrey L. Smith (1980b), pp. 22-25.

Table 27
MIT Results on Attractiveness of PV in Different Regions and Applications
(in order of decreasing attractiveness)

Residential	Institutional
Southwest	Southwest
South/Northeast	Northeast
Northcentral	Texas
Texas	South
	Northcentral

In utility applications, the credit for use of PV was calculated for different regions. No break-even price or other complete measure of PV attractiveness was computed. The credit for use of PV of course does not consider the cost of PV in that region, and thus this ranking is a less comprehensive ranking than the others. The credit was computed based on different levels of PV penetration and types of capacity displaced. The relative ranking depends on these assumptions, and no preferred assumption is indicated in this analysis.

Source: "SERI Photovoltaic Venture Analysis: Long Term Demand Estimation," Richard D. Tabors, Susan Finger with Allen Burns, Paul Carpenter, Thomas Dinwoodie, and Gerald Taylor, MIT Energy Laboratory, June 27, 1978, Appendix I in Solar Energy Research Institute (1978), pp. I-7, 12, 17-20.

Gas and Electric, and then Arizona Public Service.[27]

-General Electric in 1979 computed break-even prices for residences in five cities. From highest to lowest, the ranking was Phoenix, Boston, Miami, Omaha, and Fort Worth.[28] Thus, the ordering was essentially the same as in the MIT study of residences.

-The draft Department of Energy Multiyear Program Plan's 1980 ordering for residential, intermediate load centers, and utilities was Phoenix, Boston, and then Miami, with more pronounced differences for residential and intermediate load centers than for utilities.[29]

-A JPL study in 1983 computed residential break-even prices for nine cities. In declining order, they were (1) Honolulu, Hawaii, (2) Barstow, California, (3) Alhambra, California, (4) Miami, Florida, (5) Boston, Massachusetts, (6) Denver, Colorado, (7) Midland/Odessa, Texas, (8) Phoenix, Arizona, and (9) Lincoln, Nebraska.[30]

-A 1985 JPL study of utilities in 4 cities computed break-even costs. In declining order, they were Phoenix, Fresno, Miami, and

---

[27] Southwest Project: Resource/Institutional Requirements Analysis, Volume III--System Integration Studies, Stone and Webster Engineering Corporation, December 1979, and Southeast Regional Assessment Study--An Assessment of the Opportunities for Solar Electric Power Generation in the Southeastern United States, July 1980, as reported in Jeffrey L. Smith (1980b), pp. 21-25. Since I rely on Smith's account, it is not clear why Arizona Public Service is least attractive. Although I first suspected that different PV penetration levels were the reason, I then linearly interpolated break-even prices calculated for two different PV penetration levels for two of these utilities. Based on this, the penetration levels do not appear to be the key factor.

[28] General Electric Co. (1979) as reported in Jeffrey L. Smith (1980b), pp. 21-25.

[29] U.S. Department of Energy (1980c), pp. D-2, 5.

[30] Borden (1983), p. 24.

Boston.[31]

The possibilities for use of these break-even estimates will be discussed in the next section, with problems in this approach discussed at the end of the chapter.

OPTIONS FOR ROLL CALL ANALYSIS OF CONSUMPTION BENEFITS OF PV

The preceding discussion has developed several important points with regard to estimates of local consumption benefits of PV. First, analysis of these benefits is quite complicated. Second, estimates of module break-even prices, which vary by region, correlate with these benefits if electricity consumption does not vary across regions and if actual PV penetration levels are higher in higher break-even regions. (These are jointly sufficient, but not necessary.) Third, the cost reduction benefits of PV in grid-connected applications depend on a whole host of factors: what type of generation is displaced, the extent of capacity displacement per kW of PV, the fuel savings, the price of PV electricity (which depends primarily on insolation and technology), and the extent of PV use. Estimates for most of these variables on a district or regional basis are not available.

There are several options for how to proceed.

Option 1: Use A Regional Variable Reflecting Break-even Prices

The advantages of this option are that these measures were issued by the program, that they represent the most sophisticated analysis of

---

[31] Crosetti, Jackson, and Aster (1985), Tables 7-9.

regional attractiveness available, and that break-even prices are probably closely related to consumption benefits. Under this option, there are two major issues. The first is which ranking to use, since different numbers of cities are evaluated and the rankings vary by study. One possibility is only to score the most promising regions with all else as "other" because most of the studies attempted to evaluate the relative attractiveness of PV among only the most promising regions for PV--the Southwest, the Northeast, and the Southeast. The second issue is what variable should be used--should one use the break-even price, an integer ranking of regions, or dummy variables to indicate the region? There are two reasons why a generalized measure such as a dummy variable for region, might be preferred. First, although benefits and break-even prices are almost certainly correlated, the exact relationship depends on PV penetration levels and the level of electricity use. Second, the discrepancies in the results of the studies suggests that a general measure representing the consensus of studies might be preferred.

Option 2: Use Indicator Variables

The studies discussed above generally concluded that competing energy costs and insolation are the most important factors in determining the break-even price in grid-connected applications, with some studies including state tax treatment as well.[32] The equations developed earlier suggest that benefits in grid-connected applications are a function of competing energy costs, PV costs, and PV quantity consumed. The first

---

[32] Two sources which cite state taxes are Tabors (1982) and Borden (1983).

part of this section will show that the results from these two approaches are totally consistent, and suggest a common set of variables to indicate district benefits. These variables are per capita electricity consumption, conventional electricity price, and insolation. The section will then consider what modifications are appropriate for nongrid applications, and will discuss the specific variables that should be used for each.

1) Per capita electricity consumption is used because of the dependence of benefits on PV quantity consumed. The latter is equal to the product of per capita electricity consumption and percentage PV penetration level. Per capita electricity consumption is used rather than total electricity consumption because all economic variables should be normalized by population. The percentage PV penetration level will depend on the cost relationship between conventional and PV power, and possibly other factors such as state regulatory policy. The difference in costs between conventional and PV power of course affects benefits directly, as well as indirectly through the percentage PV penetration level.

2) The price of conventional electricity is an important, although imperfect element, of the cost relationship between conventional and PV power. It is imperfect for two reasons. First, because the conventional generation is being replaced by an alternative type of generation, the price of conventional power may refer to a different quantity of power than the corresponding alternative power figure. Determination of the differences in quantities and costs is made more difficult when the types have very different patterns of availability, as when conventional power is replaced by intermittent generation. Second, the price of conventional

electricity represents an average of the costs of different types of conventional generation, and PV is unlikely to displace capacity in the same average pattern. Both of these inadequacies of an electricity price measure may be important in a cross-sectional context since the extent of capacity replacement and the type of capacity replaced is likely to vary by region due to differing load and PV output patterns.

I have not included these factors here because there were no well-known projections at the time of the votes as to the differences in capacity displacement on a regional, much less district, basis. One reason for this was that the situation was dynamic; the extent of oil displacement at the time might be very different than at the time when PV would actually be used.

Instead of using conventional electricity price as an indicator of the benefits of replacing conventional generation, one could also use the percent of generation from oil. The rationale for this latter measure is that several studies have shown that the percent of capacity displacement that is oil is correlated with avoided cost. However, a number of problems exist with the use of this measure. First, the studies indicate that the percent of capacity replaced that is oil is correlated with avoided cost. This percent can only be determined by analysis of the role of PV in the particular system, and cannot be determined solely from the percent of generation that is oil (one still needs to know how much capacity is displaced, and how much of this is oil). Second, the level of oil generation capacity is likely to be very different at the time when PV is competitive in grid-connected applications, due to the displacement of oil by coal and nuclear in the meantime. Third, when oil use is reduced, avoided capacity costs, not the value of displaced oil, will be more important in determining avoided costs.[33] For these reasons, I have not pursued the use of this measure.

(3) <u>Insolation</u> can be used to indicate PV costs. This will be demonstrated by examination of the factors that determine PV costs. The cost of PV, as given in the 1987 Five Year Plan is

$$\mathrm{EC} = \left[\mathrm{FCR}\ (1 + \mathrm{ID})(\mathrm{MD} + \mathrm{AB} + \mathrm{PB}/\mathrm{A}) + \mathrm{AO\&M}) \right] / \ \mathrm{AEP} \qquad (6)$$

where

EC = annualized (levelized) energy cost in \$/kWh
FCR = levelized fixed charge rate
ID = indirect cost factor to account for the indirect costs associated with the installation of systems
MD = module cost in $\$/m^2$
AB = area-related balance-of-system cost in $\$/m^2$
PB = power-related balance-of-system cost in \$/kW
A = 1 / [(IN x ASE)] where
IN = average peak insolation in kWh/m^2, and
ASE = annual system efficiency, which
= BOSE x TC x ME, where
BOSE = balance-of-system efficiency
TC = temperature correction to module efficiency at 25°C, which depends on average annual module operating temperature
ME = module efficiency at 25°C

AO&M = G x CRF x OM, where
G = present worth factor
CRF = capital recovery factor (G x CRF = 1.0)
OM = yearly operation and maintenance cost in $\$/m^2$-yr.

AEP = annual energy production
= S x ASE, where
S = annual solar availability in kWh/m^2-yr

The principal issue in determining regional PV costs is which PV cost factors vary by region. I will assume that only average peak insolation (IN) and annual solar availability (S) varies by part of the

---

[33] See Flaim (1985), pp. 278-280, for discussion of these points.

country. The rationale for viewing the others as constant is described for each variable below:[34]

-The fixed charge rate (FCR) depends on the lifetime, the discount rate, and taxes. The most pronounced regional variation in these factors would result from state taxes, particularly PV provisions. These are ignored because they do not affect the cost of PV in the region, only who in the region bears the cost.

-The module cost (MD) and power-related balance of system cost (PB) depend on the state of PV technology and would not vary by region.

-The area-related balance-of-system cost (AB) for utility applications depends on the price of land, which varies by part of the country. However, there are three reasons to ignore this in our analysis. First, the votes under study range from 1975 to 1980, and, as described in Chapter 1, during much of this period it was thought that the first application of PV might be in residences, where there is no cost due to land since the arrays are mounted on the residence roof. Second, several studies of the economics of utility PV indicate that land would constitute only 1-2 percent of the area-related balance of system costs.[35] Third,

---

[34] One must make a number of simplifying assumptions so that the number of variables used in the analysis (either entered directly in the regression equation or used to calculate the benefits variable to be entered in the regression equation) is a manageable number. The PV cost formula given in (6) describes 13 variables which affect PV cost. The assumptions as to which factors do not vary by part of the country and hence are irrelevant in determining differences in benefits of PV by district, defines the list of variables which could potentially affect roll call voting in a cross-sectional analysis.

[35] Aerospace Corporation (1977, p. 39) and Taylor (1983b, p. 3-2). In addition to these point estimates, the latter also provides a range from less than 1 percent to 6 percent. Of course it would be easy to find sites where the land cost would be much greater. However, with some transmission losses, these sites can be avoided.

and probably for similar reasons, the analyses of the attractiveness of PV in different parts of the country (the 1977 Aerospace study and those cited beginning at footnote 26) do not examine land as a variable of interest; those studies performed prior to votes could be presumed to have had some effect on the evaluation of these factors in the voting decision.

-Annual system efficiency (ASE) depends on balance-of-system efficiency (BOSE), temperature correction (TC), and module efficiency at 25°. The last depends on PV technology and would not vary by region.[36] BOSE efficiency could vary due to differences in dirt accumulation and array shadowing.[37] TC would vary as well, since modules in warmer areas of the country and in higher insolation areas would operate at higher temperatures and thus the downward correction to module efficiency at 25° would be different. However, data on regional differences in these factors do not readily exist and the differences are likely to be small.

-Operations and maintenance costs "are annually recurring expenses for module replacement, salaries of operating personnel, module washing, and the upkeep of the grounds, structure, and electrical systems."[38] These costs could differ by part of the country, due to differences in the number of cleanings required or perhaps other factors. This factor is ignored due to the lack of data and because the analyses of the

---

[36] As with other parameters such as MD and AB that depend on PV technology, the values <u>observed</u> in different parts of the country may vary, because the preferred technology in different parts of the country may vary due to differences in insolation and other factors. It greatly simplifies the analysis however to regard these as constant across the country, rather than using the optimum at each point.

[37] Crosetti, Jackson, and Aster (1985), pp. 29-33.

[38] Crosetti, Jackson, and Aster (1985), p. 42.

attractiveness of PV in different locations did not examine operations and maintenance costs as a factor.

-Differences in labor rates in different parts of the country would lead to regional differences in the costs of PV power. To translate local labor cost differentials into PV power cost differentials, would require an estimate of the percent of the cost of PV power that arises from the use of local labor. To construct such an estimate, one could examine the places where labor costs appear and whether these labor costs reflect local conditions. The two most important areas are probably indirect costs and operations and maintenance. Indirect costs (ID) include engineering fees, construction contingency, owner's costs and interest during construction, with engineering fees estimated at 12-28 percent of indirect costs.[39] Operations and maintenance costs (O&M) would reflect local labor rates. For residential PV, whether differences in local wages lead to differences in O&M costs depends on whether homeowner labor for residential PV is regarded as free.[40] For utility PV, using the energy cost equation and parameter assumptions from the Five Year Plan (using the ranges for module costs and efficiency) produces estimates of operations and maintenance costs of 5-7 percent of total PV cost. What percentage of this 5-7 percent operations and maintenance cost is labor depends heavily on the assumed module replacement rate, with the baseline scenario

---

[39] Crosetti, Jackson, and Aster (1985), p. 38, Taylor (1983b), p. 3-10.

[40] As noted in Chapter 1, in the 1970s, homeowner labor for residential PV was often regarded as free. This is still done in some analyses--e.g., Taylor (1983b), p. 3-10.

showing slightly less than half of the 5-7 percent figure to be labor.[41]

Parameter Values. With the rationale established for regarding these variables as constant across regions, it is necessary to make some assumption regarding the values for these variables in order to determine values of PV cost by region using equation (6). For simplicity, I have used the values in the 1987 plan (I use the midpoints of the module cost and efficiency ranges). The use of these values may be appropriate because, as noted in Chapter 1, the Five Year Plan values lead to energy costs that are intermediate between what would be produced by the initial 50-cent-per-peak-watt goal and the longer-term 10-cent-per-peak-watt goal. Substituting these values, one obtains

$$EC = \left[(.0961)(1.5)[62.5+50+150*IN*.85*.9*.175)] + 1.1\right] /(S*.85*.9*.175)$$

or

$$EC = 121.1/S + 21.6\ (IN/S) + 8.22/S$$

The ratio IN/S or average peak insolation/annual solar availability, is nearly a constant.[42] If we treat it so, then we get

$$EC = 129.3/S + .0099 \qquad (7)$$

---

[41] Crosetti, Jackson, and Aster (1985), p. 44.

[42] This is implied by Taylor (1983b), p. 4-6. The following table confirms that this is a reasonable assumption; the first two columns are from Crosetti, Jackson, and Aster (1985), p. 23.

	IN	S	IN/S $(\times 10^{-4})$
Boston	.67	1377	4.87
Miami	.8	1797	4.45
Baseline	1.0	2000	5.00
Fresno	1.0	2141	5.00
Phoenix	1.0	2223	5.00

This demonstrates that insolation alone can be used to predict PV costs in our context.

Note that using a constant term to represent power-related costs reflects two assumptions. First, that IN/S is constant across regions; as average sunlight goes up, so too does peak insolation. Second, one builds the power-conditioning system to fully utilize this peak.[43] The sensitivity of our results to the first assumption[44] can be examined. Using a 1987 baseline value of S of 2400 kWh/m^2-yr (high-insolation location such as the desert Southwest), one obtains

$$EC = .054 + .0099 = \$0.064/\text{kWh} \tag{8}$$

Thus, the small-percentage variations in the IN/S ratio that do exist translate into equally small-percentage effects on the second term in (8), which translates into a smaller-percentage effect on the overall energy cost. The effect would be even smaller in lower-insolation regions where the first term would be larger.

Thus the use of three variables--per capita electricity consumption, conventional electricity price, and insolation--as indicators of benefits of PV in grid-connected markets is consistent with the studies of break-even prices and my earlier derivation of PV benefit formulas. Of course, other factors affect PV break-even prices, but it is not practical to

---

[43] Whether this will in fact be done depends to a great extent on whether the peak output of the PV system coincides, in terms of time of year and time of day, with the peak demand on the electricity grid. This depends on the region of the country.

[44] The sensitivity to the assumption regarding building the power system to meet the peak is more difficult to examine.

include these in the analysis, as discussed earlier.

State Solar Tax Treatment. Note that I have not included state solar tax treatment, even though this was mentioned as a key factor affecting break-even prices. State solar tax treatment refers to those provisions that vary from state to state and apply specifically to solar energy; one can infer from Borden (1983) that these are solar tax credits and exemptions of solar property from property taxes. For simplicity I will refer to all these provisions as "credits." The rationale for their inclusion is that if one assumes a fixed state revenue requirement, the effect of a state solar credit is to redistribute state tax liabilities to state taxpayers as a whole from a concentrated group (those receiving the credit).[45] The standard analysis of such redistribution, due to Mancur Olson, is that this will have a political benefit because of the concentrated nature of the beneficiaries and the diffuse nature of the losers (one could add conditions such as "the concentrated group is seen as deserving"). This suggests that the size of the state credit would be correlated with state congressional political support for PV. The larger the credit, the larger the transfer. The group that would receive the credit perceives the Congressman's support as increasing the likelihood that PV will be economic (with the favorable tax treatment) and thus that this transfer would actually take place. Even though the federal legislator is one step removed from the granting of the credit, he would be rewarded for his support.

There are several reasons for exclusion. First, these tax credits

---

[45] Due to the deductibility of state income taxes, the effect on federal tax liabilities is in the opposite direction. Of course the state effect dominates.

may not exist at the time when PV is used in a significant way.[46] Second, the state tax treatment is likely to be a function of variables which affect the Congressman's evaluation of PV. Solar tax credits may be more likely to be adopted in states where PV would be most attractive without the credit. Constituent ideology could also play a role in affecting both Congressional support of PV and the existence of state solar credits. Thus the second reason for exclusion of state solar tax treatment is very similar to the argument made against the inclusion of ideology indices determined from other votes in roll call analyses (see Chapter 2): the state solar tax treatment or the ideology index is itself a function of the other explanatory variables.

Interpretation of results with state solar tax credits included would be difficult. Does significance of state solar credits indicate that (1) Congressmen have a high discount rate and therefore are valuing credits which may be gone before PV use is large, (2) Congressmen believe these credits will continue, or (3) the district would support solar for economic or ideological reasons that are not captured by the economic and ideology variables included? Due to the difficulty in interpretation, solar tax credits will not be included.

Non-Grid-Connected Market. With respect to the non-grid-connected market, sunlight and population density are good indicators. Sunlight is again a good measure of the cost per unit output of the PV system. Electricity is clearly not a good measure of the cost of alternatives. Some measure of the extent of grid-connectedness would be best, but such

---

[46] For example, Borden (1983) excludes solar tax credits from his baseline case.

measures do not appear to be available.[47] Because of this lack of data, I use population per square mile of land area as a variable which is probably highly correlated with grid-connectedness.

However, there may be problems with this variable. My proposed approach is to use insolation, electricity price, per capita electricity consumption, and population density as the variables related to consumption benefits. With these variables, the importance of nongrid applications is measured only by whether population density is significant. Aside from the fact that population density is an imperfect measure of grid-connectedness, it is also correlated with land prices which affect the cost of central-station PV. Thus less densely populated regions may be more attractive for central-station PV. However, as argued above, land prices are only a small portion of PV central-station costs and do not affect residential grid-connected applications, which were viewed as important at the time of the votes. Thus the significance of population density might still be interpreted as indicating the importance of nongrid applications in particular. If the variable is not significant, this supports the argument that nongrid applications were unimportant.

<u>Specific Variable Choices</u>. With the rationale for selection of variables hopefully clear, we now turn to specific choices regarding definition of variables. The insolation measure is discussed in more detail in Chapter 4 and the Data Appendix. Three reasons were instrumental in the selection of this particular data set. First,

---

[47] This question is not asked in Census, Energy Information Administration, or Edison Electric Institute surveys, nor is this data submitted in regional reliability council reports.

insolation values are provided for a large number (235) of sites. This simplifies the extrapolation to 435 districts. Second, although other solar data sets are available, this set was published by the photovoltaic program at JPL. Third, I had been previously acquainted with the author of the study.

With respect to conventional electricity prices, there are a variety of options with regard to which conventional electricity price should be employed. The first choice is between past or current price, and projections of future prices. The second choice is whether to use average price or marginal (the cost of new generation). The third is between average price for all customers or average residential price. In all cases, the grid-connected market is the relevant market since the nongrid market does not depend on the level of electricity prices (except in the cases where connecting to the grid is an option).

