DYNAMICS OF GROWTH IN SOLAR MARKETS*

Olav Fjellså
Resource Policy Group
Sagv. 21, Oslo 4, Norway

ABSTRACT

As a step towards increasing our understanding of the dynamics of growth in solar markets, a simple generic System Dymanics model describing market penetration by a characteristic renewable energy technology is employed. The analysis demonstrates that for some classes of renewable energy, incentives are now adequate to provide for the necessary rates of growth. Technologies with slighty different features in our model are never able to sustain themselves in the market, no matter what federal subsidies they receive. A third group of solar technologies still needs support, even though it will evolve to become very competitive in the market without any subsidies as little as a decade from now. Relatively modest federal supports of these technologies now can bring them quickly to levels where they are economically, environmentally, and socially attractive energy options that provide significant oil savings. For these technologies federal support through initial stages of commercialization would be appropriate.

---

* The paper is based on a work done together with Dennis Meadows when the author worked as a Visiting Resource Fellow at Dartmouth College.

1. Different Views on Solar Energy

Federal policies that provided growing support for solar energy in the USA throughout the 1970's have recently been reversed. One result is a growing debate over the potential for growth by renewable energy sources that may be left to tend for themselves in the market.

Some argue that any renewable energy option with real social merit will be adopted without federal support of their commercialization. They point to rapid growth in the use of several solar technologies suggesting that market incentives alone will now suffice to spur investment in any renewable energy technology that offers a "legitimate" alternative to conventional fuels. In essence, their policies are based on the simple causal model shown in Figure 1.

In this view of market penetration, the government's proper role is to decontrol conventional fuel prices to conduct basic research on renewable energy technologies, bringing them to the level of first operational prototypes. Any technology that offers cheaper energy than conventional fuels will then attract consumers. Sales of the renewable source will provide profit that stimulate investment in production capacity of the technology, raise its supply, and further enchance its price competitiveness with conventional fuels. In this view, technologies that do not offer price advantages sufficient to attract consumers and spur

investment in production capacity are not socially useful, anyway, and thus they should not be given federal subsidies.

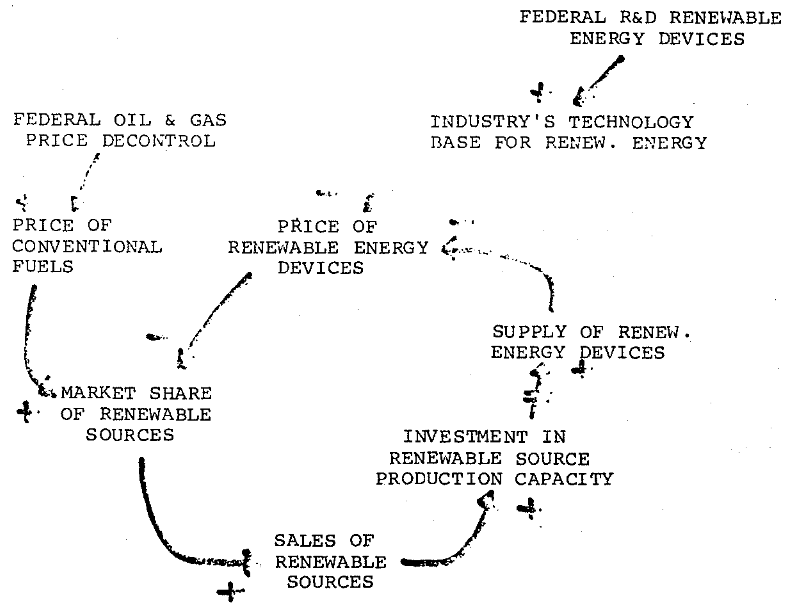


Figure 1: A simple model of market penetration by renewable energy sources.

According to this model, any federal attempts to influence the market through promotion, investment tax credits, bulk purchases, or related influences on the market are inefficient. Either they subsidize technologies that would succeed in the market anyway, or they serve to stimulate the use of devices that are inherently noncompetitive.

Solar supporters on the other hand indicate that the market for energy has many structural features that block market growth by new technologies, even those with substantial, longterm promise. They believe that the federal subsidies and institutional constrains that favor conventional energy forms should be included when comparison is done. They feel that the loss of federal support for solar now, while there is still significant discrimination in favor of established energy technologies will prevent most renewable energy forms from ever making a significant contribution to the nation's energy system.

The differences between the two viewpoints appear great. But those on both sides of the debate would acknowledge the possibility for four different relationships between federal subsidies and growth in solar markets; they are portrayed in Figure 2.

In Figure 2A, the solar technology grows to play an important role in the economy without federal subsidies; in Figure 2B even major subsidies do not succeed in producing growth for the renewable energy device. In Figure 2C the solar market prospers only so long as federal subsidies are continued. After they end, the renewable energy device fails to compete in its own, and its industry disappears. In Figure 2D subsidies ultimately provide the foundation for self-sustained growth in competitive markets. In this fourth case,

a relatively modest investment by the government establishes a healthy solar industry which soon prospers without federal assistance.

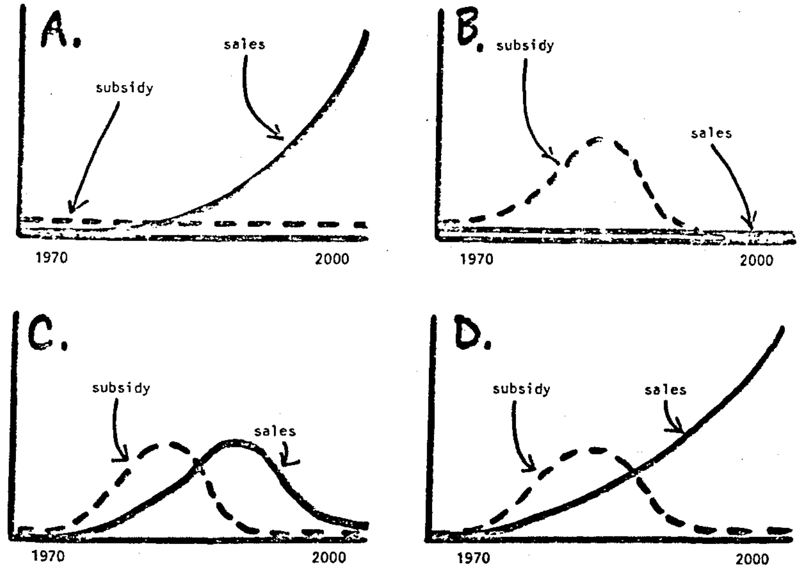


Figure 2: Four possible relationships between federal subsidies and growth in the use of solar energy.

Devices characterized by 2A and 2B certainly do not warrant support. The government's policy regarding systems similar to that in 2C will depend principally on non-market results such as the strategic value of reducing oil imports or the political appeal of arresting environmental deteroiration by greater reliance on solar energy sources. Even staunch advocates of the market would be inclined to provide federal support for technologies that can potentially follow the path shown in 3D. Indeed, current federal subsidies of nuclear energy are justified precisely because the technology is presumed to have the potential for growth like that shown in 2D.

Among the solar options available today are certainly technologies that fit into each the patterns portrayed in Figure 2. Unfortunately, experience with solar energy markets is still so limited, that it does not yet provide clearcut evidence on the long-term effects of federal subsidies. Past federal support, coupled with greatly increased fossil fuel prices and concern over future oil embargoes, has undeniably lead to rapid growth in some sectors of the solar industry:

> The number of passive solar homes has increased from approximately 500 in 1977 to between 60,000 and 80,000 by 1