Past/Current Price vs. Future Price. The benefit of PV in grid-applications depends on the quantity of electricity generated by PV as well as the cost difference between PV and conventional electricity. At the time of the votes, the level of PV generation was so small that the resulting level of benefits was infinitesimal compared to the future promise of PV in grid-connected applications. It is therefore reasonable to assume that Congressmen were voting based on future benefits, not current benefits. To test this, one would like to use two different specifications of electricity price--the current price to represent current benefits and agency estimates of future price, to represent future benefits.

Unfortunately, such an approach would not work for a number of reasons. First, voters and Congressmen might use past and current prices to project future prices, rather than using agency projections, even though one would expect that agency projections would be more accurate. Second, voters and Congress might be responding to today's problems rather than attempting to predict the future. Thus significance of past or current price variables in a PV roll call analysis does not have a unique interpretation, nor can one test the relative importance of current vs. future benefits by using current vs. future electricity prices.

Average vs. Marginal Price. Due to average cost pricing by utilities, decisions made by nonutilities to replace utility power by PV are made based on the average price. However, sell-back of power to the utility will be based on avoided costs (marginal price). The decision by the utility as to whether new power should be PV or some other source is based on the marginal price of each.[48]

Average vs. Residential Price. The cost of electricity is allocated by state regulatory policies to customer classes, with the result that different classes have different power prices. Some analysts (e.g., Nivola (1986)) have used residential prices in roll call analyses, because they believe these prices are more politically salient than the overall average. The relationship of these customer class prices to the overall state average will vary by state depending on the regulatory policies in each state. It is difficult to predict how the relationship of various

---

[48] The decision as to whether and when to replace existing capacity with new capacity is based on the cost of power replaced, as well as the marginal price of the new source.

customer class prices will change over time.[49]

Data Availability. Past and current prices are available by state, whereas projections of future prices were only made by region. Past/current data are for customer class (e.g., residential) and average. Agency projections are average and marginal prices.

Based on these considerations as well as the availability of data, I will test the following alternative specifications for electricity price.

-Average price year of vote

-Average price year of vote and percent change from 2 years earlier

-Average residential price year of vote

-Average residential price year of vote and percent change from 2 years earlier

-Projected 1985 marginal price for region[50]

-Projected 1985 average price for region

Option 3: Calculate District-Unique Variable Based on Indicator Variables

The benefit framework developed in the equations above can be used to develop a simplified local benefits model which can then be used to generate a benefit variable for grid-connected uses. Nongrid applications

---

[49] Jeffrey L. Smith (1980b), Vol. II, p. 16, describes this as an impossible task.

[50] Projections are for 1985 made by the Energy Information Administration in 1977. EIA projected prices for 1985 and 1990 in that document. Although either could be used, I have used 1985 since the 50 cents per peak watt by 1985 was a more prominent goal than the 1990 goal. The regional estimates are more aggregated than the state estimates used for past and present prices since there are only ten regions.

will be evaluated as before.

Simplifying the Model. Recall that our expression for the benefit of a PV program (repeated below) involves the discounted difference in energy costs resulting from the accelerated adoption of PV due to the program, plus the reduction in PV costs after the time when PV would be adopted anyway.

$$B = \sum_{i \in R} \left[\int_{T_i}^{T_i+\Delta T_i} [U_i(t)-C_p(t,T_i)]e^{-kt}dt + \int_{T_i+\Delta T_i}^{\infty} [C_{np}(t,T_i)-C_p(t,T_i)]e^{-kt}dt \right] \qquad (9)$$

Where PV would not be adopted without a program, this reduces to

$$\sum_{i \in R} \int_{T_i}^{\infty} [U_i(t)-C(t,T_i)]e^{-kt}dt \qquad (10)$$

Even if the PV program only serves to accelerate the adoption of PV, a similar simplification results once one realizes that the second integral in (9) will be small relative to the first and will not differ much by region. The second integral will be small compared to the first integral for two reasons. First, the second integral compares the cost differences in PV with and without a program, after the point that PV becomes economic without the program. Because this will be a long time in the future, the differences will be heavily discounted. Second, once PV becomes economic without the program, the differences in PV costs with and without the program are likely to be relatively small. Large cost reductions are required to make PV economic; once these are achieved, further reductions are limited due to limits on conversion efficiency and other factors. The second integral is also unlikely to differ much between regions because the PV cost reductions due to the PV program will be similar in all regions of the country.[51] Thus the second term will not lead to significant differences in regional benefits and thus can be ignored. The remaining first integral is the same as in the case where PV would not be adopted without a program, except that the upper limit of integration is different.

Focusing now only on the first integral, to calculate benefits by region using this procedure, one would determine, using price projections for conventional and PV power, when PV would become economic in each region, and discount the differences in the cost of conventional and PV power from then on, or until PV would become economic without the program. These price projections will be on a price per kilowatt hour basis, and therefore will ignore the complications associated with determining the savings in conventional power costs described above.

Because this approach requires PV and conventional price projections over time by locale, and these are not available, alternatives to this approach that rely on less information are desirable. In particular, one could examine cost differences at a single point in time for all locales, rather than examining cost differences over time, with the beginning point for each locale being when PV becomes economic in the locale (and the ending point being when PV would be economic without the program for that locale). Whether these two approaches produce the same ranking depends on whether the ordering of regions by PV cost and conventional electricity

---

[51] Although the federal PV program might place a different emphasis among different technologies than a private program, these would not translate <u>ex ante</u> into different effects on regional benefits such as would be the case if one program emphasized concentrators and the other flat plate technologies.

cost changes over time. The ordering of regions by PV cost is unlikely to change; such changes could however occur if technological developments favored one region over another (e.g., technological developments of concentrator technology would favor areas in which a higher proportion of the total insolation is direct insolation). Changes in regional ordering of conventional electricity costs may be somewhat more likely.

As in the indicator approach, although it is difficult to estimate the quantity of PV that will be used in each district which, along with cost differences, will determine total benefits, the quantity of PV that will be used in each district is almost certainly highly positively correlated with the cost advantage that PV has over conventional power in that district. Thus the ordering of districts would not change much whether one includes the PV quantity of not, and thus we can focus merely on the cost difference.

PV Power Costs. In the "indicator" approach (option two), quantitative estimates were not made for PV costs (sunlight itself was shown to be an adequate indicator). Since quantitative estimates of PV costs are required to calculate benefits in option three, the issue arises whether one should utilize the cost equation developed for PV or use approaches similar to that used for conventional power. Price expectations could be based solely on past and current prices, or price expectations could be based on estimates of future prices that were made by federal agencies and others at the time. Neither of these two alternatives is however appropriate for PV. With respect to the first, price data for PV has never been published by region as it has for other generation sources. More importantly, what price data existed in the

1970s would be a poor basis for projection of future prices because the limited data were heavily influenced by factors such as the size of the buy and because of the large price declines expected. With respect to the second alternative, PV prices were not projected by region.[52]

To use the cost equation to calculate PV costs, it is necessary to calculate the S values from the insolation data set. I assume the highest value in the data set corresponds to an S value of 2400.

Conventional Power Costs. In utilizing the alternatives for conventional power described for option two, one must realize that, unlike the indicator approach, the ordering of districts in terms of net PV benefits may vary if either variable, conventional energy cost or PV power cost, is transformed by a scalar. This is because one variable is being subtracted from the other. This means that ordering of districts by net benefits depends on the year chosen to compare prices[53] as well as assumptions underpinning the conventional and PV price projections. This is one reason why the indicator approach should precede use of a benefits variable.

The marginal and average price projections discussed earlier are available for 1985 and 1990. It is unclear which is the better year for comparison to PV costs, as derived by the PV formula, since the parameter values I have chosen reflect PV costs intermediate between those achieved

---

[52] The projections discussed earlier for a few representative cities were the break-even PV module prices required, not the PV electricity prices resulting from use of a single PV module price. Aerospace Corporation (1977), p. 43, showing prices for five cities is a rare exception.

[53] The same problem exists in the earlier formulation, where one is integrating the difference over a number of years.

by the 1985 cost goal of 50 cents per peak watt and the 1990 goal of 10 cents per peak watt. Because of the greater prominence of the 1985 goal, I will use that year as the comparison year. Current year prices need to be "scaled up" to the comparison year; I do this by multiplying these prices times the ratio of the projected 1985 average price to the average price in the year of the vote.

PREFERRED OPTION

Option 1, use of a variable reflecting break-even prices, is not chosen due to four problems with using these estimates in roll call analysis of PV voting. In order of declining importance, they are as follows. First, the estimates only exist for a few cities. There is no good way to make estimates for fifty states and 435 congressional districts. Second, all of the break-even estimates were published after eight of the nine votes had occurred (with seven of the nine votes occurring two years before the first estimate), and thus these estimates were not available at the time of the vote. Third, the ranking varies across the studies to some degree. Changes over time in ranking would be a valuable addition to a roll call analysis if the ranking were changing in a consistent manner across votes, and if the votes could be compared by pooling or in other ways. With neither the case, the changes in ranking suggest that (1) the choice of a ranking by the roll call analyst is somewhat arbitrary and (2) the rationale that Congressmen were relying on these rankings is weakened because the rankings present a confused picture. Fourth, in addition to confusion resulting from differences in rankings between studies, the picture that emerges is also a complicated one. The MIT study found that the ordering of regions depends on the whether the market is utility or intermediate load/residential and on assumptions regarding penetration level and type of capacity displaced. As noted in Chapter 1, the issue of whether the residential or utility market would be economic first was the most hotly contested issue during this period. Similarly, the extent of oil displacement was also highly controversial.

The third option, which estimates the cost difference between PV and conventional power in 1985, to reflect the benefits of grid-connected uses, and which utilizes population density as an indicator that nongrid uses were valued, may produce insignificant results if the scale factors for PV and conventional power are incorrectly chosen. This could result from choosing the "wrong" year for comparison, the wrong escalation factor for conventional power, or the wrong rate of cost decline for PV.

Thus, the second option, which uses conventional electricity price, insolation, per capita electricity consumption, and population density as indicators of benefits in grid-connected and non-grid-connected applications, is the preferred option. The third option will also be performed, although I am not optimistic as to the results.

CHAPTER FOUR

ECONOMETRIC ANALYSIS OF ROLL CALL VOTING ON PHOTOVOLTAICS

To test the hypotheses concerning the role of party, ideology, and distributive politics developed in Chapters 1 and 3, congressional roll call votes concerning photovoltaics were analyzed using an econometric model.[1] The votes analyzed (Table 28) are the set of all roll call votes pertaining to photovoltaics funding since 1974 with the exception of the following.[2]

First, votes on final passage of energy authorization or energy and water development appropriation bills are not included. Photovoltaics or solar represented less than 10 percent of the energy or energy and water development budget and thus votes on final passage cannot be used as proxies for solar or photovoltaics votes.[3]

Second, extremely lopsided votes were ignored for two reasons. The estimations are likely to fail and the reasons why a few voted differently from the vast majority are likely to be different than the determinants of voting behavior in more contested votes. The two lopsided votes were the Solar Energy Research, Development and Demonstration Act of 1974, adopted 383-3, and the Solar Photovoltaic Energy Research, Development,

---

[1] Regressions models to explain congressional voting have been used extensively in the 1970s and 1980s. Chapter 2 surveys these.

[2] The universe of votes was generated from descriptions of floor action on energy programs found in the annual Congressional Quarterly Almanac. I believe this to be a complete list.

[3] Banks used votes on final passage of NASA authorization bills in his study of the space shuttle. However, the space shuttle represented approximately 30 percent of the funds in the NASA budget, and was the largest item in the budget. Appropriation bills were not used by Banks because NASA is appropriated as part of the larger HUD and Independent Agencies budget.

Table 28
Selected Roll Call Votes

Senate votes:

-Gravel (D Alaska) amendment to increase FY 1976 and transition quarter authorization for solar energy research and development by $63 million and $18 million respectively. Rejected 34-59, July 31, 1975. CQ 366.

-Glenn (D Ohio) amendment to increase appropriation for solar energy research and development in fiscal year 1976 and the transition quarter by $46 million. Adopted 52-31, December 5, 1975. CQ 554.

-Hart (D Colo) amendment to increase FY 1977 appropriations for solar energy programs by $16.4 million. Adopted 54-41, June 23, 1976. CQ 312.

House votes:

-Richmond (D N.Y.) amendment, to the McCormack (D Wash) amendment, to increase FY 1976 and transition quarter appropriation for solar energy research by $54.1 million and $9.9 million, respectively. Rejected 190-219, June 24, 1975. CQ 255. The McCormack amendment to increase FY 1976 and transition quarter appropriations for solar energy by $13 million and $9.5 million was subsequently passed by voice vote.

-Anderson (R Ill) amendment to the Brown (D Calif) substitute amendment, to eliminate the $58 million increase for solar heating and cooling programs, thus cutting the increase for solar electric and other programs from $116 million to $58 million. Rejected 188-207, May 19, 1976. CQ 204.

-Brown (D Calif) substitute amendment to the Jeffords (R Vt) amendment to redistribute the $116 million increase for solar electric, ocean thermal, wind energy, biomass, and related programs to $58 million for these programs and $58 million for solar heating and cooling. Also deleted line item authorization for specific technologies and provisions to increase ERDA staffing. Adopted 265-127, May 19, 1976. CQ 205.

-Jeffords (R Vt) amendment to increase FY 1977 authorization by $116 million for solar electric, ocean thermal, wind energy, biomass, and related items. Adopted 321-68 as amended by Brown amendment, May 19, 1976. CQ 206.

-Tsongas (D Mass) amendment to increase FY 1978 authorization by $28 million for federal purchase of solar photovoltaic systems and $10 million for technology development. Adopted 227-179, September 21, 1977. CQ 535.

-Fuqua (D Fla) amendment to increase 1981 appropriations for energy supply, research, and development by $107 million, of which $49 million was for solar programs and the rest for fusion. Adopted 254-151, June 24, 1980. CQ 327.

Source: <u>CQ Almanac</u>. <u>Congressional Record</u>, May 19, 1976, pp. H14410-14427; September 21, 1977, p. H9765; June 24, 1980, pp. H16604-16614.

and Demonstration Act of 1978, adopted 385-14. The votes in the Senate on these two bills were voice votes.

Third, non-roll-call votes were excluded because one knows only whether the measure passed, in the case of a voice vote, or the vote total, in the case of a standing vote, and not the votes of individual members. Explanations of voting behavior in voice and standing votes depends on the existence of a large number of votes since each vote is only one data point. There were only eight non-roll-call votes on photovoltaics during this period, and thus these are ignored.[4]

The nine votes selected for analysis, along with the eight non-roll-call votes and the two lopsided votes that were excluded, are interesting in a number of respects. Only one floor vote has been taken during the decline of the program. This was the Brown amendment to transfer $20 million from space nuclear research to solar energy in the FY 1989 appropriation. The amendment did not specify how much of this was to go

---

[4] The non-roll-call votes were the following. House: (1) Richmond (D N.Y.) amendment to increase the FY 1976 authorization for solar energy to $194.8 million from the $140.7 million provided in the committee version, with a comparable increase for the transition quarter. Approved 43-31, standing vote, June 20, 1975; (2) McCormack (D Wash) amendment to increase 1976 solar appropriations by $13 million. Adopted after rejection of Richmond amendment (see list of roll call amendments in table below), June 24, 1975; (3) Conte-Koch amendment to increase 1977 solar appropriations by $95 million, adopted June 15, 1976; (4) Tsongas (D Mass) amendment to increase 1978 ERDA appropriation by $24 million (including $19 million for photovoltaics), agreed to October 19, 1977; (5) Brown (D Calif) amendment to transfer $20 million from space nuclear research to solar energy in 1989 appropriation, adopted May 17, 1988. Senate: (1) Solar Energy Research, Development, and Demonstration Act of 1974. Approved, voice vote, Sept. 17, 1974; (2) Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978, adopted by voice vote, October 10, 1978; (3) Dole (R Kansas) amendment, to appropriate $3.75 million for a photovoltaic demonstration project. Approved, September 9, 1980. (Kansas was one of 5 states that were possible locations for this project).

to photovoltaics.[5] Prior to this vote, the last vote was in September 1980, on the FY 1981 budget, which was the peak year of appropriations for photovoltaics. In addition, there has never been a floor vote on a proposal to decrease the budget below the committee-approved level, or to cancel the program entirely. Most have been to increase the budget over the committee level, and many of these were successful. All of the nine votes selected for analysis provided for increases over the committee level.

The nine votes selected for analysis include eight that affect solar authorizations or appropriations and one (Tsongas amendment) which affects only PV authorizations. This limitation of the data has important implications for the selection of the explanatory variables for energy price, federal expenditures, and manufacturers, as well as for the interpretation of results.

The Senate econometric model is specified in Table 29 (the Data Appendix provides additional information regarding these variables).[6] The model for the House is the same (replacing Member for Senator) except for the following. First, there is no variable for terms since all House

---

[5] Congressional Record, May 17, 1988, pp. H3314-3318 and Report from Senate Appropriations Committee accompanying energy and water development appropriation bill, Senate Report 100-381, June 9, 1988, pp. 90-93. The Senate report, which is always the best source of information concerning the effect of an approved House amendment since the effect of that amendment is incorporated into the tables under "House allowance," carries the $20 million separately as a "general increase."

[6] This is the model specification that, along with a model specification to be presented at the end of the chapter, outperforms all others that were tested. The other specifications that were tested are discussed later in this chapter. Once this "best specification" was developed, all the regressions that are described in this chapter were run against this specification for comparison and these are the results that are described in this Chapter.

Table 29
Econometric Model of Senate Roll Call Voting on Photovoltaics

$$\Pr(V_i = 1) = F(a + B_1P_i + B_2T_i + B_3ACA_i + B_4AP_i + B_5APS_i + B_6AU_i$$

$$+ B_7AUS_i + B_8ELP_i + B_9DEN_i + B_{10}I_i + B_{11}F_i + B_{12}MAN_i$$

where F(.) is logistically distributed;

V_i = vote by senator (0 = antiphotovoltaic vote; 1 = prophotovoltaic vote);

a = constant;

P_i = party affiliation of senator at time of vote (0 = Rep., 1 = Dem.);

T_i = year term of senator ends (either 77, 79, or 81);

ACA_i = ACA score of senator for year of vote, divided by 100;

AP_i = Membership of senator on Appropriations committee, year of vote; (0 = nonmember, 1 = member);

APS_i = Membership of senator on Appropriations subcommittee overseeing PV budget, year of vote (0 = nonmember, 1 = member);

AU_i = Membership of senator on committee overseeing PV authorization, year of vote (0 = nonmember, 1 = member);

AUS_i = Membership of senator on subcommittee overseeing PV authorization, year of vote (0 = nonmember, 1 = member);

ELP_i = State average electricity price, year of vote (1975 dollars per million BTU);

DEN_i = Natural log of population density in state in year of vote (thousands of persons/square mile);

I_i = Estimated average annual insolation (sunlight) in state (MWH/sq. meter); and

F_i = Estimated real per capita PV expenditures to state in fiscal year being voted on, discounted at 10% (FY 1976 dollars per capita)

MAN_i = PV manufacturer in state in 1980 (0 = no, 1 = yes);

terms end at the same time. Second, insolation, population density, photovoltaic spending, and photovoltaic manufacturer estimates pertain to the district of the member.[7] The House model uses total photovoltaic spending in the district (in millions of dollars) in contrast to the per capita figures used in the Senate model since there is little variation in the population of Congressional districts.

The predicted signs of the coefficients on a vote will be as follows:

$B_1 > 0$ .... Democrats are more likely to vote pro-PV.

$B_3 < 0$ .... The more liberal, the more likely a pro vote.

$B_4 < 0$ .... Appropriations committee members are likely to vote no.

$B_8 > 0$ .... The higher the electricity price, the more likely a pro vote.

$B_9 < 0$ ... The less dense the population, the more likely a pro vote.

$B_{10} > 0$ ... The sunnier, the more likely a pro vote.

$B_{11} > 0$ ... The more PV funds, the more likely a pro vote.

---

[7] Population density in the House model refers to 1970 population per square mile in the district, from U.S. Department of Commerce (1973, 1974a, 1974b, 1974c). The Senate model used state population estimates for intercensus years (year of the vote). Since these estimates are not available for Congressional districts, a census year (1970) is used. 1970 data probably give a better picture (than 1980 data) of population density in the years of the House votes (1975-1980) since the number of districts in a state for the votes in question was determined by 1970 population data. For example, where population growth has been rapid, use of 1980 data would overstate population density per district because the 1980 population figures would yield more districts for that state. Furthermore, it is difficult to find 1980 population data per district (with the districts defined prior to the redistricting resulting from the 1980 census). District population density is expressed in persons/square mile.

$B_{12} > 0$ ... If a PV manufacturer is present, the more likely a pro vote.[8]

The predicted sign for the coefficient of term depends on the relative strength of the three classes of factors we have hypothesized affect PV voting: party and ideology factors, consumption factors, and federal PV expenditure and manufacturer factors. The importance of each of these factors is predicted to depend on how close or far off one's election is. Party and ideology are predicted to be most important for those whose election is near. Voting in accord with one's party is most important the closer the election. Similarly with ideology--representing constituent ideology is most important for this same group of Senators.[9] Consumption factors work exactly the opposite--the further off the election, the more likely a yes vote, for photovoltaics in particular (and solar programs in general) were viewed as having a medium to long-term payoff. Those with short time horizons for these benefits would favor other programs. Finally, federal expenditure and manufacturer factors are most important for those with elections upcoming.

The predicted signs for the committee membership variables are

---

[8] Roessner (1982) cites the results of Assessment of Solar Photovoltaic Industry, Markets and Technologies, Booz, Allen, and Hamilton, September 30, 1978, which conducted a survey of industry executives regarding the federal program. A third found the program a positive influence on their business, one half found it negative, with the remainder believing it had little effect. However, I still believe the sign should be positive. Most of the negative responses (pp. IV-40-43) discuss the possibility of dropping out of the program. This presumably means no longer receiving government research funds or producing modules for government purchases--this is different than calling for its termination.

[9] This is in contrast to the idea, noted briefly in Chapter 2, that ideological voting is "shirking," i.e., voting one's own ideology rather than constituent interests. Under that interpretation, ideology would be less important for those with elections the closest.

derived from hypotheses concerning committee norms and committee membership.[10] These hypotheses suggest that appropriation subcommittee, authorization committee, and authorization subcommittee members are often cross-pressured on floor votes to increase funding above the committee level. Committee norms are to support the committee level and hence vote against funding increases. However, the committee assignment process works so that program supporters gravitate to those committees exercising jurisdiction over programs benefiting their districts. This would tend to lead committee members to support funding increases.

The strength of the "support the committee" effect depends on several factors. The effect is presumably stronger on bills of the same type (authorization bills for authorization full and subcommittee members, appropriation bills for appropriation subcommittee members). On bills of the opposite type, one might support one's own committee's position or support the other committee's position with the expectation that such deference would be reciprocated.

The predicted sign for the appropriation subcommittee, authorization committee and authorization subcommittee dummy variables depends on the relative strengths of the committee norm and assignment effects. For these reasons, no prediction will be made for these three variables.

Since the appropriations committee oversees all appropriations, the committee assignment process would not result in this committee being dominated by energy interests. Thus members of the appropriations committee should vote against funding increases in accord with the norm

---

[10] For appropriations committee norms, see Fenno (1966, 1973). For committee membership, see Shepsle (1978).

of supporting one's bill on the floor. Thus B_4 is predicted to be negative.

INTERPRETATION AND CODING OF VOTES

As indicated earlier, a vote by a Representative or Senator that is considered prophotovoltaic is coded as 1, whereas antiphotovoltaic votes are coded as 0. Pairs are coded as votes, whereas abstentions and unpaired absences are treated as missing data.[11] A "yes" vote on the Anderson amendment or Brown amendment is considered "antiphotovoltaic," whereas yes votes on the rest of the votes are considered prophotovoltaic. Coding in this fashion is designed to produce the same pattern of signs of coefficients across all votes.

The Anderson and Brown amendments were not isolated votes, but instead were part of the Anderson, Brown, and Jeffords series of votes on the solar portion of the FY 1977 authorization. The Jeffords amendment proposed to increase the authorization for solar electric, ocean thermal, and biomass technologies by a total of $116 million. The Brown amendment, a substitute amendment to the Jeffords amendment, redistributed this $116 million by giving half ($56 million)[12] to solar heating and cooling and half to those technologies that got the entire $116 million under the Jeffords amendment. The Anderson amendment to the Brown amendment

---

[11] In the analysis of Clinch River voting, Cohen employs a two-stage procedure in which one is interested in why members abstain. Since the number abstaining in the photovoltaic votes is relatively small, I simply code abstentions as missing data, and only analyze those voting.

[12] Congressional Quarterly describes this as $58 million to heating and cooling and $58 million for the other technologies. The text of the amendments and the ensuing discussion make clear that the numbers are $56 million, with the other $4.2 million to go to program management.

allocated money to the same technologies as the Jeffords amendment, but the total increase was only \$58 million.[13] The sequence of votes was Anderson (rejected 188-207), then Brown (adopted 265-127), and then Jeffords, as substituted for by Brown (adopted 321-68).

The effect of various combinations of vote outcomes is shown in Table 30. If Jeffords is rejected, there is no increase for "solar electricity" (for simplicity in discussion of these amendments, I will use this term to refer to PV, solar thermal, ocean thermal, wind, and biomass) or heating and cooling, regardless of what happened earlier. Assuming Jeffords is accepted, the following outcomes result. The rejection of Brown would lead to a \$112 million increase for solar electric and none for heating and cooling, regardless of whether Anderson was approved or rejected. If Brown is adopted, the decision on Anderson makes no difference in the solar electric increase (\$56 million) but determines whether heating and cooling gets a \$56 million or zero increase. Thus Anderson is basically a vote on whether to eliminate the solar heating and cooling increase by reducing total funding; Brown is a vote on whether to provide a solar heating and cooling increase by redistributing the solar

---

[13] The conclusion that the \$58 million goes entirely to non heating and cooling technologies is supported by three pieces of evidence. First, the <u>1976 Congressional Quarterly Almanac</u> description of the vote (p. 62-H). Second, the text of the Anderson and Brown amendments (<u>Congressional Record</u>, May 19, 1976, pp. H14416 and 14420). The key section in the Anderson amendment is "Strike lines 5 and 6" which, by a process of elimination, one can deduce refers to in the Brown amendment "Page 3, line 20, strike out '\$78,900,000' and insert in lieu thereof '\$314,900,000'." This is a typo in the <u>Congressional Record</u>; the latter number should be \$134,900,000 and represents the \$56 million increase over the \$78.9 million provided for heating and cooling in the committee bill. Finally, the statement of the bill's sponsor in introducing the amendment, as well as the comment of Mr. Jeffords later in the debate, implies that funding is directed to the Jeffords technologies. <u>CR</u>, pp. H14420 and 14423.

Table 30

Effects of Various Combinations of Anderson and Brown Adoption/Rejection

Anderson Outcome	Brown Outcome	Funding Outcome
Adopted	Adopted	56 Solar electric 0 Heating and cooling
	Rejected	112 Solar electric 0 Heating and Cooling
Rejected	Adopted	56 Solar electric 56 Heating and cooling
	Rejected	112 Solar electric 0 Heating and cooling

Note: Table can be read as a vote tree from left to right. Funding outcomes are the increase over the committee level, in millions of dollars. "Solar electric" are the technologies provided for in the Anderson and Jeffords amendments, i.e., PV, solar thermal, ocean thermal, biomass, and wind. All outcomes shown assume Jeffords is adopted. If Jeffords is rejected, there is no increase for solar electric or heating and cooling above the committee level, no matter what the Anderson or Brown outcome is.

increase.

How various groups would vote under straightforward and sophisticated voting is described in Table 31 for Anderson and Table 32 for Brown. Straightforward voting in Anderson suggests that a "no" vote be coded the same as "yes" votes for the non-Anderson/Brown votes. (Although PV supporters per se have no preference, the other variables affecting solar voting support this coding). Similarly, straightforward voting in Brown suggests that "no" votes be coded as prophotovoltaic.

The rationale for sophisticated voting on Anderson or Brown is that the probability of adoption of a proposal is affected by the adoption or rejection of amendments to that proposal. Thus the preceding analysis, which analyzed the effect of an amendment assuming that the proposal to which it was an amendment would be adopted, may not be a good guide as to whether voting for or against the amendment was pro- or antiphotovoltaic. The analysis is simplest for the Brown vote. Once Anderson is defeated, the choice in Brown is between a wider or narrower allocation of a constant amount of funds. Those who would prefer the narrow allocation (e.g., PV supporters) might vote for the broader allocation (a "logroll") if they thought this increased the chances of approval of some increase, and vice versa. The Anderson case is more complicated. Anderson narrows the coalition (thus endangering the increase) but provides for a smaller total increase (thus enhancing the chance of passage). To determine how to vote, one would have to determine the net effect of these two factors.

Although sophisticated voting may, as a general rule, be rare due to

Table 31
Straightforward and Sophisticated Voting on Anderson Amendment

	Straightforward	Sophisticated
Solar Supporters (as a group), High Electricity Price or Sunlight, Low ACA Score, or Low Density	No (eliminates heating and cooling increase)	Yes (if maintaining option of $56 million solar increase enhances likelihood of passage of some solar increase more than losses due to resulting $0 increase for heating and cooling) or No (if vice versa)
PV Supporters	No preference	"
Heating and Cooling Supporters	No	" (thereby increasing the likelihood of support for heating and cooling in future)
Appropriations Committee	Yes (smaller increase)	Exact opposite of analysis for solar supporters, et al.

Note: Opponents in each category have exactly the opposite preferences as do supporters. "PV supporters" is meant to include solar electric, ocean thermal, wind energy, and biomass, but exclude solar heating and cooling. Analysis of sophisticated voting in table assumes smaller increases are more likely to pass than larger ones if both increases are directed toward the same group.

Table 32
Straightforward and Sophisticated Voting on Brown Amendment
(once Anderson is defeated)

	Straightforward	Sophisticated
Solar Supporters (as a group)	No preference	Yes (preserves solar coalition)
PV Supporters	No	Yes (preserves coalition)
Heating and Cooling Supporters	Yes	No (redistribution amendments should be opposed) or Yes (general solar increase more likely to pass than targeted one)
Appropriations Committee	No preference (total funding unchanged) or Yes (provides a more balanced increase than Jeffords)	No (increases likelihood of passage of Jeffords and thus of increase)
High Electricity Price	No (takes money from solar electric)	Yes (increases likelihood of passage of Jeffords)
High Sunlight, Low Density, Liberals	No preference	Yes (increases likelihood of passage of Jeffords)

Note: Opponents and PV supporters as in previous table. Analysis of sophisticated voting in table assumes increases for all solar technologies are more likely to pass than those which benefit only non heating and cooling technologies. Since the focus of this study is on PV, the straightforward assumption that sunlight, density, and liberalism do not distinguish among solar technologies is a working assumption which might be rejected by more complete analysis of PV relative to other solar technologies.

the difficulty of explaining the vote,[14] actual vote outcomes, if one assumes that members' preferences are reasonably well-known to each other, may provide more specific evidence as to its likelihood in particular cases. Large majorities of passage or rejection of proposals later in the vote tree argue against sophisticated voting, since the alteration provided in the amendment is less likely to have determined the outcome of the subsequent proposal. Thus adoption of Brown 265-127 and Jeffords 321-68 argues against sophisticated voting on Anderson and Brown. The case for Brown is more clear--it seems unlikely that the heating and cooling portion of the coalition was so large that the 321-68 outcome would be reversed. Anderson was defeated, so its passage was clearly not necessary for the passage of Brown and Jeffords. If Anderson is adopted, then the question is whether the increase for solar electric to be voted on ultimately will be $56 million or $112 million (vote on Brown), and then whether this increase or none at all will be approved (Jeffords). We have just argued that the $112 million increase would have passed, so clearly the $56 million increase would have passed. So the only question is whether the increase would have been 56 or 112 had Anderson passed. Disgruntled heating and cooling supporters, combined with those that believed a $112 million increase for solar electric was too large, might have limited the increase to $56 million.

Two additional vote patterns also suggest straightforward voting on Anderson. Of the 68 who voted against Jeffords and who voted on Anderson

---

[14] Inferences about what a member supports are incorrect unless explained. Explanation is costly and perhaps not convincing, since the plausibility for the sophisticated vote depends on probabilities of acceptance of proposals which may be difficult for the target of the explanation to know.

and Brown, 65 voted for Anderson. This suggests either that they were strongly opposed to money going to heating and cooling, or, more likely, they voted yes on Anderson as a way to limit the solar increase to $56 million (they then would have voted yes on Brown). Under either interpretation, the Jeffords opponents are voting straightforwardly on Anderson. Of the 131 voting against Brown and who voted on Anderson, 97 (or 74 percent) voted against Anderson. Those who vote sincerely against Brown are solar electric advocates. Solar electric advocates *per se* have no preference on Anderson, and thus other factors, such as their general support for solar energy, should affect their voting. The 74-percent-against figure is consistent with this interpretation.

Ignoring the previous arguments based on actual numerical vote outcomes, some of the sophisticated voting in the table is more likely than others. Heating and cooling supporters face a $56 million increase for heating and cooling with Brown and $0 with Jeffords. The only reason for a sophisticated vote against Brown would be on the principle that such redistributionist proposals endangered the future health of the coalition, since unamended Jeffords provides for $0 increase for heating and cooling. By contrast, a sophisticated vote of PV supporters in favor of Brown offers more immediate rewards by maintaining the coalition that would provide a $56 million increase for these technologies if Brown wins.

Strategic voting to assure passage of a lower authorization is more plausible in the case of the Gravel amendment. Gravel proposed the largest percentage increase in authorizations that was ever offered as an amendment to a committee recommendation for solar energy. Proponents of the program would well have believed that such an amendment would defeat the entire program, especially in its infancy (1975). Or, proponents argued (and could have believed) that this amount was simply too large for the nascent program to digest, creating the prospect that the funds would be wasted and hence the political climate for the program in subsequent years would be undermined. At the very beginning of the rapidly growing program, the beneficiaries of a still further increase are likely to be unidentified as yet, so that little or no political costs associated with distributive losses are likely to be suffered from voting against such a large increase. For these reasons, the distributive effects of the Gravel amendment should be less than for the other votes.

The Tsongas amendment is also unique. It proposed an increase in only the photovoltaics program, whereas the other votes dealt with a broad array of renewables programs. Also, most of the increase in the Tsongas amendment was for the purchase of PV systems, whereas other amendments primarily increased R&D money. Advocates of PV could well be conflicted on this vote as well. If votes are taken on each program separately, the solar coalition could unravel. Some PV proponents would have disliked the emphasis on procurement in the Tsongas amendment. At the same time, members with extensive photovoltaic expenditures or PV manufacturers in their constituencies (or in constituencies where non-grid-connected opportunities were important--see Chapter 3), may have been subjected to considerable pressure to enhance the PV program.

Finally, the Fuqua amendment differs from the others in that it includes an appropriation for fusion research as well as solar. Hence, it would have a broader support constituency than proposals to support only solar, including conservatives who support nuclear power. In addition, the fact that Fuqua was the Chairman of the Science and Technology Committee (the authorizing committee), a sought-after committee,[15] would also broaden support for the amendment.

REGRESSION RESULTS[16]

The sign of all coefficients has the same interpretation across votes. A positive (negative) coefficient indicates that increasing that variable increases (decreases) the probability of a prophotovoltaic vote.

All of the equations are significant at the .0001 confidence level, using the likelihood ratio test. The test is defined by

LRT = 2 * [Log of Unconstrained maximum likelihood estimator
minus Log of constrained maximum likelihood estimator]

which is distributed chi-square with degrees of freedom equal to the number of restrictions. The null-hypothesis (i.e., that all coefficients are equal to zero) is rejected if the statistic exceeds a prescribed critical value.[17] This critical value increases with the number of variables and is approximately equal to 40.9 for 13 variables (the Senate equations).

The regression results are reported in Table 33. Recall that no predictions were made regarding three committee membership variables--

---

[15] Barone and Ujifusa (1982), pp. 215-216, and Barone, Ujifusa, and Matthews (1979), p. 177.

[16] All numerical results were obtained with the Statistical Software Tools (SST) program developed by Jeffrey A. Dubin and R. Douglas Rivers.

[17] Amemiya (1981), p. 1498.

Table 33
Regression Results with All Variables, Best Specification of Each
(t statistics in parentheses)

Independent Variable	Vote Calendar Year of Vote								
	SENATE			HOUSE					
	Gravel 1975 AUTH	Glenn 1975 APP	Hart 1976 APP	Rich. 1975 APP	And. 1976 AUTH	Brown 1976 AUTH	Jeffords 1976 AUTH	Tsongas 1977 AUTH	Fuqua 1980 APP
constant	-11.6	-7.81	-33.5	-.09	-.62	-2.39	1.15	2.47	5.43
	(.79)	(.48)	(2.38)	(.07)	(.47)	(1.89)	(.61)	(2.06)	(4.09)
party	.86	-1.50	-.13	-1.81	-.72	.85	.32	-.72	-1.38
	(1.02)	(1.84)	(.19)	(4.48)	(1.88)	(2.52)	(.81)	(1.94)	(3.03)
term	.12	.04	.40	------------------------------------					
	(.67)	(.19)	(2.28)						
aca	-4.01	-6.39	-4.61	-5.12	-5.46	-1.23	-5.23	-3.91	-5.26
score	(2.49)	(3.87)	(3.68)	(7.46)	(7.99)	(2.26)	(6.21)	(6.14)	(5.91)
app	-.50	-3.11	-.68	-1.10	-.36	-.42	-.12	-.89	-1.98
dummy	(.57)	(2.56)	(.67)	(2.77)	(.89)	(1.11)	(.22)	(2.36)	(4.74)
app sub	-.69	1.85	-.67	-8.02	-.28	-.65	-.02	-.11	-.61
dum	(.57)	(1.33)	(.54)	(.16)	(.26)	(.56)	(.02)	(.13)	(.51)
auth	.86	.99	-.81	.61	.29	-.94	-.47	-.98	11.0
dummy	(.38)	(.62)	(.39)	(.83)	(.39)	(1.17)	(.60)	(1.55)	(.14)
auth sub	-3.30	.15	1.13	.04	-.99	.10	-.37	.43	-8.25
dummy	(1.32)	(.08)	(.51)	(.05)	(1.13)	(.10)	(.36)	(.56)	(.11)
elect.	.24	.17	.02	.12	.21	.23	.17	.16	.10
price	(1.51)	(1.18)	(.15)	(2.29)	(3.50)	(4.04)	(1.88)	(2.81)	(1.78)
log of	-.60	-.32	-.28	-.09	.14	-.10	.01	-.11	-.01
pop. den.	(1.90)	(1.18)	(1.14)	(1.42)	(1.95)	(1.56)	(.06)	(1.67)	(.20)
insolation	-.72	4.12	1.77	1.79	1.45	.70	1.13	-.47	-1.46
	(.51)	(2.47)	(1.39)	(3.26)	(2.37)	(1.27)	(1.32)	(.87)	(2.49)
PV	4.37	-2.53	3.51	-.24	-51.8	.22	-.18	.42	.25
spending	(1.11)	(1.12)	(1.83)	(.42)	(.26)	(.73)	(.78)	(1.53)	(.99)
PV manuf.	-1.14	2.43	-.77	.49	.18	.66	-.24	.68	.64
dummy	(1.26)	(2.04)	(.90)	(.84)	(.30)	(1.30)	(.24)	(1.10)	(.88)
LRT	52.0	45.8	47.0	130.4	175.0	89.4	297.8	114.4	179.2

appropriation subcommittee, authorization, and authorization subcommittee--due to the conflicting pressures of norms to uphold the committee recommendation vs. the effects of program supporters being assigned to these committees. Because subcommittee membership implies full committee membership, the effect of being on the subcommittee, relative to not being on the full committee at all, is given by the sum of the coefficients on the full and subcommittee variables.[18] The effect of being on the subcommittee, relative to being on the full committee, is given by the coefficient of the subcommittee variable alone.

The results are clearest for the appropriation committee. In all nine votes, the effect of membership on this committee is to oppose funding increases over the committee level, and this effect is significant in four of the nine votes.[19] The effect of being on the appropriations subcommittee, in all cases except the Glenn amendment, is to increase the likelihood of a no vote over that resulting from membership on the full committee. However the t-statistic in each of the 8 instances is below 1.

The effect of membership on the authorization committee is mixed.

---

[18] The significance of this sum of coefficients can be tested by the t-statistic for subcommittee membership in the following model:

$$v = \ldots + b1*(\text{comm-subcomm}) + (b1+b2)*\text{subcomm} + \ldots$$

[19] Appropriations committee members support Anderson and Brown. Both are consistent with straightforward voting. The former cuts the amount of the funding increase whereas the latter provides that the increase in Jeffords will be more consistent with the original committee balance among solar technologies than provided for in Jeffords. Sophisticated voting would oppose the Brown amendment because it increases the likelihood of passage of a funding increase. The same is true for Anderson if loss of heating and cooling support is more important than votes gained by maintaining a $56 million increase option.

In 5 out of 9 cases, it is to increase funding, yet the only significant result, or nearly so, is the opposition to the Tsongas increase. The effect of authorization subcommittee membership is mixed and never significant.

Because no theoretical prediction was made for three committee variables (appropriation subcommittee, authorization committee, and authorization subcommittee) due to the conflicting pressures on these committees, because of the weak results for these three variables, and because committee behavior is not the focus of this study, the remaining regressions in this chapter will be estimated without these three variables.

The reestimated model results are shown in Table 34. The coding assumption of "no" votes on Anderson and Brown as prophotovoltaic is supported by the fact that this assumption produces signs of the coefficients on ACA score, appropriations committee membership, electricity price, log of population density, and sunlight that are the same as for the other votes. The conclusion reached above that sophisticated voting is unlikely is supported by the fact that straightforward voting correctly predicts the sign of the coefficients on these five variables for both votes, except for the cases of liberals and members from low-density or high-sunlight areas, voting on Brown.[20] My analysis of straightforward considerations was that these three groups would have no preference based on the assumption that solar programs do not differ along these dimensions. Since the focus of this effort has

---

[20] It is true that the sophisticated prediction for Anderson for these variables is ambiguous.

Table 34
Roll Call Regression Results without Insignificant Committee Variables
(t statistics in parentheses)

Independent Variable	Vote Calendar Year of Vote								
	SENATE			HOUSE					
	Gravel 1975 AUTH	Glenn 1975 APP	Hart 1976 APP	Rich. 1975 APP	And. 1976 AUTH	Brown 1976 AUTH	Jeffords 1976 AUTH	Tsongas 1977 AUTH	Fuqua 1980 APP
constant	-7.73	-7.68	-33.5	-.19	-.52	-2.36	1.24	2.60	5.05
	(.57)	(.50)	(2.40)	(.16)	(.40)	(1.89)	(.66)	(2.18)	(3.99)
party	.81	-1.60	.08	-1.83	-.73	-.84	.32	-.74	-1.38
	(.98)	(2.00)	(.11)	(4.55)	(1.92)	(2.53)	(.82)	(2.01)	(3.16)
term	.07	.05	.40	------	------	------	------	------	------
	(.39)	(.26)	(2.29)						
aca	-3.43	-6.20	-4.59	-5.14	-5.41	-1.20	-5.11	-3.94	-5.31
score	(2.23)	(3.96)	(3.67)	(7.52)	(7.98)	(2.22)	(6.17)	(6.22)	(6.17)
app	-.65	-1.93	-1.09	-1.28	-.35	-.41	-.04	-.83	-2.24
dummy	(1.02)	(2.70)	(1.68)	(3.33)	(.94)	(1.13)	(.09)	(2.41)	(5.66)
elect.	.30	.09	.04	.12	.20	.23	.17	.15	.12
price	(2.12)	(.68)	(.30)	(2.36)	(3.43)	(3.99)	(1.82)	(2.67)	(2.13)
log of	-.65	-.19	-.31	-.09	-.14	-.09	.01	-.11	-.03
pop. dens.	(2.16)	(.80)	(1.31)	(1.44)	(1.90)	(1.44)	(.08)	(1.70)	(.42)
insolation	-1.17	4.20	1.67	1.89	1.37	.63	1.01	-.52	-1.15
	(.85)	(2.62)	(1.31)	(3.47)	(2.27)	(1.14)	(1.21)	(.97)	(2.06)
PV	3.83	-2.18	3.33	-.21	-.05	-.20	-.17	.39	.27
spending	(1.06)	(1.13)	(1.82)	(.37)	(.25)	(.69)	(.76)	(1.53)	(1.02)
PV manuf.	-.82	1.87	-.69	.46	.21	.70	-.28	.66	.89
dummy	(1.00)	(1.75)	(.81)	(.79)	(.35)	(1.40)	(.29)	(1.10)	(1.21)
LRT	45.8	42.2	46.4	125.8	173.0	85.0	296.2	110.6	152.4
nobs	93	83	95	419	402	399	388	406	405
% Pro-PV	36.6	62.7	56.8	46.5	47.8	67.2	82.5	55.9	62.7

been on PV, a more thorough analysis of this assumption is beyond the scope of this study. In any event, the opposition of these three groups to Brown is exactly opposite of the support predicted by sophisticated considerations (increases likelihood of passage of solar increase). Thus, these cases too support the assumption of straightforward voting.

Party and Ideology

The regression results support the hypothesis that ideology has a significant influence on photovoltaic support.[21] The predicted relationship for ideology (conservatives vote anti-PV) is highly significant in all equations. It is least significant in the Brown vote, which is consistent with the thesis advanced above that this amendment would split the solar coalition, and in the Gravel vote, which is consistent with the idea that solar proponents would be divided on this vote due to the large increase proposed.

The results for party are contrary to the prediction that Democrats are likely to vote pro-PV. In the Senate, party has no clear effect. In the House, Republicans are more likely to support solar energy than Democrats, once one has controlled for ideology. One possible explanation for this is that the votes which constitute the ACA index may be, on average, votes for which supporting one's party position (or one's President, if of the same party) may be more important than the solar votes under consideration. If this were the case, consider the effect on two Congressmen, one of each party and of the same ideology (somehow

---

[21] Or, to paraphrase the Republican presidential campaign slogan of 1988, PV voting is "about ideology."

objectively measured). Suppose there is a conservative, Republican president (the argument is the same if there is a liberal, Democratic president). The Republican Congressman votes with his party on the important votes in the ACA index; his resulting ACA score is higher than the Democratic congressman of equal ideological persuasion. When the Republican votes on an ideological issue like solar energy where party loyalty is less important, his biased ACA score lumps him with more conservative congressmen who are, based on ideology, more likely to oppose solar energy. Controlling for ACA score (not ideology), the Republican is more likely to vote for solar energy.

This hypothesis about the effects of including both ideology and party in roll call analyses should be tested in other roll call studies. This issue has often not arisen in studies to date because they have not included both variables. Of course the proper specification of ideology in a congressional vote equation is a controversial issue in the recent literature on congressional voting.[22]

---

[22] This issue is discussed in Chapter 2. One objection is that the significance of the ideology variable may only indicate the importance of variables not included in the voting regressions. Suppose that what really determined congressional voting behavior were the economic characteristics of districts and how bills affect these. Then the ideology measure constructed from voting behavior on a group of bills would reflect the economic characteristics of districts. Regressing solar energy votes on ACA scores and obtaining significance on the coefficient of ACA scores thus would not imply that solar energy votes were "ideological," in the usual sense of the term.

The controversy is discussed in detail in Carson and Oppenheimer (1984), Kalt and Zupan (1984), and Peltzman (1984). One approach is to attempt to remove the influence of these economic variables, either by regression analysis to yield a noneconomic residual ideology or by selection of votes which appear to be basically "ideological" and not economically determined. Another approach is to try to include the relevant economic variables in the regression. If the included economic variables also influence the included ideology index, the significance level of the economic variables may be understated and the hypotheses

The results concerning ideology and party suggest that ideology, not party, was the basis of the reduction in the program after the 1980 election.

Distributive Politics

The regression results generally confirm the hypothesis that photovoltaic support is influenced by distributive politics, but the results are more equivocal than for ideology. Furthermore, while both the consumption and expenditure/production components are positively related to support for photovoltaics, the consumption benefits seem to be more important. The consumption benefits of the program are represented in the regressions by electricity price, sunlight, and population density.

The electricity relationship is of the right sign in all votes, with significant coefficients in all but the Glenn and Hart votes. Sunlight, on the other hand, is about equally significant in the House and Senate votes. It has the wrong sign in three votes but only significantly so in the vote on the Fuqua amendment. Since half of the spending increase in this amendment was for nuclear power (the other votes pertain only to solar items), the wrong sign is not surprising. The Gravel and Tsongas votes (the other votes with incorrect signs) are also somewhat special, as discussed above. The lack of significance for sunlight in the Tsongas vote indicates that its explicit reward to PV may have split the "sunlight" coalition. The opposition of high sunlight areas to the Brown amendment (a vote to reallocate an increase for solar electric to all

---

regarding the role of these economic variables are therefore tested in a conservative manner.

solar), suggests that the "sunlight coalition" preferred increases targeted to PV or solar electric over increases in all solar programs.

The fact that the electricity and sunlight results are generally of the correct sign and significant supports the hypothesis that PV was seen as a potential benefit. Because of the high cost of PV at the time, PV could have been viewed not as a potential benefit, but as a potential curse in which use of PV would be mandated despite the existence of lower cost alternatives and these costs would be borne by the areas forced to use PV. Such mandated use of uneconomic PV never became a subject for serious debate within the program (the PURPA requirement that utilities buy power from alternative sources at avoided cost is not PV-specific and "avoided cost" might not be burdensome to utilities). In the absence of concrete proposals, it is difficult to predict the criteria for mandated use and thus what regression coefficients might have different predictions than previously argued. However, areas with high electricity price and sunlight might have been candidates, and therefore it is significant that these areas supported, rather than opposed, PV.

It is also important to note that since all but one of the votes pertain to all solar energy programs and not just PV, and solar programs such as heating and cooling substitute for other types of energy as well as for electricity, other energy prices are potential explanatory variables. Energy prices are highly correlated, and when both electricity and residential natural-gas prices are included in a regression, the coefficients for electricity are far more significant. Only the regressions with electricity prices only are reported here.

The natural log of population density was included in the regressions as an imperfect proxy for the extent of grid-connectedness. PV would be economic in non-grid-connected applications long before it would be economic in grid-connected applications. Although the grid market was expected to eventually dominate, nongrid applications could be judged as important by those who were less optimistic about the competitiveness of PV, who had high discount rates, or who were from areas that offered relatively more opportunities for nongrid applications. Variables to represent the first two of course are not available, but the extent of grid-connectedness would be negatively correlated with nongrid opportunities. Thus the predicted sign for the natural log of population density is negative.[23] The results are of the right sign in all but the Jeffords amendment, where the significance level is very low (.08), and have t-statistics in excess of 1.4 in six of the other eight. The almost-significant result in the Tsongas vote is significant since a government procurement program, which was the essence of the Tsongas vote, would have benefits primarily in nongrid applications, as explained in Chapter 3.

The interpretation of the results for population density is clouded, as discussed in Chapter 3, by the fact that population density is also correlated with land prices. Thus the negative sign on population density could mean nothing about greater potential for nongrid applications in particular, but simply reflect greater potential for all types of PV due to lower land prices and hence lower PV generation costs. However, as

---

[23] I initially used simply population density, with poor results. Upon further reflection, the log transformation made much better sense. In the House data, the population density varies from approximately .5 persons per square mile to over 75,000. Increases in population density at low densities would be likely to have far more effect on grid-connectedness than at high densities.

also discussed in Chapter 3, the low proportion of PV costs represented by land costs for central-station PV with no effect of land costs on residential rooftop PV, suggests the grid-connected interpretation may be better.

The importance of the distributive effects of PV expenditures and production receives weak support in the regressions. These expenditure benefits are represented by federal PV expenditures whereas the production benefit is represented by a PV manufacture dummy variable. The correlation between these two is .41 for Gravel and Glenn, .59 for Hart, .35 for Richmond, .13 for Anderson/Brown/Jeffords, .29 for Tsongas, and .21 for Fuqua.[24] The spending variable has the incorrect sign (negative) in 5 of the 9 votes and PV manufacture the wrong sign (negative) in three votes. However, the positive signs are more significant than the negative signs for both variables, particularly PV manufacturer, with t-statistics often exceeding unity.

The results for the Tsongas and Fuqua votes are especially interesting. These are the only two votes with correct signs for both variables. Furthermore, all four t-statistics exceed unity. Tsongas, the single vote that most clearly dealt exclusively with PV interests, has the second highest t-value for PV spending of any vote. Tsongas and Fuqua

---

[24] A comparison of the annual program summaries with the list of PV manufacturers suggests that the portion of federal PV expenditures that went to PV manufacturers is small. This is corroborated by the complaints of PV manufacturers that they were not receiving more of the funding. The correlation between PV expenditures and manufacture is therefore probably partially due to collocation. Due to the infant state of the industry, PV manufacturers were similar to research firms and thus would need somewhat similar skills. Collocation would also facilitate access to technology-specific human capital (e.g., hiring of employees of the other firms). The correlation is of course higher when FY76-83 spending is used instead of the yearly figures.

are also the last two votes, and thus the geographical pattern of PV expenditures and PV manufacture might have been clearer at this point than in earlier votes.[25] On the other hand, the significance levels for PV manufacture are lower in Tsongas than in Glenn, Brown, and Fuqua. Although the greater significance of the Fuqua result may be a result of when PV manufacture is measured, the greater significance levels in the Glenn and Brown vote is surprising, since a federal procurement program (the distinctive aspect of the Tsongas vote) provides much larger benefits per dollar of expenditure to current manufacturers than a research and development program does.

There are two reasons why the results on expenditures and production are perhaps the most that could be expected. First, the program is relatively small, and thus other effects might be more important. Second, the data used had several problems. The spending variable represents an estimate of PV spending whereas all but the Tsongas vote concern other solar programs as well.[26] Photovoltaics and solar expenditures by state or district are probably positively correlated, but PV spending probably has lower significance levels than solar spending would. Finally, the PV manufacturer data only refer to a single point in time and do not distinguish between large and small manufacturers or take account of

---

[25] An additional reason for better performance of the PV manufacture variable in the later votes is that these votes are closest to the time (1980) when the PV manufacture data were compiled.

[26] No estimates of district solar funding are available in convenient form. I do not know whether a "bottoms up" approach to collect this information for each of the other solar programs, such as was used for photovoltaics, is possible. However, if such data were available in the form available for PV, it would require several man-months of effort to collect.

several manufacturers being present in the same area.

There is also weak evidence that distributive effects of PV expenditures or PV manufacture are more likely to lead to pro-photovoltaic votes for Republicans than for Democrats, which is the opposite of the effect found by Cohen for government expenditures in the Clinch River study. Table 35 shows that the coefficient of the spending variable for Republicans is greater than for Democrats in all but the Anderson vote, although the difference in coefficients is significant only in the Richmond and Brown vote. The coefficient of the PV manufacture variable is greater for Republicans than for Democrats in all but the Gravel, Anderson, and Jeffords vote, although the difference in coefficients is never significant. The latter three votes are special in different ways: Gravel because of the large increase proposed, and Anderson and Jeffords as the only amendments of the nine proposed by Republicans.

Instead of focusing just on whether the responsiveness to PV spending and manufacture differ by party, one can determine whether all coefficients are stable across party lines. Table 36 shows that in some cases, notably Richmond, Brown, and Anderson, there do seem to be different effects for all variables as a whole across party lines.

The distributive politics hypothesis receives a different kind of test from the coefficients on when the terms of Senators end. Our hypothesis suggests that party and ideology factors and expenditure/manufacture factors lead to a negative coefficient on term whereas consumption factors cause a positive one. The results presented to date suggest that party/ideology and consumption factors are the most important, so the likely effect on the coefficient of term is unclear.

Table 35
Differences in Responsiveness to PV Spending and PV Manufacture by Party

	Restricted		Unrestricted	
	PV Spending	PV Manu.	PV Spending	PV Manu.
Gravel	1.83 (.46)	-.25 (.20)	5.23 (.80)	-1.35 (.68)
Glenn	5.71 (1.00)	4.50 (1.17)	1.11 (.18)	4.16 (1.10)
Hart	2.30 (.88)	.74 (.56)	2.24 (.66)	.05 (.03)
Richmond	4.23 (2.81)	1.45 (1.28)	4.04 (2.48)	.38 (.30)
Anderson	-46.4 (.07)	-.35 (.31)	-.01 (.01)	-.35 (.31)
Brown	2.33 (1.84)	.95 (.99)	2.23 (1.74)	.46 (.46)
Jeffords	69.4 (.03)	-7.22 (.13)	.15 (.07)	-7.25 (.13)
Tsongas	.13 (.20)	.38 (.32)	.07 (.12)	.34 (.27)
Fuqua	.88 (1.24)	.97 (.67)	.78 (1.06)	.59 (.39)

Note: The "restricted" results assume that there are no party effects on the other variables. Thus the entries under "restricted" for PV spending assume that there is no party effect on PV manufacture. The "unrestricted" assume there are no party effects on variables other than PV spending and manufacture. For example, for PV spending, the former is the negative of the coefficient of (party*PV spending) in the estimation (p denotes party)

$V = \ldots + (b1-b2)(p*PVsp) + b2*PVsp$, and the latter is the negative of the coefficient of (p*PVsp) in the estimation

$$V = \ldots + (b1-b2)(p*PVsp) + b2*PVsp + (b3-b4)(p*PVman) + b4*PVman$$

where neither has p as a separate variable.

Table 36
Stability of Coefficients (Equation Taken as a Whole) Across Party Lines

	Republican	Democrat	Sum	Combined	Sign. Level
Gravel	Failed	-29.8	NA	-42.1	NA
Glenn	-13.6	-19.7	-33.3	-38.7	42.0
Hart	-10.7	-25.5	-36.2	-42.6	65.6
Richmond	-79.8	-143.3	-223.1	-239.5	99.9
Anderson	-63.5	-125.5	-189.0	-194.0	47.0
Brown	-84.8	-142.2	-227.0	-237.5	98.6
Jeffords	-75.8	-42.2	-118.0	-121.1	See below
Tsongas	-78.1	-145.4	-223.5	-228.1	34.8
Fuqua	-77.0	-125.1	-202.1	-210.0	90.9

Note: Republican and Democrat columns are the log likelihood at convergence of each equation estimated separately (without party as a variable) for Republicans and Democrats. The sum column is the sum of these two. The combined column is the log likelihood at convergence of the equation estimated without party for the combined data set. The significance column lists the significance levels at which the Republican coefficient is different than (two-tailed test) the Democratic coefficient in the equation taken as a whole. This is determined by the likelihood ratio test with degrees of freedom equal to the number of variables (including the constant) on the RHS. The unrestricted is shown in the "sum" column, the unrestricted in the "combined" column. In the Jeffords vote, the significance level for the 1-tailed test is 37.5%.

With respect to the failure of the Gravel estimation for Republicans, Doug Rivers argued this is because the number of RHS variables (eight) exceeds the number of observations for one of the alternatives of the dependent variable (seven, since the Republican vote on this amendment was 7 yea, 29 against) leading to perfect discrimination of the dependent variable.

In all three Senate votes (House votes are obviously not appropriate here), the further off one's election, the more likely one is to vote for PV. This positive relationship is significant in only one equation however.

The positive coefficient on term suggests that the economic benefits of PV played a larger role in PV voting than ideology or expenditure/manufacture considerations. However, this conclusion depends on assumptions regarding how the importance of various factors would vary by term. To test these assumptions directly, one can estimate each vote with the observations segmented by term. The results are presented in Tables 37-39. The party and ideology results strongly support the notion that these are most salient to those whose election is closest--the coefficients are more negative, the closer the election. This is the predicted relationship for ideology[27] and this pattern is consistent with

---

[27] Kalt and Zupan (1984) found that the proportion of Senators voting against their ideology was largest for those nearing election, and concluded that ideological voting, "shirking," was less prevalent for this group. Although the Kalt and Zupan methodology is not entirely clear, my attempt to replicate it for PV finds no difference between Senators with elections closest and all other Senators. Using the regression model from Table 34 (without the insignificant committee variables), I examined those cases in which the regression model predicted the incorrect vote. For each Senate vote, I determined how all Senators would vote if voting strictly based on ideology (e.g., if 40 percent of Senators voted for an amendment, I assumed that the 40 percent of those voting with the highest ACA scores would vote for the amendment). Summing across the three votes, I find the following:

Senator's Electoral Ideology Status	Incorrect Predictions	of which	Voted against ACA
Up for	25		8
Not up for Reelection	36		11

Thus there is no significant difference between these groups. There is

Table 37
Coefficients of Party and Ideology, Sample Segmented by Term

	Near Future	Medium Future	Furthest Off
Party			
Gravel	-.69 (.32)	Failed	2.26 (1.10)
Glenn	-9.01 (1.72)	2.47 (.99)	-.25 (.10)
Hart	-.41 (.24)	.72 (.23)	1.42 (1.03)
Ideology			
Gravel	-6.75 (1.46)	Failed	2.47 (.81)
Glenn	-16.2 (1.68)	-3.89 (1.38)	-6.84 (1.44)
Hart	-3.54 (1.32)	-10.5 (1.59)	.47 (.20)

Table 38
Coefficients of Consumption Factors, Sample Segmented by Term

	Near Future	Medium Future	Furthest Off
Electricity			
Gravel	.10 (.38)	Failed	.62 (1.59)
Glenn	-.01 (.05)	.25 (.45)	-.49 (.83)
Hart	-.02 (.05)	-.51 (.66)	.36 (1.19)
Sunlight			
Gravel	3.64 (1.11)	Failed	-7.04 (1.67)
Glenn	14.9 (1.40)	10.1 (1.50)	3.16 (.69)
Hart	-1.82 (.58)	-.41 (.05)	-.83 (.28)

Table 39

Coefficients of Expenditure/Manufacture, Sample Segmented by Term

	Near Future	Medium Future	Furthest Off
PV Expend.			
Gravel	2.77 (1.43)	Failed	22.5 (1.72)
Glenn	-9.36 (.78)	42.7 (1.47)	408 (.20)
Hart	6.84 (1.87)	27.2 (1.24)	30.0 (1.09)
PV Manu.			
Gravel	-1.41 (.90)	Failed	1.02 (.69)
Glenn	2.09 (.99)	7.43 (.11)	53.0 (.15)
Hart	-4.01 (1.72)	2.41 (.68)	8.73 (.17)

the ex post theory set forth above concerning why Republicans support solar energy if one has controlled for ACA score.[28] Electricity price works as predicted (it matters most to those whose election is furthest off) but sunlight works in the opposite fashion.[29] Finally, expenditure and manufacture work opposite to predictions, being most important for those with elections furthest off.

The appropriate interpretation of the positive coefficient of term is therefore unclear. Actually, the expenditure and manufacture results make sense in a way. The Senate votes were taken at the outset of the program (1975-1976), when spending was beginning to grow extremely rapidly. Because this pattern was likely to continue, those with elections the furthest off could expect expenditure and manufacture much larger (measured either as an average yearly amount or heavily weighted toward right before the election) than had been experienced with those

---

however, a significant difference if one segments the "not up for reelection" group into those up for reelection in 1979 and 1981. Errors are 11 and 25 respectively, but voting against ideology are 2 and 9. Thus the nearest and furthest group behave similarly, with the middle group behaving differently.

Thus, although the Kalt and Zupan methodology applied to PV does not find a difference in the two groups, it does if there are three groups. In any case, the methodology used in the text measures whether ideology is more significant in one group or another. What exactly is measured by the Kalt and Zupan methodology is less clear.

[28] The distorting effect of party loyalty on ACA score would be greatest for Senators whose election is upcoming.

[29] The other consumption factor, population density, generally becomes stronger in the predicted direction (for the variable in the unsegmented regressions) the further off the election, following the prediction for consumption factors in general. However, no prediction had been made regarding the effect of term of this variable, because although the immediate benefits of PV would be concentrated in nongrid (low-density) applications, how immediate and hence how these would be viewed by senators of different terms is unclear.

facing reelection in 1976. If one accepts this ex post reasoning, one is left with distributive politics factors collectively (with the exception of sunlight) being more important than party/ideology factors. However, the results for the term coefficients are also consistent with the hypothesis that Senators are voting based on economic benefits to the nation as a whole, rather than their state.

ALTERNATIVE SPECIFICATION OF VARIABLES

The specification above of two variables--electricity price and PV spending, as well as the separate specification of electricity price and insolation as opposed to a combined benefits variable--is controversial on theoretical grounds. In this section, I examine the performance of alternative specifications in these areas.

Electricity Price

In earlier stages of this research, I had used electricity price in all regressions. It was one of the most significant explanatory variables. Upon further reflection, it seemed that per capita electricity expenditures was a better variable, or better still, per capita electricity expenditures as a percent of personal income. The rationale for these revisions was that, although areas where the per unit cost of electricity was high might benefit more by the development of a less costly alternative and therefore would support PV, the total cost of electricity or this total as a percent of total income would more accurately reflect the stake of these areas in the development of PV.

The results with per capita electricity expenditures, electricity expenditures as a percent of state personal income, and electricity price are reported in Table 40. These results indicate that price far outperforms expenditure or expenditure as a percent of income. The average significance level is highest for electricity price (2.17), followed by PCEE as a percent of per capita personal income (1.16), followed by PCEE (.98). As suggested above, the predicted sign is positive for all three variables. Five out of nine signs for PCEE, and six out of nine for PCEE as a percent of per capita personal income, are however negative, compared with positive signs for all nine for electricity price, with especially strong results in the House votes.

One potential problem with the rationale for using expenditure, rather than price, is the interaction of two facts: (1) PV is likely to be a relatively high-cost source of power and (2) low prices increase consumption. Areas where power is relatively cheap are likely to consume relatively large amounts,[30] and thus expenditures may be moderate rather than low. Yet these areas might have little interest in PV since it would not likely displace their cheap power. To investigate this possibility, I ran the regressions with expenditures as a percent of personal income but excluded the observations with the lowest 20 percent in electricity price. The results, also shown in Table 40, are not on the whole better than the results with all observations included.

The results above indicate that the state average electricity price in the year of the vote outperforms state per capita electricity expenditure in the year of the vote or state electricity expenditure as

---

[30] The correlation between electricity consumption and price is -.71 in 75 and -.73 in 76 for the Senate votes, and in the House is -.79 for 75, -.82 in 76, -.83 in 1977, and -.84 in 1980.

Table 40
Coefficient of Electricity Expenditure and Price Variables
(PCEE denotes state Per Capita Electricity Expenditure)

Vote	PCEE	PCEE/State PI	Electricity Price	PCEE/State PI(Exclu)
Gravel	9.64	-9.11	.30	-27.2
	(1.08)	(.23)	(2.12)	(.53)
Glenn	-5.07	-58.1	.09	-63.4
	(.60)	(1.55)	(.68)	(1.23)
Hart	1.03	-6.85	.04	80.9
	(.17)	(.21)	(.30)	(1.58)
Richmond	5.31	10.0	.12	15.4
	(1.46)	(.61)	(2.36)	(.71)
Anderson	-5.11	2.95	.20	10.2
	(1.36)	(.17)	(3.43)	(.43)
Brown	-.25	-25.6	.23	-45.6
	(.08)	(1.57)	(3.99)	(2.04)
Jeffords	8.90	46.3	.17	18.0
	(1.90)	(2.14)	(1.82)	(.64)
Tsongas	.39	-20.9	.15	-19.1
	(.14)	(1.51)	(2.67)	(.99)
Fuqua	-4.10	-31.6	.12	-39.4
	(2.07)	(2.48)	(2.13)	(2.10)
Average T-stat.	.98	1.16	2.17	1.14

Note: Four sets of regressions were run with other model variables as specified in the text. In each set of regressions, one electricity variable was used: (1) state per capita electricity expenditures (thousands of current dollars) in year of vote, (2) state per capita electricity expenditures as a percent of state personal income, both in year of vote, expressed as a fraction, (3) average electricity price in year of vote (dollars per million BTU), and (4) state per capita electricity expenditures as a percent of state personal income, excluding 20 percent of the 100 Senators and 435 Representatives (those with the lowest electricity price).

a percent of state personal income in the year of the vote. However, as noted in Chapter 3, there are several other specifications which merit investigation:

- average residential price, the year of vote
- projected 1985 average price for region
- projected 1985 marginal price for region
- average price year of vote and percent change from 2 years earlier
- average residential price and percent change from 2 years earlier

Table 41 reports the t-statistics of the electricity price coefficient for the first three of the above, along with those for average electricity price in the year of the vote. Each model is estimated in unnested form, i.e., exactly one electricity price variable, due to the high collinearity between the alternative specifications.[31] The results indicate that current average price slightly outperforms the 1985 marginal price, with current residential and 1985 average trailing further behind. The 1985 prices are only available on a regional basis and this probably hurts their performance somewhat. The ordering using the Akaike Information Criterion (Table 42) is the same.[32]

---

[31] Correlations depend on which vote year is being used and whether the vote is Senate or House. The correlations are presented below:

-average and residential electricity price is .97
-average and 1985 average is .70-.71 in the Senate and .81-.85 in the House
-average and 1985 marginal is .69-.72 in the Senate and .76-.79 in the House
-residential and 1985 average is .75-.77 in Senate and .85-.87 in House
-residential and 1985 marginal is .70-.71 in Senate and .72-.75 in House
-1985 average and 1985 marginal is .74 in Senate and .71 in House

[32] This procedure is recommended in Amemiya (1981) for this problem. However, with the models differing only in the one variable, this procedure is almost certainly equivalent to choosing the model with the largest t-statistic for each equation (whether this equivalence carries

Table 41
T Statistics for Alternative Specifications of Electricity Variable

	Average	1985 Marginal	Residential	1985 Average
Gravel	2.12	1.44	2.13	2.21
Glenn	.68	.40	.91	1.17 (-)
Hart	.30	1.16	.65	.43
Richmond	2.36	1.53	2.21	1.60
Anderson	3.43	3.30	3.07	2.68
Brown	3.99	3.33	3.77	2.53
Jeffords	1.82	2.77	1.55	1.85
Tsongas	2.67	2.07	2.41	2.50
Fuqua	2.13	2.63	1.46	1.46
Average t-statistic	2.17	2.08	2.02	1.83

Note: A minus sign after the t-statistic indicates that sign of coefficient is negative. Models are estimated in unnested form, i.e., exactly one electricity price variable per model. Electricity price variables are (1) average electricity price, year of vote, in state, (2) 1985 marginal price in region, (3) average residential electricity price, year of vote, in state, and (4) 1985 average price in state.

Table 42
Alternative Specifications of Electricity Variable
(Using Akaike Information Criterion)

	Average	1985 Marginal	Residential	1985 Average
Gravel	41.6	43.1	41.5	41.2
Glenn	36.4	36.6	36.2	35.9 (-)
Hart	42.6	41.9	42.4	42.6
Richmond	227.5	229.2	227.9	229.1
Anderson	192.1	192.6	193.4	194.6
Brown	234.1	237.1	235.1	239.4
Jeffords	120.7	118.2	121.2	120.8
Tsongas	226.1	227.5	226.7	226.5
Fuqua	204.5	203.2	205.8	205.8
Average	147.3	147.7	147.8	148.4

Note: The Akaike Information Criterion = -unconstrained log likelihood + K where K is the number of parameters to be estimated. One chooses the model for which the AIC is the smallest. See Amemiya (1981). Since the number of variables is the same in each specification and the log likelihood is negative, this is equivalent to choosing the model with the smallest (in absolute value) unconstrained log likelihood. The latter are the numbers shown in the table. A minus sign after the log likelihood indicates that the sign of the coefficient is negative.

Table 43 presents the results of whether price change (ratio of current average price to average price two years earlier) should be included with average electricity price. One would predict either that the coefficients would have no particular sign if only the current price level matters or that the sign would be positive, with more rapid price increases expected to increase support for alternatives such as PV. The coefficient is negative in five of the nine. Only two of the nine votes have coefficients with t-statistics in excess of unity, and these two are of different sign. Thus Congressmen do not seem to be voting based on the increase in the average electricity price.

The change in residential prices fares little better. Table 44 shows that while the significance level of the coefficient on price change exceeds unity in two votes, both of which have the predicted positive sign, the coefficient is negative on six of the nine votes.

Photovoltaic Spending

The spending variable used in the estimations above is the estimated federal photovoltaic expenditures to the district or state during the fiscal year of the authorization or appropriation being voted on, in real terms and discounted at 10 percent to FY76 dollars. Earlier in the research, estimated photovoltaic spending in the district/state over a longer period, FY 76-83, was used for three reasons. First, logrolling and information cost considerations suggest that representatives might vote according to the total effect of the program on their district over

---

through to averages over several votes is not clear). Henceforth I shall only use the t-statistic comparison in these cases.

Table 43
Coefficient of Change in Average Electricity Price
(price year of vote divided by price two years earlier)
(t statistics in parentheses)

	Change in Price	Electricity Price	Correlation
Gravel	1.03 (.32)	.28 (1.85)	.58
Glenn	-2.44 (.80)	.13 (.92)	.58
Hart	-1.33 (.37)	.04 (.30)	-.18
Richmond	.53 (.44)	.10 (1.75)	.59
Anderson	-4.27 (2.11)	.17 (2.90)	-.40
Brown	-1.11 (.58)	.22 (3.67)	-.40
Jeffords	3.09 (1.25)	.19 (2.05)	-.40
Tsongas	.25 (.13)	.15 (2.65)	-.30
Fuqua	-1.48 (.74)	.13 (2.27)	.41

Table 44
Coefficient of Change in Average Residential Electricity Price
(price year of vote divided by price two years earlier)
(t statistics in parentheses)

	Change in Price	Electricity Price	Correlation
Gravel	2.74 (.74)	.26 (1.54)	.60
Glenn	-2.34 (.67)	.16 (1.09)	.60
Hart	-1.26 (.37)	.10 (.69)	-.10
Richmond	2.01 (1.46)	.06 (.99)	.58
Anderson	-1.77 (.87)	.17 (2.85)	-.36
Brown	-1.18 (.61)	.21 (3.53)	-.36
Jeffords	6.67 (2.51)	.19 (2.07)	-.36
Tsongas	-.79 (.37)	.13 (2.35)	-.33
Fuqua	-.69 (.33)	.08 (1.45)	.47

time, rather than the specific increments to the program provided for in the amendment or in that year's authorization. Second, estimates of the spending in a particular district/state for a given year are less reliable than the estimates over an eight-year period because of the way the spending file was constructed. Third, due to the inadequacies of the source material, the year-by-year estimates are poorest at the outset of the 76-83 period, which is when practically all the votes occurred. The results of vote year spending vs. FY 76-83 spending are compared in Table 45. Although the results are very similar, vote year spending slightly outperforms FY 76-83 spending.

To test the theory of retrospective voting, total program spending was divided into past, current, and future spending. Reelection considerations suggest that past spending should be irrelevant,[33] present spending the most important,[34] and future spending discounted more than it would be on economic grounds alone.[35] To test this theory, I shall

---

[33] Past spending is that which was determined by votes before the last time the member was elected. The coefficient on this should be zero, since voters would have already used that information in deciding how to vote in the last election.

[34] Present expenditures are those that are determined in the time period between the last election and the next election for the member in question.

[35] Future funding is that which is determined after the next election for this member. The coefficient on future expenditures should be smaller than the coefficient on current expenditures due to this higher political discount rate. Thus since

$b1*current + b2*future$ is equal to

$(b1-b2)*current + b2*(current + future)$

the hypothesis that $b1 > b2$ is tested by a 1-tailed t-test on the coefficient of current in the second line.

Table 45
Significance of Year of Vote Spending vs. FY 76-83 Spending
(t statistics in parentheses)

	Year of Vote	FY 76-83
Gravel	3.83 (1.06)	-75.3 (.79)
Glenn	-2.18 (1.13)	-144 (.92)
Hart	3.33 (1.82)	82.5 (.68)
Richmond	-.21 (.37)	39.0 (1.15)
Anderson	-.05 (.25)	-4.54 (.12)
Brown	-.20 (.69)	-47.8 (.96)
Jeffords	-.17 (.76)	-42.6 (.93)
Tsongas	.39 (1.53)	51.3 (1.42)
Fuqua	.27 (1.02)	42.6 (1.13)
Number of votes correct signs	4	4
Average t-stat. all votes	.96	.90
Average t-stat. w/ correct sign	1.36	1.10
Average t-stat. House,w/ corr. sign	1.28	1.28

Note: Models estimated in unnested form with one spending variable due to high correlation between year of vote spending and FY 76-83 spending: .54-.61 in Senate and .76-.93 in House. FY 76-83 spending for Senate votes in thousands of FY 1976 dollars per capita, discounted at 10 percent; for House, in millions of FY 1976 dollars, discounted at 10 percent.

use the actual spending figures for these years rather than expected expenditures, which are unobservable. The model thus assumes perfect foresight--alternatively, one could use a model of adaptive expectations (suggested to me by Jeff Dubin) where the expected expenditures are a function of past and current expenditures. Although this more sophisticated method might be preferred on theoretical grounds, even the simplest approach founders on the high degree of correlation among past, present, and future funding, as we shall see below.

Note that the definition of past, present, and future spending implies that how spending is classified will vary among Senators for a given vote. Current expenditures are those that are determined (voted on) in the 6-year period between their elections, with past and future spending defined accordingly. Since their terms differ, the definitions of these spending categories differ. All House members will consider current expenditures as those that are determined in the 2-year period between Congressional elections.[36]

The precise definitions are shown in Table 46. To illustrate, the Tsongas vote in September 1977 was a vote on the FY 1978 authorization. The last election was November 1976, at which point the FY 1977 authorization/appropriation would have been approved (1976 was an election year and hence Congress would be adjourned). Thus FY 76-77 is considered past, FY 78-79 is considered present (since FY 1979 will generally be

---

[36] Special elections are ignored. Members not standing for reelection are assumed to vote as if they were, so as to help their party's candidate.

Table 46
Definitions of Past, Present, and Future Spending for Different Votes
(fiscal years)

Vote and Date of Vote	Past	Present	Future	
Gravel 7/31/75	na	76-77	78-83	for terms ending 1/77
		76-78	79-83	for terms ending 1/79
		76-80	81-83	for terms ending 1/81
Glenn 12/75		Same as Gravel		
Hart 6/76		Same as Gravel		
Richmond 6/75	na	76-77	78-83	
Anderson Brown Jeffords 5/76		Same as Richmond		
Tsongas 9/77	76-77	78-79	80-83	
Fuqua 6/80	76-79	80-81	82-83	

determined prior to November 1978), and FY 80-83 is considered future.[37]

The results are shown in Table 47, with three estimations for each Senate vote, each defined by the set of Senators with a common term. For every vote, the sign of present spending is opposite to that for future spending. I do not believe that one should try to interpret these signs in the normal manner, e.g., a negative sign on present spending indicating spending increases makes voting pro-PV less likely, etc. Instead, I think the pattern of opposite signs is purely a statistical artifact of the high correlation between these variables (.74-92 in the Senate votes depending on the group of Senators, and in the House, .73-.78 between present and future, .72-.82 between past and present, and .61-.64 between past and future, for the years defined by the House votes). For example, the reason that the past and future variables have the same sign in the two votes with three spending variables is probably because the correlation is lowest between these two.

To produce more reliable estimates, a procedure whereby one uses ordinary least squares (OLS) to eliminate the collinearity between past, present, and future spending before estimating the regression, was also

---

[37] How this procedure is implemented with respect to the Fuqua vote is somewhat arbitrary. For all votes, I have used a 1981 funding level of 139.2 million. This is the final figure reflecting cuts made in 1981 after the 1980 election. I have classified 1980-81 funding as "present" for the Fuqua vote since the original 1981 funding was determined in the same election cycle as the Fuqua vote (in fact the Fuqua vote was on this 1981 funding). A more complicated procedure would have been to use for Fuqua the original funding level of 160.2 for 1981 funding, and put the cut into 1982 funding (future action). The 1978 supplemental, considered in October 1977, poses no problem since it occurs in the same election cycle as the original action. The 1980 rescission was only for $7 million, and therefore is not large enough to worry about.

Table 47
Signs of Past, Present, and Future Funding Coefficients
(t statistics in parentheses)

	Past	Present	Future
Gravel, term=77	NA	+ (1.46)	- (1.24)
term=79	Failed ----------------------------------		
term=81	NA	+ (.82)	- (.87)
Glenn, term=77	NA	- (1.36)	+ (1.09)
term=79	NA	+ (1.71)	- (.62)
term=81	NA	Failed---------------	
Hart, term=77	NA	+ (1.49)	- (.71)
term=79	NA	+ (.88)	- (.40)
term=81	NA	- (1.46)	+ (2.22)
Richmond	NA	- (.41)	+ (.82)
Anderson	NA	- (.64)	+ (.46)
Brown	NA	- (.72)	- (.38)
Jeffords	NA	- (.65)	+ (.25)
Tsongas	+ (1.09)	- (.91)	+ (.89)
Fuqua	+ (.15)	- (1.35)	+ (1.58)

Note: Senate equations estimated without term for each group of Senators.

employed.[38] As is clear from Table 48, the same problem of opposite signs

---

[38] The following procedure was suggested to me by Da-Hsiang Donald Lien to deal with this problem. Let P and F represent present and future spending, respectively.

1. Regress F on P with OLS. This produces a residual e that is uncorrelated with P.

$$F = a + bP + e$$

2. Estimate the vote model using logit with P and residual from (1) on RHS, along with other variables.

$$Vote = \ldots + cP + de + error$$

3. Use the estimated coefficients from the OLS and logit regressions to produce an estimate of the coefficients of P and F in a vote model. From (1),
$e = F - a - bP$. Substitute for e in (2) to give

$$Vote = \ldots + cP + d(F-a-bP)$$

$$+ \ldots - ad + dF + (c-db)P$$

The coefficient of F is therefore d and the coefficient of P is therefore (c-db). The significance of the coefficient of F is given by the t-statistic for d; the significance of the coefficient of P can be calculated, with some effort.

For the two votes with past, present, and future spending (denoted P, C, and F), a similar approach is employed:

1. Regress C on P with OLS, producing a residual e1.

$$C = a + bP + e1$$

2. Regress F on P and e1 with OLS, producing a residual e2.

$$F = c + dP + fe1 + e2$$

3. Estimate vote model with logit, with P, e1, and e2 on RHS, along with other variables.

$$Vote = g + \ldots + hP + ie1 + je2 + error$$

4. Rearrange (1) to yield $e1 = C - a - bP$ and (2) to yield

$$e2 = F - c - dP - fe1$$

$$= F - c - dP - f(C - a - bP)$$

Table 48
Past, Present, and Future Funding Coefficients
(Using OLS multicollinearity procedure)

	Past	Present	Future
Gravel, term=77	NA	6.61	-1.71
term=79	Failed ----------------------------------		
term=81	NA	.75	-1.11
Glenn, term=77	NA	-9.57	1.83
term=79	NA	10.4	-1.42
term=81	NA	Failed---------------	
Hart, term=77	NA	2.88	-.36
term=79	NA	23.8	-1.90
term=81	NA	-2.31	37.9
Richmond	NA	-.11	.10
Anderson	NA	-.20	.05
Brown	NA	.20	-.02
Jeffords	NA	-.28	.04
Tsongas	.42	-.25	.10
Fuqua	.04	-.40	1.46

Note: Senate equations estimated without term for each group of Senators. Units of spending are dollars per capita for Senate and millions of dollars for House.

occurs throughout with this procedure. Thus, based on the results with the straightforward approach and the OLS approach, the theory of retrospective voting cannot be tested with these data.

Another possibility is that rather than using year-of-vote spending (i.e., the total appropriation for that year), we should only use the spending being voted on in the amendment, i.e., the increase in spending over what would exist without the amendment. To test this, the normal approach would be to enter both the amendment and single year estimates in the same model. Unfortunately the only estimate I have of amendment expenditures by state or district is simply total PV spending by state or district times the ratio of amendment appropriation/total PV appropriation, and thus one cannot enter both in the same regression. Instead, one could estimate the model in unnested form with each variable. Since the model is the same except for the spending variable, and since the spending variables are perfectly correlated, the two sets of estimations would be identical in the following respects:

-the coefficients and T-statistics on all variables except spending

-the T-statistics on spending

-the log likelihood of the regression

and the preferred model will be the one with more stable coefficients on spending across votes. Unfortunately, the increase in PV spending from

---

$$= F - c + (fb - d)P - fC + fa$$

5. Substitute for e1 and e2 in vote model

$$V = g + \dots + hP + i(C-a-bP) + j(F - c + (fb-d)P - fC + fa)$$

$$= \dots + [h - ib + j(fb-d)]P + (i-jf)C + jF$$

to yield coefficients of P, C, and F in vote model.

several of the amendments (e.g., Glenn and Hart) is not clear, and thus this shall not be pursued.[39]

Finally, the voting decision need not respond to a change in PV spending according to the S-shaped response curve imposed by the logit estimation procedure. Although this is the response that one would predict, it is possible in principle to estimate directly the slope along various spending intervals. If three intervals are desired, one replaces spending on the RHS with three interaction terms:

d1*spending, d2*spending, d3*spending

where

d1 = 1 if the spending in the district was in the low range of funding by district (state for Senators)

d2 = 1 if the spending in the district was in the middle range of funding by district

d3 = 1 if the spending in the district was in the high range of funding by district

The coefficients on these interaction terms then represent the slopes along the three sections of the curve. If the bottom group contains only those with no spending, the model should be estimated by replacing spending with

d2*spending, d3*spending

---

[39] An alternative would be to compare amendment spending to single year spending for solar, rather than PV, amounts. While the solar increases due to the amendments are clear, one has to assume that solar spending has the same geographic distribution that PV does.

since inclusion of d1*spending will result in a singular matrix since this product is always equal to zero if no member of the bottom group has spending.

The results of three different definitions of three intervals are shown in Tables 49-51. In all three tables, the bottom group consists of exactly those with no spending. In the first table, only three of the coefficients of the middle group are larger (<u>not</u> in an absolute value sense) than for the high group, and two of these middle group coefficients have very low significance levels. To lessen the responsiveness in the high group, the high group was narrowed in the second table. Now four of the middle group coefficients are larger, but three of the four occur where the coefficient of the continuous form of the variable is of the wrong sign. The last table narrows the high group even more, but the result is that only two of the middle group coefficients are larger. Thus, the results in all three tables do not support the hypothesis of a S-shaped response to spending.

Benefits Model

As discussed in Chapter 3, an alternative to the use of electricity expenditure or price and sunlight variables in the regressions is to combine these into a benefits variable. The estimate of the cost of PV electricity developed there is

$$\text{PV cost} = 129.3/S + .0099 \text{ in \$/kWh}$$

To transform our insolation data to use this equation, one only needs to

Table 49
Piecewise Estimation of Spending Coefficient, Largest High Group

	Middle PV Spending	High PV Spending
Gravel	-4.08 (2.28)	.35 (.99)
Glenn	.72 (.06)	-2.18 (1.11)
Hart	3.10 (.49)	3.34 (1.80)
Richmond	.29 (.03)	-.21 (.36)
Anderson	-4.33 (.93)	-.05 (.24)
Brown	-.38 (.09)	-.20 (.69)
Jeffords	4.84 (.95)	-.16 (.74)
Tsongas	-2.06 (.80)	.40 (1.52)
Fuqua	-.63 (.26)	.27 (1.03)

Note: Approximately 25 states receive no spending. In the House, 381 districts in FY 76, 364 in FY 77, 343 in FY 78, and 315 in FY 81 receive no spending. High PV spending group consists of 9-10 states (Senate votes) and 35-40 districts. Middle PV spending group is defined as the rest that receive some spending.

Table 50
Piecewise Estimation of Spending Variable, Smaller High Group

	Middle PV Spending	High PV Spending
Gravel	13.8 (2.72)	2.83 (1.86)
Glenn	.59 (.08)	-2.22 (1.01)
Hart	2.40 (.67)	3.48 (1.79)
Richmond	-1.35 (.68)	-.14 (.24)
Anderson	-.15 (.14)	-.05 (.24)
Brown	.55 (.57)	.26 (.76)
Jeffords	.13 (.68)	-.18 (.75)
Tsongas	.18 (.18)	.39 (1.51)
Fuqua	-1.64 (1.26)	.32 (1.11)

Note: High group in Senate votes consists of about 5 states and 18 districts.

Table 51
Piecewise Estimation of Spending Variable, Smallest High Group

	Middle PV Spending	High PV Spending
Gravel	4.36 (1.01)	3.24 (.92)
Glenn	2.54 (.36)	-2.43 (.80)
Hart	1.78 (.79)	11.6 (.18)
Richmond	-2.01 (1.67)	.18 (.31)
Anderson	-.59 (.72)	-.03 (.16)
Brown	-.38 (.53)	-.18 (.63)
Jeffords	-.62 (.65)	-.16 (.78)
Tsongas	-.02 (.03)	.45 (1.45)
Fuqua	-.56 (.73)	.35 (1.12)

Note: High group consists of about 3 states and 9 districts.

multiply by 1000 since the maximum value in our district insolation set = 2.4, whereas the maximum value assumed for S in the equation is 2400. Since price the year of the vote outperformed alternative specifications (electricity expenditure, average electricity price in 1985, marginal electricity price in 1985, residential price the year of vote, average price the year of vote combined with ratio of price the year of the vote to price two years earlier, and similarly for residential), this shall be used in our benefits model. However, it is necessary to "scale up" this price so that it is an estimate of electricity prices that might exist at the time when PV attains the parameters that result in the PV cost equation above. To scale up, I multiply by the ratio of the average 1985 price to the average current year price.[40] Finally, since our PV cost estimate is in \$/kWh and our electricity price in \$/million BTU, the former is divided by .003412 to convert it to \$/million BTU.[41]

This procedure produces the following benefit estimate:

ben = elprice*mean(ave85)/mean(elprice) - (.129/ins.+.0099)/.003412

The results with this benefits variable are compared to the separate use of electricity price and insolation in Table 52. The benefits variable has the correct sign in every vote, whereas electricity price has

---

[40] The 1985 estimates for ten regions are converted to state and district estimates by assuming that each state and district in the region has the same price. Since the scale-up factor is somewhat arbitrary, the 1985 and year of vote averages are the simple average of state (Senate votes) and district (House votes) estimates; they are not quantity-weighted.

[41] U.S. Dept. of Energy (1984c), p. 229. The omission of the word "million" in this source is clearly a mistake.

Table 52

Separate Electricity Price and Insolation Variables vs. Combined Variable

(t statistics in parentheses)

	Price	Insolation	LRT Sign.	Benefits	LRT Sign.
Gravel	.30	-1.17	45.7	.06	43.1
	(2.12)	(.85)	99.999837	(1.80)	99.999793
Glenn	.09	4.20	42.2	.03	34.4
	(.68)	(2.62)	99.999309	(1.06)	99.992401
Hart	.04	1.67	46.5	.02	45.2
	(.30)	(1.31)	99.999884	(.75)	99.999915
Richmond	.12	1.89	125.8	.03	116.7
	(2.36)	(3.47)		(2.38)	
Anderson	.20	1.37	173.1	.05	171.8
	(3.43)	(2.27)		(3.62)	
Brown	.23	.63	84.9	.06	85.4
	(3.99)	(1.14)		(4.02)	
Jeffords	.17	1.01	296.4	.04	295.8
	(1.82)	(1.21)		(1.95)	
Tsongas	.15	-.52	110.6	.03	107.5
	(2.67)	(.97)		(2.38)	
Fuqua	.12	-1.15	152.4	.02	145.2
	(2.13)	(2.06)		(1.29)	

Note: LRT denotes likelihood ratio test = 2 (log unconstrained maximum likelihood estimator minus log constrained maximum likelihood estimator). The Senate model has 10 variables in separate model and 9 in combined, whereas the House model has 9 in separate and 8 in combined. Significance levels evaluated using SST. Levels for all House regressions reported by SST = 100 percent.

the correct sign in all votes and insolation in six of the nine. In all but one vote, the significance level of the combined benefits variable lies between the significance levels of the electricity price and insolation variables; in the Brown vote the significance level of benefits is slightly greater than the maximum of the significance levels of the other two variables. The significance levels of the overall regression, as computed by the likelihood ratio test, show little difference. The levels for the separate specification are slightly greater in 2 of the 3 Senate votes, and the significance of the combined specification in the Brown vote would be greater since the LRT value is higher and there are fewer variables.

The benefits variable performs much better than I would have expected, with low expectations resulting from the potential problems with scaling the electricity price and PV price variable (the latter derived from insolation) in order to subtract one from the other to get benefits. Because the numerical comparisons cited in the previous paragraph are not conclusive, the choice between the two specifications is probably best made in terms of the more philosophical considerations discussed in the chapter on benefits.

The results for the model with all variables (except the three insignificant committee variables excluded earlier) using the benefit specification are shown in Table 53.

CONCLUSION

The regression results indicate that the votes of individual members on PV roll calls was influenced by several measurable characteristics of

Table 53
Roll Call Regression Results
(PV benefits, PV expenditures year of vote)
(t statistics in parentheses)

Independent Variable	Vote Calendar Year of Vote								
	SENATE			HOUSE					
	Gravel 1975 AUTH	Glenn 1975 APP	Hart 1976 APP	Rich. 1975 APP	And. 1976 AUTH	Brown 1976 AUTH	Jeffords 1976 AUTH	Tsongas 1977 AUTH	Fuqua 1980 APP
constant	-6.11 (.47)	-1.58 (.11)	-32.0 (2.33)	3.36 (4.84)	2.93 (4.15)	.17 (.28)	3.98 (4.03)	2.89 (4.21)	4.30 (5.09)
party	.20 (.28)	-.89 (1.30)	.23 (.35)	-1.54 (4.08)	-.61 (1.69)	-.86 (2.72)	.36 (.95)	-.93 (2.64)	-1.65 (3.88)
term	.06 (.38)	.04 (.23)	.41 (2.35)	------	------	------	------	------	------
aca score	-4.56 (3.23)	-4.10 (3.50)	-3.89 (3.84)	-4.61 (7.31)	-5.21 (8.13)	-1.25 (2.42)	-5.02 (6.30)	-4.22 (6.80)	-5.80 (6.85)
app dummy	-.53 (.86)	-1.74 (2.60)	-1.08 (1.69)	-1.28 (3.38)	-.38 (1.00)	-.41 (1.12)	-.04 (.08)	-.81 (2.36)	-2.22 (5.67)
PV benefits	.05 (1.80)	.03 (1.06)	.02 (.75)	.03 (2.38)	.06 (3.62)	.06 (4.02)	.04 (1.95)	.03 (2.38)	.02 (1.29)
log of pop. dens.	-.47 (2.14)	-.34 (1.42)	-.46 (2.08)	-.12 (1.89)	-.16 (2.23)	-.09 (1.49)	-.01 (.11)	-.09 (1.34)	.02 (.31)
PV spending	3.41 (1.18)	-1.90 (1.33)	3.71 (2.07)	-.17 (.28)	-.03 (.14)	-.20 (.69)	-.15 (.72)	.33 (1.37)	.19 (.77)
PV manu. dummy	-1.24 (1.63)	2.03 (2.15)	-.55 (.68)	.81 (1.42)	.43 (.75)	.68 (1.41)	-.07 (.08)	.45 (.76)	.56 (.80)
LRT	43.2	34.4	45.2	116.6	171.6	85.4	295.6	107.4	145.2

the member and the area he represented. Of the member characteristics examined, ideology and membership on the appropriations committee affected votes in the predicted manner, whereas predictions were not made for membership on the appropriations subcommittee, authorization committee, and authorization subcommittee, and these had little or no effect. The highly significant ideological results for ideology are consistent with the strongly ideological character of solar energy politics discussed in Chapter 1.

Several characteristics of the state or district relating to the benefits of the federal PV program had important effects on voting. Sunlight, electricity price, and population density--three characteristics which would significantly affect the relative magnitude of PV benefits to the different districts or states of a successful PV program--all had important effects in the direction predicted. When sunlight and electricity price were combined into a benefit measure, this too had a significant effect. Less important, and not always of the right sign, were federal PV expenditures and the presence of PV manufacturers in the area. My guess is that these factors would be less important than ideology or economic benefits of the technology, even if the expenditure and manufacturer data were better.

Because time series analysis of PV voting is not possible, one is forced to rely on these cross-sectional analyses to make inferences about the factors that led to the rise and the fall of the solar energy program. The regression results support the conclusion that a major factor in the rise and fall of the solar energy program were the changes in ideology in the Administration and the Congress. Similarly, the importance of electricity price and sunlight (sunlight provides the cross-sectional variation in PV price that over time is a function of changes in the technological outlook), or the combined benefits variable, in the regressions supports the conclusion in Chapter 1 that changes in the outlook for energy prices and PV prices were also instrumental in the rise and fall of the program. Finally, the weak results for the expenditure and manufacturer data suggest that the lack of a significant "pork barrel" aspect of the program may have contributed to the program's political demise in the 1980s.

DATA APPENDIX

The data used in the econometric analysis are explained below and the source of the data indicated. I entered all data manually.

Votes and Party

Source: The year-end Congressional Quarterly vote tabulations shown below:

Gravel	1975 CQ Almanac, p. 53-S, vote 366.
Glenn	1975 CQ Almanac, p. 84-S, vote 554.
Hart	1976 CQ Almanac, p. 45-S, vote 312.
Richmond	1975 CQ Almanac, pp. 80-81-H, vote 255.
Anderson	1976 CQ Almanac, pp. 62-63-H, vote 204.
Brown	1976 CQ Almanac, pp. 62-63-H, vote 205.
Jeffords	1976 CQ Almanac, pp. 62-63-H, vote 206.
Tsongas	1977 CQ Almanac, pp. 156-157-H, vote 535.
Fuqua	1980 CQ Almanac, pp. 98-99-H, vote 327.

ACA Score

Ratings by interest groups are highly correlated and thus the choice of the rating is unlikely to affect the results. Use of ACA scores in this study was motivated by the fact that ACA calculates scores based on the ratio of favorable votes to votes cast by that member, whereas ADA scores are based on the ratio of favorable votes to total votes, and thus the absence of a vote is counted as equivalent to a conservative vote. Kalt (1981, p. 305) used a special ADA index which avoided this problem.

Source of ACA scores:

Rating year	*Congressional Quarterly* Issue
1975	May 22, 1976, pp. 1291-1307.
1976	February 5, 1977, pp. 220-235.
1977	April 15, 1978, pp. 914-929.
1980	March 21, 1981, pp. 516-522.

Term

Source: *The World Almanac and Book of Facts*, 1976, pp. 343-345.

Committee and Subcommittee Membership

The appropriations subcommittee in both the Senate and House was the Subcommittee on Public Works. In the House, the authorizing committee was the Committee on Science and Technology, and the subcommittee in 1975-1976 was the Subcommittee on Energy Research, Development and Demonstration, in 1977 was the Subcommittee on Advanced Energy Technologies and Energy Conservation Research, Development, and Demonstration, and in 1980 was the Subcommittee on Energy Development and Applications. In the Senate, the authorizing committee in 1975-1976 was Interior and Insular Affairs, and the subcommittee was the Subcommittee on Energy Research and Water Resources.

Membership on committees was determined by the lists printed at the beginning of authorization and appropriation hearing documents. Since the hearings do not show membership for the full Senate Appropriations Committee, this is taken from the *1975 CQ Almanac*, p. 52.

State Electricity Expenditures (1973-1981)

State electricity expenditures in current dollars in year of vote from U.S. Department of Energy (1984c). State population estimates are as of July 1 of year of vote, including Armed Forces stationed in area, from Statistical Abstract of the United States. State per capita personal income in year of vote in current dollars from Bureau of Economic Analysis, U.S. Department of Commerce, Survey of Current Business, April 1977, August 1978, and April 1982.

State Average Electricity and Residential Average Electricity and Natural Gas Price (1973-1981)

State overall average electricity and average residential electricity and natural gas prices from U.S. Department of Energy (1984c).

1985 Regional Electricity Price

1985 marginal and average prices are the 1985 midrange scenario, Series C with natural gas regulation from U.S. Department of Energy (1978d), Vol. II Appendix.

Insolation

Insolation for district (House votes) and state (Senate votes) are derived from insolation estimates for 235 locations, with 168 values for each location, corresponding to 14 different tilt angles from 0 to 90 degrees for each of 12 months. These are contained in Jeffrey H. Smith (1980). To pick a single number for each of these 235 locations, I ignored the possibility of changing the array tilt each month or of interpolating between the array tilt angles given. I simply chose the array tilt angle which maximized annual insolation, and used the annual insolation figure resulting from year round use of this angle. This procedure also ignores the relatively small gains and losses from array shadowing and reflector augmentation. To obtain congressional district and state estimates, the following procedure was used employing the figures chosen above. If the district had (1) exactly 1 of the 235 locations in the district, this figure was used; (2) more than 1 of the 235, the figures were averaged; and (3) none, an estimate based on values for nearby locations was used. State figures represent the average of the district values obtained above.

PV Expenditures

Information on annual expenditures in each contract was obtained from the following annual photovoltaic program summaries: U.S. Energy Research and Development Administration (1976), U.S. Department of Energy (1978b, 1978e, 1980a, 1981, 1982, 1983b, 1984a). The program summaries contain a one page description for each current photovoltaics contract or grant. I began with the last of the program summaries listed immediately above and then went back through each earlier volume adding those contracts which did not appear in later volumes. On contracts appearing in more than one volume, expenditure information appearing in the most recent volume was used in case of conflicting information between volumes.

This process was complicated by the number of contracts (approximately two hundred in each volume) and the difficulty in identifying the same contract across the years because of changes in contract identification numbers and descriptions. In addition, identifying year to year spending was sometimes arbitrary because sometimes only cumulative funding totals were available for a contract.

The ensuing assignment of spending by year to districts and states proceeded as follows. The contract description provides a city name for each contractor. The corresponding congressional district was then identified as follows:

(1) I looked for the city in the list of 9900 cities and their districts in the 1977 Congressional Staff Directory by Charles B. Bronson.

(2) If multiple districts were listed for a city, then Congressional Quarterly (1974) was used. This lists major companies and universities in each district, and I often could find the contractor involved and thus resolve the district.

(3) If the city was not listed in Bronson, I used the North American Road Atlas, 1981, to locate the city and then used the district maps in Congressional Quarterly (1974) to determine the district.

(4) In case of multiple districts which could not be resolved, I divided the money equally among the districts.

(5) In cases of projects built in one location by a contractor located in another, I divided the money equally between the two locations. This procedure is important because it determines the treatment of demonstration projects where the prime contractor is not located at the site.

The resulting data for each district and state for each year were then multiplied by the ratio of appropriation in that year divided by the sum of the contract/grant spending in that year, as determined by the above process. This procedure was used because the sum of contract/grant spending was often only 50-75% of the appropriation for that year, thus indicating that the process was somehow missing some funding.

Per capita spending is used in the Senate model. For simplicity, I used 1980 state population figures to compute per capita expenditures, rather than using state population estimates for each year in the FY76-83 period.

PV Manufacturers

U.S. Department of Energy (1980b), pp. 31-34 contain lists of commercial flat photovoltaic module manufacturers, concentrator solar cell manufacturers, photovoltaic concentrator module manufacturers, and photovoltaic power system suppliers compiled by the Solar Energy Industries Association in September 1980. I did not find comparable lists for earlier years.

REFERENCES

Abrams, Burton A. (1977) "Legislative Profits and the Economic Theory of Representative Voting: An Empirical Investigation," Public Choice, Volume 31, Fall 1977, pp. 111-119.

Aerospace Corporation (1975) Mission Analysis of Photovoltaic Solar Energy Systems, Final Report, Volume I, Summary, Prepared with the Support of the National Science Foundation, Research Applied to National Needs, Aerospace Report No. ATR-76(7476-01)-1, Vol. I, December 1, 1975.

Aerospace Corporation (1977) Mission Analysis of Photovoltaic Solar Energy Conversion Volume I, Executive Summary, Prepared for Division of Solar Energy, U.S. Energy Research and Development Administration, Aerospace Report No. ATR-77(7574-07)-01, Vol. I; ERDA Report No. SAN/1101-77/1, March 1977.

Aerospace Corporation (1978) Analysis of Photovoltaic Total Energy Systems for Single Family Residential Applications, ATR-78(7694-02-1), August 1978.

Amemiya, Takeshi (1981) "Qualitative Response Models: A Survey," Journal of Economic Literature, Vol. 19, December 1981, pp. 1483-1536.

American Institute of Aeronautics and Astronautics (1975), Solar Energy for Earth; An AIAA Assessment, April 21, 1975. Reprinted in National Solar Energy Research, Development, and Demonstration Program--Definition Report Solar Energy Research, Development and Demonstration Act of 1974 Oversight Hearings before the Subcommittee on Energy Research, Development and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, July 16, 1975, pp. 396-514.

American Physical Society (1979) Principal Conclusions of the American Physical Society Study Group on Solar Photovoltaic Energy Conversion, January 1979.

Arnold, R. Douglas (1979) Congress and the Bureaucracy: A Theory of Influence, Yale University Press.

Arnold, R. Douglas (1981a) "Legislators, Bureaucrats, and Locational Decisions," Public Choice, Vol. 37, pp. 107-132. Reprinted in Congress: Structure and Policy, edited by Mathew D. McCubbins and Terry Sullivan, Cambridge University Press, 1987, pp. 523-548.

Arnold, R. Douglas (1981b) "The Local Roots of Domestic Policy," in The New Congress, edited by Thomas E. Mann and Norman J. Ornstein, American Enterprise Institute for Public Policy Research, pp. 250-287.

Aster, Robert W. (1978) Economic Analysis of a Candidate 50 Cent/Wpk Flat-Plate Photovoltaic Manufacturing Technology, Jet Propulsion Laboratory Low-Cost Solar Array Project Report 5101-94, December 1, 1978.

Aster, R. (1983) "The SERI Memo to Annan Re: JPL Concerns about PV Goals," Jet Propulsion Laboratory Interoffice Memorandum 311.3-1033, December 22, 1983.

Barone, Michael and Ujifusa, Grant (1981) The Almanac of American Politics 1982, Barone & Company.

Barone, Michael; Ujifusa, Grant; and Matthews, Douglas (1979) The Almanac of American Politics 1980, E.P. Dutton.

Bernstein, Robert A. (1985) "Comment on Carson and Oppenheimer," The American Political Science Review, Vol. 79, pp. 824-825.

Bernstein, Robert A. and Anthony, William W. (1974) "The ABM Issue in the Senate, 1968-1970: The Importance of Ideology," American Political Science Review, Vol. 68, September 1974, pp. 1198-1206.

Bernstein, Robert A. and Horn, Stephen R. (1981) "Explaining House Voting on Energy Policy: Ideology and the Conditional Effects of Party and District Economic Interests," Western Political Quarterly, Vol. 34, No. 2, June 1981, pp. 235-245.

Bezdek, Roger H.; Hirshberg, Alan S.; Babcock, William H. (1979) "Economic Feasibility of Solar Water and Space Heating," Science, Vol. 203, March 20, 1979, pp. 1214-1220.

Bleiden, H.R. (1973) "A National Plan for Photovoltaic Conversion of Solar Energy," in Photovoltaic Conversion of Solar Energy for Terrestrial Applications, Workshop Proceedings, Vol. I. Working Group and Panel Reports, October 23-25, 1973, Cherry Hill, New Jersey, Organized by the Jet Propulsion Laboratory, Sponsored by the National Science Foundation, RANN-Research Applied to National Needs, NSF-RA-N- 74-013, pp. 81-103.

Borden, C.S. (1982) "Memo to Jeff L. Smith Subject: Fixed Charge Rates for Flat-Plate and Concentrator PV System Cost Analysis," JPL Interoffice Memorandum 311.3-188/6352B, March 19, 1982.

Borden, C.S. (1983) The Value of Residential Photovoltaic Systems: A Comprehensive Assessment, Prepared for the U.S. Department of Energy by the Jet Propulsion Laboratory, Photovoltaics Program Technology Development and Applications Center Report 5220-19, JPL Publication 83-63, DOE/ET-20356-8, September 15, 1983.

Borden, Chet (1984a) Memorandum to R. Annan/R. Powell/E. Burgess/J. Stone/W. Callaghan, PAIC:CSB:720-84-1697, "Subject: Recommended parameter values for Five Year Research Plan," February 13, 1984.

Borden, Chet (1984b), Letter to Robert (Bud) Annan, "Reference: PAIC:CSB:720-84-1697-IOM-Subject: Recommended parameters values for Five-year Research Plan," Jet Propulsion Laboratory, PAIC:CSB:720-84-1695, February 14, 1984.

Brownson, Charles (1977)(ed.), Congressional Staff Directory 1977, Congressional Staff Directory.

Buck, Alice L. (1982) A History of the Energy Research and Development Administration, U.S. Department of Energy, DOE/ES-0001, March 1982.

Bush, Leon R. (1983) Photovoltaic Energy Systems Summary Report, Aerospace Corporation Report ATR-83 (3828-02)-INA, Prepared for U.S. Department of Energy, Division of Photovoltaic Energy Technology, June 1983.

Callaghan, W.T.; Henry, P.K.; McGuire, P.A. (1985) "Cherry Hill Revisited: Economic Payoff for Technical Achievements in Flat-Plate Photovoltaics 1975-1985," Proceedings of the 18th IEEE Photovoltaics Specialists Conference.

Carpenter, P. and Taylor, G. (1978) An Economic Analysis of Residential Grid-Connected Solar Photovoltaic Power Systems, MIT Energy Laboratory Report MIT-EL-78-CO7TR, May 1978, Revised December 1978.

Carson, Richard T. and Oppenheimer, Joe A. (1984) "A Method of Estimating the Personal Ideology of Political Representatives," American Political Science Review, Vol. 78, pp. 163-178.

Carson, Richard T. and Oppenheimer, Joe A. (1985) "A Reply to Our Critics," The American Political Science Review, Vol. 79, pp. 827-830.

Chappell, Henry W., Jr. (1981a) "Campaign Contributions and Voting on the Cargo Preference Bill: A Comparison of Simultaneous Models," Public Choice, Vol. 36, pp. 301-312.

Chappell, Henry W., Jr. (1981b) "Conflict of Interest and Congressional Voting: A Note," Public Choice, Vol. 37, pp. 331-336.

Chappell, Henry W., Jr. (1982) "Campaign Contributions and Congressional Voting: A Simultaneous Probit-Tobit Model," The Review of Economics and Statistics, Vol. 64, No. 1, February 1982, pp. 77-83.

Cohen, Linda R. "The Applications Technology Satellite Program," Chapter 6 in The Technology Pork Barrel, Brookings Institution, forthcoming.

Cohen, Linda R. and Noll, Roger G. (1984) "The Electoral Connection to Intertemporal Policy Evaluation by a Legislator," Center for Economic Policy Research, Stanford University, No. 36, September.

Committee on Science and Astronautics (1974), U.S. House of Representatives, Solar Photovoltaic Energy Hearings before the Subcommittee on Energy, June 6 and 11, 1974.

Committee on Science and Technology (1976), U.S. House of Representatives, ERDA Authorization Fiscal Year 1977 Part II-Solar Energy, Hearings before the Subcommittee on Energy Research, Development, and Demonstration, February 5, 6, 1976.

Committee on Science and Technology (1977), U.S. House of Representatives 1978 ERDA Authorization (Solar-Geothermal), Hearings before the

Subcommittee on Advanced Energy Technologies and Energy Conservation Research, Development and Demonstration, Volume I, February 24, 25, March 1, 3, 1977.

Committee on Science and Technology (1979), U.S. House of Representatives, 1980 Department of Energy Authorization, Hearings before the Subcommittee on Energy Development and Applications, Volume V, February 21, 22, 26, 27, 28, March 1, 2.

Committee on Ways and Means (1985), U.S. House of Representatives, Tax Reform Act of 1985, H. Rept. 99-426, December 7, 1985.

Commoner, Barry (1979) The Politics of Energy, Alfred A. Knopf, New York.

Congressional Research Service (1983) Handbook of Alternative Technology Development and Policy, Report No. 83-43 SPR, March 1.

Congressional Quarterly (1974), Congressional Districts in the 1970s, 2nd edition.

Coughlin, Cletus C. (1985) "Domestic Content Legislation: House Voting and the Economic Theory of Regulation", Economic Inquiry, Vol. 23, July, pp. 437-448.

Crandall, Robert W. (1983) Controlling Industrial Pollution: The Economics and Politics of Clear Air, Brookings Institution.

Crosetti, M.R.; Jackson, B.L.; Aster, R.W. (1985) A Sensitivity Analysis of Central Station Flat-Plate Photovoltaic Systems and Implications for National Photovoltaic Program Planning, Prepared for the U.S. Department of Energy by the Jet Propulsion Laboratory, Flat Plate Solar Array Project 5101-265, JPL Publication 85-92, DOE/JPL-1012-114, August 30, 1985.

Danielsen, Albert L. and Rubin, Paul H. (1977) "An Empirical Investigation of Voting on Energy Issues," Public Choice, Vol. 31, Fall 1977, pp. 121-128.

Davis, Otto A. and Jackson, John E. (1974) "Representative Assemblies and Demands for Redistribution: The Case of Senate Voting on the Family Assistance Plan," in Redistribution through Public Choice, Harold M. Hochman and George E. Peterson (ed.), Columbia University Press, pp. 261-288.

Doane, J.W.; O'Toole, R.P.; Chamberlain, R.G.; Bos, P.B.; Maycock, P.D. (1976) The Cost of Energy from Utility-Owned Solar Electric Systems: A Required Revenue Methodology for ERDA/EPRI Evaluations, Jet Propulsion Laboratory, JPL-5040-29, ERDA/JPL-1012-73/3, June 1976.

Doane, J.W. and Gresham, J.B. (1983) Photovoltaics Requirements Estimation-A Simplified Method, AP-2475, Research Project 1975-3, Prepared by Science Applications, Inc. for the Electric Power Research Institute, February 1983.

Dunlap, Riley E. and Allen, Michael Patrick (1976) "Partisan Differences on Environmental Issues: A Congressional Roll-Call Analysis," Western Political Quarterly, Vol. 29, No. 3, September 1976, pp. 384-397.

Eldrige, F.R. (1973) "MITRE Photovoltaic Energy System Study," in Photovoltaic Conversion of Solar Energy for Terrestrial Applications, Workshop Proceedings, Vol. II, Invited Papers, October 23-25, 1973, Cherry Hill, New Jersey, Organized by the Jet Propulsion Laboratory, Sponsored by the National Science Foundation, RANN-Research Applied to National Needs, NSF-RA-N-74-013, pp. 113-117.

Electric Power Research Institute (1978), Requirements and Assessment of Photovoltaic Power Plants in Electric Utility Systems, prepared by the General Electric Co.'s Electric Utility Systems Engineering Department for EPRI (ER-685), June 1978.

Electric Power Research Institute (1982) TAG^{TM} Technical Assessment Guide, Technology Evaluation Group of EPRI Planning and Evaluation Division, P-2410-SR, Special Report, May 1982.

Electric Power Research Institute (1983) Photovoltaic Power Systems Research Evaluation, A Report of the EPRI Ad Hoc Photovoltaic Advisory Committee, AP-3351, Project 1348-15, Final Report, Prepared by Strategies Unlimited, December 1983.

Feldstein, Paul J. and Melnick, Glenn (1984) "Congressional Voting Behavior on Hospital Legislation: An Exploratory Study," Journal of Health Politics, Policy, and Law, Vol. 8, No. 4, Winter 1984, pp. 686-701.

Fenno, Richard F., Jr. (1966) The Power of the Purse.

Fenno, Richard F., Jr. (1973) Congressmen in Committees; Little, Brown and Company.

Fiorina, Morris P. (1979) "Comments," in Collective Decision Making: Applications from Public Choice Theory, Clifford S. Russell (ed.), Resources for the Future, pp. 46-51.

Flaim, Theresa (1985) "Avoided costs for solar facilities," Energy Policy, Vol. 13, No. 3, June, pp. 267-282.

Fowler, Linda L. and Shaiko, Ronald G. (1987) "The Grass Roots Connection: Environmental Activists and Senate Roll Calls," American Journal of Political Science, Vol. 31, No. 3, August, pp. 484-510.

Friedmann, Peter A. and Mayer, David G. (1980) "Energy Tax Credits in the Energy Tax Act of 1978 and the Crude Oil Windfall Profits Tax Act of 1980," Harvard Journal on Legislation, Vol. 17, No. 3, pp. 465-504.

Gates, William R. (1988) "Federally Supported Commercial Technology Development: Solar Thermal Technologies 1970-1982," Research Policy, Vol. 17, No. 1, February, pp. 27-42.

General Electric Co. (1979) *Regional Conceptual Design and Analysis Studies for Residential Photovoltaic Systems*, for Sandia Laboratories, SAND 78-7039, January.

Godolphin, David (1983) "Current Status of the State Tax Credits," *Solar Age*, May, pp. 46-47.

Goldsmith, John V. (1974) Testimony in *Solar Photovoltaic Energy*, Hearings before the Subcommittee on Energy of the Committee on Science and Astronautics, U.S. House of Representatives, June 6, 11, 1974.

Hamilton, T.W. (1981) *Potential Benefits of Photovoltaic System Development--Methodology and Results*, Jet Propulsion Laboratory, 5210-16, November.

Hammond, Allen L. and Metz, William D. (1977) "Solar Energy Research: Making Solar after the Nuclear Model?", *Science*, Vol. 197, July 15, 1977, pp. 241-244.

Henry, Paul K. (1980) "Technical Readiness $2.80 Wp," *Progress Report 16 for the Period April to September 1980 and Proceedings of the 16th Project Integration Meeting*, Low-Solar Array Project Report 5101-160, DOE/JPL-1012-51, JPL Publication 80-100, pp. 447-458.

Henry, Paul K. (1982) "Economic Projections and FSA Research Priorities," *Progress Report 21 for the Period April 1982 to January 1983 and Proceedings of the 21st Project Integration Meeting*, Flat-Plate Solar Array Project Report 5101-222, DOE/JPL-1012-88, JPL Publication 83-48, pp. 505-508.

Herwig, Lloyd O. (1974) "Solar Research and Technology," Presentation to the American Physical Society, February 7, 1974. Reprinted in *Energy Research and Development and Small Business*, Hearings before the Select Committee on Small Business, U.S. Senate, May 13,14 1975, Part 1A, pp. 1228-1253.

Jackson, John E. (1971) "Statistical Models of Senate Roll Call Voting," *The American Political Science Review*, Vol. 65, No. 2, June, pp. 451-470.

Jet Propulsion Laboratory (1974a) *Proposed Program Development Plan for the National Science Foundation Low Cost Silicon Solar Array Program*, 1200-172, June 20, 1974.

Jet Propulsion Laboratory (1974b) *Executive Report of Workshop Conference on Photovoltaic Conversion of Solar Energy for Terrestrial Applications Held at Cherry Hill, New Jersey October 23-25, 1973*, Sponsored by National Science Foundation RANN-Research Applied to National Needs, JPL Special Publication 43-12, October 15, 1974.

Jet Propulsion Laboratory (1975) *Proceedings of the First ERDA Semiannual Solar Photovoltaic Conversion Program Conference*, University of California, Los Angeles, CA; July 22-25, 1975; JPL Document 5040-13.

Jet Propulsion Laboratory (1980) A Review of the American Physical Society Report on Solar Photovoltaic Energy Conversion, Photovoltaics Program Technology Development and Applications Lead Center Report 5230-2, February 1, 1980.

Joint Committee on Taxation (1980), "Summary of H.R. 3919 The Crude Oil Windfall Profits Tax of 1980 (As Agreed to by the Conferees)," JCS-7-80, U.S. Congress, February 28, 1980.

Jones, Gary J. (1985), Letter to A. D. Krantz, January 28, 1985.

Kalt, Joseph P. (1981) The Economics of Oil Price Regulation, MIT Press, Cambridge.

Kalt, Joseph P. (1982) "Oil and Ideology in the United States Senate," The Energy Journal, Vol. 3, No. 2, April 1982, pp. 141-166.

Kalt, Joseph P. and Zupan, Mark A. (1984) "Capture and Ideology in the Economic Theory of Politics," American Economic Review, Vol. 74, No. 3, June 1984, pp. 279-300.

Kau, James B. and Rubin, Paul H. (1978) "Voting on Minimum Wages: A Time-Series Analysis," Journal of Political Economy, Vol. 86, No. 2, Pt. 1, April 1978, pp. 337-342.

Kau, James B. and Rubin, Paul H. (1979a) "Public Interest Lobbies: Membership and Influence," Public Choice, Vol. 34, No. 1, pp. 45-54.

Kau, James B. and Rubin, Paul H. (1979b) "Self-Interest, Ideology, and Logrolling in Congressional Voting," Journal of Law and Economics, Vol. 22, October 1979, pp. 365-384.

Kau, James B. and Rubin, Paul H. (1984) "Economic and Ideological Factors in Congressional Voting: The 1980 Election," Public Choice, Volume 44, pp. 385-388.

Kau, James B.; Keenan, Donald; and Rubin, Paul H. (1982) "A General Equilibrium Model of Congressional Voting," Quarterly Journal of Economics, Vol. 97, No. 2, May 1982, pp. 271-293.

Kelly, Henry (1978) "Photovoltaic Power Systems: A Tour Through the Alternatives," Science, Vol. 199, February 10, 1978, pp. 634-643.

Kenski, Henry C. and Kenski, Margaret C. (1980) "Partisanship, Ideology, and Constituency Differences on Environmental Issues in the U.S. House of Representatives: 1973-78," Policy Studies Journal, Vol. 9, No. 3, Winter 1980, pp. 325-335.

Kidder, Tracy (1980) "The Future of the Photovoltaic Cell," Atlantic Monthly, June 1980, pp. 68-76.

Krehbiel, Keith and Rivers, Douglas (1988a) "Sophisticated Voting in Congress: A Reconsideration," manuscript, September 16, 1988.

Krehbiel, Keith and Rivers, Douglas (1988b) "The Analysis of Committee Power: An Application to Senate Voting on the Minimum Wage," American Journal of Political Science, Vol. 32, pp. 1150-1174.

Landsberg, Hans H. (1979) Energy: The Next Twenty Years, Report by a Study Group Sponsored by the Ford Foundation and Administered by Resources for the Future, Hans H. Landsberg, Chairman, Ballinger.

Lazzari, Salvatore and Gravelle, Jane (1984) Effective Tax Rates on Solar/Wind and Synthetic Fuels as Compared to Conventional Energy Resources, Congressional Research Service, Rept. No. 84-85 E, May 16.

Leonard, S.L.; Rattin, E.J.; Siegel, B. (1977) Mission Analysis of Photovoltaic Solar Energy Conversion, Volume I, Executive Summary, Aerospace Corporation Report No. ATR-77(7574-07)-1, Vol. I, Prepared for the U.S. Energy Research and Development Administration, Division of Solar Energy, ERDA Report No. SAN/1101-77/1, March 1977.

Leonard, S.L.; Rattin, E.J.; Siegel, B. (1978) Photovoltaic Mission Analysis, Final Summary Report, Aerospace Corporation Report No. ATR- 78 (7694-07)-1, Prepared for the U.S. Department of Energy, Division of Distributed Solar Technology, August 1978.

Leonard, S.L. and Siegel, B. (1980) Central Station Applications Activities and Supporting Studies, Aerospace Corporation Report No. ATR-80(7820-04)-2, Prepared for the Jet Propulsion Laboratory, January 1980.

Lopreato, Sally C. and Smoller, Fred (1978) "Explaining Energy Votes in the Ninety-Fourth Congress," Center for Energy Studies, University of Texas at Austin, June 1978.

Lovins, Amory B. (1976) "Energy Strategy: The Road Not Taken," Foreign Affairs, Vol. 55, No. 1, October, pp. 65-96.

Lovins, Amory B. (1977) Soft Energy Paths: Toward A Durable Peace, Ballinger.

Maidique, Modesto A. (1979) "Solar America," in Energy Future, Report of the Energy Project at the Harvard Business School, edited by Robert Stobaugh and Daniel Yergin, Random House, pp. 183-215.

Markus, Gregory B. (1974) "Electoral Coalitions and Senate Roll Call Behavior: An Ecological Analysis," American Journal of Political Science, Vol. 43, August 1974, pp. 595-607.

Maycock, Paul D. and Stirewalt, Edward N. (1985) A Guide to the Photovoltaic Revolution, Rodale Press, Emmaus, Pa.

Maycock, Paul D. (1986) "The Jet Propulsion Laboratory Low Cost Solar Array Project 1974-1986," Presentation at FSA Project Integration Meeting, Pasadena, CA, April 29, 1986.

McConnell, Robert D. (1984) Letter to Chet Borden, February 27, 1984.

McCracken, Samuel (1979) "Solar Energy: A False Hope," Commentary, Vol. 68, Number 5, November 1979, pp. 61-67.

Metz, William D. (1978) "Energy Storage and Solar Power: An Exaggerated Problem," Science, Vol. 200, June 30, 1978, pp. 1471-1473.

Mitchell, Edward J. (1977) Energy and Ideology, American Enterprise Institute.

Mitchell, Edward J. (1979) "The Basis for Congressional Energy Policy," Texas Law Review, March 1979, pp. 591-613.

MITRE Corporation (1973) Systems Analysis of Solar Energy Programs, MTR-6513, Contract NSF-C831, December 1973.

MITRE (1974) "Recommendations to RANN/NSF Solar Energy R&T Program," the MITRE Corporation, M74-21, February 1974, reprinted in Solar Energy Research and Development, Hearings before the Joint Committee on Atomic Energy, U.S. Congress, May 7 and 8, 1974, pp. 419-501.

Moore, J. Glen (1985) Renewable Energy Tax Credit Extension Efforts in the 98th Congress, Congressional Research Service, Library of Congress, Report No. 85-4 SPR, January 1.

Morgan, David R. (1985) "Comment on Carson and Oppenheimer," The American Political Science Review, Vol. 79, pp. 825-826.

National Science Foundation (1973) Workshop Proceedings, Photovoltaic Conversion of Solar Energy for Terrestrial Applications, Volumes I and II. October 23-25, 1973. NSF-RA-N-74-013.

National Science Foundation (1974a) Assessment of the Technology Required to Develop Photovoltaic Power Systems for Large-Scale National Energy Applications, October 15, 1974, Jet Propulsion Laboratory, NSF-RA-N-74-072.

NSF/NASA (1972) "An Assessment of Solar Energy as a National Energy Resources," Prepared by the NSF/NASA Solar Energy Panel, December 1972. Reprinted in Solar Energy Research and Development, Hearings before the Joint Committee on Atomic Energy, May 7, 8, 1974, pp. 676-759 and in Energy Research and Development and Small Business, Hearings before the Select Committee on Small Business, U.S. Senate, May 13, 14, 1975, part 1C, pp. 2960-3043.

National Solar Energy Program (1974), Reprinted in ERDA Authorization-Part IV 1976 and Transition Period, Solar and Physical Research, Hearings before the Subcommittee on Energy Research, Development and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, February 21, 1975, pp. 183-413.

Navarro, Peter (1984) The Policy Game: How Special Interests and Ideologues are Stealing America, Wiley.

Nelson, Richard R. (1982), (ed.) Government and Technical Change: A Cross-Industry Analysis, Pergamon.

Nivola, Pietro S. The Politics of Energy Conservation, Brookings Institution, 1986.

Office of Science and Technology (1972), "Data for Use in the Assessment of Energy Technologies," AET-8, April 1972. A report submitted to the Office of Science and Technology.

Office of Technology Assessment, U.S. Congress (1975) An Analysis of the ERDA Plan and Program, October 1975.

Office of Technology Assessment, U.S. Congress (1978) Application of Solar Technology to Today's Energy Needs, Volume 1, June 1978; Volume 2, September 1978.

Office of Technology Assessment, U.S. Congress (1982) Solar Power Satellites, August 1981.

Office of Technology Assessment, U.S. Congress (1985) New Electric Power Technologies: Problems and Prospects for the 1990s, OTA-E-246, July 1985.

Orren, Lowell H. and Chamberlain, Robert G. (1981) A Decision Rule for the Installation of a Solar Electric System, Economic Research Series, Jet Propulsion Laboratory, No. 9, July.

Ouchi, William G. (1984) The M-Form Society: How American Teamwork Can Recapture the Competitive Edge, Addison-Wesley.

Pashigian, B. Peter (1985) "Envvironmental Regulation: Whose Self-Interests Are Being Protected?", Economic Inquiry, Vol. 23, October, pp. 551-584.

Peltzman, Sam (1984) "Constituent Interest and Congressional Voting," Journal of Law and Economics, Vol. 27, No. 1, April 1984, pp. 181-210.

Peltzman, Sam (1985) "An Economic Interpretation of the History of Congressional Voting in the Twentieth Century," American Economic Review, Vol. 75, No. 4, September 1985, pp. 656-675.

Poole, Keith T. (1988) "Recent Developments in Analytical Models of Voting in the U.S. Congress," Legislative Studies Quarterly, Vol. 13, No. 1, February, pp. 117-133.

Redfield, David (1981) "Photovoltaics," Solar Law Reporter, Vol. 3, No. 2, July/August, pp. 217-244.

Riddlesperger, James W., Jr. and King, James D. (1982) "Energy Votes in the U.S. Senate," The Journal of Politics, Vol. 44, No. 3, August 1982, pp. 838-847.

Roessner, J. David (1982) "Government-Industry Relationships in Technology Commercialization: The Case of Photovoltaics," Solar Cells, Vol. 5, pp. 101-134.

Sanders, Arthur (1985) "Comment on Carson and Oppenheimer," The American Political Science Review, Vol. 79, pp. 826-827.

Schmalensee, Richard (1980) "Appropriate Government Policy Toward Commercialization of New Energy Supply Technologies," Energy Journal, Volume 1, No. 2, April 1980, pp. 1-40.

Schroedel, Jean Reith (1986) "Campaign Contributions and Legislative Outcomes," Western Political Quarterly, Vol. 39, pp. 371-389.

Select Committee on Small Business (1975), U.S. Senate, Hearings on Energy Research and Development and Small Business, May 13, 14, 1975 (part 1); October 8, 22, November 18, 1975 (part 2).

Shepsle, Kenneth A. (1978) The Giant Jigsaw Puzzle: Democratic Committee Assignments in the Modern House, The University of Chicago Press.

Silberman, Jonathan I. and Durden, Garey C. (1976) "Determining Legislative Preferences on the Minimum Wage: An Economic Approach," Journal of Political Economy, Vol. 84, No. 2, April 1976, pp. 317-329.

Sissine, Fred J. (1988) Renewable Energy: Federal Program and Congressional Interest, Congressional Research Service Issue Brief IB87140, updated October 28, 1988.

Slonski, M.L. (1979) Energy Systems Economic Analysis (ESEA) Methodology and User's Guide, Jet Propulsion Laboratory Low-Cost Solar Array Project Report 5101-102, February 15, 1979.

Slonski, Marie and Easter, Bob (1979) "Cost Effectiveness Aspects of FPUP Strategy," Jet Propulsion Laboratory memorandum, September 12, 1979.

Jeffrey H. Smith (1980) Handbook of Solar Energy Data for South-Facing Surfaces in the United States, Volume 1, DOE/JPL-1012-25, Volume 1. JPL Publication 79-103, Volume 1, January 15, 1980.

Smith, Jeffrey L. (1980a) Federal Policies to Promote the Widespread Utilization of Photovoltaic Systems, Supplement: Review and Critique, Jet Propulsion Laboratory Publication 80-32, Photovoltaics Program, Technology Development and Applications Lead Center Publication 5260-10, Prepared for U.S. Department of Energy, DOE/JPL-1012-45, April 15, 1980.

Smith, Jeffrey L. (1980b) Photovoltaics as a Terrestrial Energy Source: Volume 1, An Introduction, Volume II, System Value, Volume III, An Overview, Jet Propulsion Laboratory, Photovoltaics Program, Technology Development and Applications Lead Center Publication 5220-15, Prepared for U.S. Department of Energy, DOE/ET-20356-6, October 1980.

Smith, Jeffrey L. (1981) "Photovoltaics," Science, Vol. 212, June 26, 1981, pp. 1472-1478.

Solar Energy Research Institute (1978) Photovoltaic Venture Analysis, July 1978.

Solar Energy Research Institute (1982) Basic Photovoltaic Principles and Methods, SERI/SP-290-1448, February 1982.

Solar Energy Research Institute (1984) Basic Photovoltaic Principles and Methods, Van Nostrand Reinhold Company.

Stone, Jack (1985), Letter to Andrew Krantz, "Subject: Review of the 15 cent/kWh Planning Target and Other Parameters in the Photovoltaics Program Five Year Research Plan," January 4, 1985.

Subpanel IX (1973) Report of Subpanel IX to the Atomic Energy Commission Chairman in support of her development of a comprehensive Federal energy research and development program, reprinted in Solar Energy Research and Development, Hearings before the Joint Committee on Atomic Energy, May 7, 8, 1974, pp. 337-418.

Tabors, Richard D. (1982) Economic and Market Analysis of the Photovoltaic Technology, MIT Energy Laboratory, draft, August.

Taylor, Roger W. (1982) "Utility Requirements for Photovoltaic Power," Presented at 161st Meeting of the Electrochemical Society, Montreal, Canada, May 10, 1982.

Taylor, Roger W. (1983a) "Photovoltaic System Requirements: Central and Distributed Applications," EPRI Conference Proceedings: Solar and Wind Power-1982 Status and Outlook, EPRI AP-2884, Electric Power Research Institute, Palo Alto, CA, February 1983.

Taylor, Roger W. (1983b) Photovoltaic Systems Assessment: An Integrated Perspective, AP-3176-SR, September 1983.

Teem, John M. (1975) Testimony in Energy Research and Development in Small Business Hearings before the Select Committee on Small Business, U.S. Senate, May 14, 1975, Part 1, pp. 165-287.

Terasawa, Katsuaki L. (1984) "Cost of Production Rate Uncertainty," Arroyo Center, Jet Propulsion Laboratory, AC-RR-84-002, May 1984.

U.S. Department of Commerce (1973) Congressional Dsitrcit Data Book 93rd Congress (A Statistical Abstract Supplement).

U.S. Department of Commerce (1974a) Congressional District Data 94th Congress:Texas, CDD-94-1, April.

U.S. Department of Commerce (1974b) Congressional District Data 94th Congress:California, CDD-94-2, May.

U.S. Department of Commerce (1974c) Congressional District Data 94th Congress:New York, CDD-94-3, September.

U.S. Department of Commerce (1978) Statistical Abstract of the United States 1978, Bureau of the Census.

U.S. Department of Commerce (1986) Statistical Abstract of the United States 1987, Bureau of the Census.

U.S. Department of Energy (1978a) National Photovoltaic Program Plan, February 3, 1978, Assistant Secretary for Energy Technology, Division of Solar Technology, DOE/ET-0035(78), March 1978.

U.S. Department of Energy (1978b) Photovoltaic Systems Program Summary, Assistant Secretary for Energy Technology, Office of Solar, Geothermal, Electric and Storage Systems, DOE/ER-0075, December 1978.

U.S. Department of Energy (1978c) Domestic Policy Review of Solar Energy, Final Report, Research, Development, and Demonstration Panel, TID-28837, UC-13, October 1978.

U.S. Department of Energy (1978d) Annual Report to Congress, Volume II, Appendix, DOE/EIA-0036/2 App., September.

U.S. Department of Energy (1978e) FY 1977 Photovoltaic Program Summary, DOE/ET 0019/1, January.

U.S. Department of Energy (1979a) National Photovoltaics Program Multi-Year Program Plan, draft, June 6, 1979.

U.S. Department of Energy (1979b) National Energy Plan II, May.

U.S. Department of Energy (1979c) Solar Collector Manufacturing Activity, July through December 1979, Energy Information Administration, DOE/EIA-0174(79/2), March 1979 (sic).

U.S. Department of Energy (1980a) Photovoltaic Energy Systems Program Summary, Assistant Secretary for Conservation and Solar Energy, DOE/CS-0146, January 1980.

U.S. Department of Energy (1980b) National Photovoltaics Program: Electrical Power from Solar Cells, Prepared by the Jet Propulsion Laboratory, September 1980.

U.S. Department of Energy (1980c) National Photovoltaics Program Multi-Year Program Plan (draft), September 30, 1980.

U.S. Department of Energy (1980d) National Photovoltaics Program Systems Development Plan (draft), December 1980.

U.S. Department of Energy (1980e) Federal Policies to Promote the Widespread Utilization of Photovoltaic Systems, Assistant Secretary for

Conservation and Solar Energy. Volume I: Executive Summary, Findings; DOE/CS-0114/1, February 20, 1980; Volume II:Technical Document, DOE/CS-0114/2, March 24, 1980.

U.S. Department of Energy (1980f) Solar Energy Program Summary Document FY 1981, DOE/CS-0050, Dist. Category UC-58, August 1980.

U.S. Department of Energy (1980g) Reducing U.S. Oil Vulnerability: Energy Policy for the 1980s, An Analytical Report to the Secretary of Energy prepared by Assistant Secretary for Policy and Evaluation, November 19, 1980.

U.S. Department of Energy (1980h) Second Draft Solar Power Systems Market Strategy Document, July 22, 1980.

U.S. Department of Energy (1981) Photovoltaic Energy Systems Program Summary, Assistant Secretary for Conservation and Renewable Energy, DOE/CE-0012, January 1981.

U.S. Department of Energy (1982) Photovoltaic Energy Systems Program Summary, Prepared by the Solar Energy Research Institute and the Jet Propulsion Laboratory for the Assistant Secretary, Conservation and Renewable Energy, DOE/CE-0033, January 1982.

U.S. Department of Energy (1983a) National Photovoltaics Program Five Year Research Plan 1984-1988, Draft, Photovoltaic Energy Technology Division, Office of Solar Electric Technologies, March 1983.

U.S. Department of Energy (1983b) Photovoltaic Energy Systems Program Summary Fiscal Year 1982, Prepared by the Solar Energy Research Institute and the Jet Propulsion Laboratory for the Assistant Secretary, Conservation and Renewable Energy, DOE/CE-0033-1, April 1983.

U.S. Department of Energy (1983c) National Photovoltaics Program Five Year Research Plan 1984-1988, Photovoltaics: Electricity from Sunlight, Photovoltaic Energy Technology Division, Office of Solar Electric Technologies, May 1983.

U.S. Department of Energy (1983d) Solar Collector Manufacturing Activity, 1982, Energy Information Administration, DOE/EIA-0174(82), May 1983.

U.S. Department of Energy (1984a) Photovoltaic Energy Systems Program Summary Fiscal Year 1983, Prepared by the Solar Energy Research Institute and the Jet Propulsion Laboratory for the Assistant Secretary, Conservation and Renewable Energy, DOE/CE-0033/2, January 1984.

U.S. Department of Energy (1984b) Solar Collector Manufacturing Activity 1983, Energy Information Administration, DOE/EIA-0174(83), June 1984.

U.S. Department of Energy (1984c) State Energy Price and Expenditure Report 1970-1981, Energy Information Administration, DOE/EIA-0376(81).

U.S. Department of Energy (1985a) Photovoltaic Energy Systems Program

Summary FY 1984, DOE/CE-0033/3, April 1985.

U.S. Department of Energy (1985b) Annual Progress Report: Photovoltaics 1984, DOE/CE-0128, June 1985.

U.S. Department of Energy (1985c) Solar Collector Manufacturing Activity 1984, Energy Information Administration, DOE/EIA-0174(84), August 1985.

U.S. Department of Energy (1985d) Photovoltaic Energy Systems Program Summary FY 1985, DOE/CH-10093-H1, December 1985.

U.S. Department of Energy (1987a) Five Year Research Plan 1987-1991 Photovoltaics: USA's Energy Opportunity, Photovoltaic Energy Technology Division, Office of Solar Electric Technologies, May 1987.

U.S. Department of Energy (1987b) Solar Collector Manufacturing Activity 1986, Energy Information Administration, DOE/EIA-0174(86), October 1987.

U.S. Department of Energy (1988a) Annual Energy Review 1987, Energy Information Administration, DOE/EIA-0384(87), May 1988.

U.S. Department of Energy (1988b) Photovoltaic Energy Systems Program Summary FY 1987, DOE/CH/10093-H4, February 1988.

U.S. Energy Research and Development Administration (1975a) A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future Volume 1:The Plan, ERDA-48, Vol. 1, June 28, 1975.

U.S. Energy Research and Development Administration (1975b) A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future Volume 2:Program Implementation, ERDA-48, Vol. 2.

U.S. Energy Research and Development Administration (1975c) Definition Report: National Solar Energy Research, Development and Demonstration Program, ERDA-49, June 1975. Reprinted in Energy Research and Development and Small Business, Hearings before the Select Committee on Small Business, U.S. Senate, October 8, 22, and November 18, 1975, part 2, pp. 4961-5044.

U.S. Energy Research and Development Administration (1976) Photovoltaic Conversion Program Summary Report, Division of Solar Energy, ERDA 76-161, November 1976.

U.S. Federal Energy Administration (1974) Project Independence Blueprint Final Task Force Report: Solar Energy, Prepared by the Interagency Task Force on Solar Energy Under Direction of the National Science Foundation, November 1974.

U.S. General Accounting Office (1979) Letter to the Honorable James R. Schlesinger, The Secretary of Energy, B-178205, EMD-79-40 (30712), April 19, 1979.

U.S. General Accounting Office (1982) Probable Impacts of Budget

Reductions on the Development and Use of Photovoltaic Energy Systems, EMD-82-60, B-206660, 1982.

U.S. General Accounting Office (1983) The Business Energy Investment Credit for Solar and Wind Energy, GAO/RCED-83-8, March 7, 1983.

U.S. Government Printing Office (1987) 1987-1988 Official Congressional Directory.

U.S. House of Representatives (1979) "Message from the President Transmitting Proposals for a National Solar Energy Strategy," Document 96-154, June 20, 1979.

U.S. House of Representatives (1981) "Program for Economic Recovery: Message from the President of the United States," Document 97-21, February 18, 1981.

U.S. House of Representatives (1985) Making Appropriations for Energy and Water Development for the Fiscal Year Ending September, 30, 1986, and For Other Purposes, Conference Report, H. Rept. 99-307. October 9, 1985.

U.S. Senate (1980) "Department of Energy Authorization for Fiscal Year 1981-Civilian Applications," Committee on Energy and Natural Resources, Report 96-687, May 8, 1980.

U.S. Senate (1981) "Authorizations for Department of Energy Civilian Programs, Fiscal Year 1982," Committee on Energy and Natural Resources, Report 97-81, May 15, 1981.

Wayman, Frank Whelon (1985) "Arms Control and Strategic Arms Voting in the U.S. Senate: Patterns of Change, 1967-1983," Journal of Conflict Resolution, Vol. 29, No. 2, June 1985, pp. 225-251.

Wayman, Frank and Kutler, Edward (1985) "The Changing Politics of Oil and Gas Price Deregulation: Ideology, Campaign Contributions, and Economic Interests, 1973-1982," Presented at the Annual Meeting of the American Political Science Association.

Weingast, Barry R., Shepsle, Kenneth A., and Johnsen, Christopher (1981) "The Political Economy of Benefits and Costs: A Neoclassical Approach to Distributive Politics," Journal of Political Economy, Vol. 89, No. 4, August, pp. 642-664.

Weingast, Barry R. and Moran, Mark J. (1983) "Bureaucratic Discretion or Congressional Control? Regulatory Policymaking by the Federal Trade Commission," Journal of Political Economy, Vol. 91, No. 5, pp. 765-800.

Welch, W. P. (1982) "Campaign Contributions and Legislative Voting: Milk Money and Dairy Price Supports," Western Political Quarterly, Vol. 35, No. 4, December 1982, pp. 478-495.

Westinghouse Electric Corporation (1977) Final Report Conceptual Design and Systems Analysis of Photovoltaic Power Systems, Research and

Development Center, April 1977.

Westinghouse Corp. (1978) Regional Conceptual Design and Analysis Studies for Residential Photovoltaic System, for Sandia Laboratories, Draft Final Report, November 1978.

Wolf, Martin (1974) "Photovoltaic Conversion for Large Scale Terrestrial Solar Energy Utilization," Statement in Solar Photovoltaic Energy Hearings before the Subcommittee on Energy, Committee on Science and Astronautics, U.S. House of Representatives, June 6 and 11, 1974.

Wright, John R. (1985) "PACs, Contributions, and Roll Calls: An Organizational Perspective," The American Political Science Review, Vol. 79, No. 2, June 1985, pp. 400-414.

(author unknown), Sunset Review Report Photovoltaic Energy Technology, Draft/Review Copy, November 19, 1981.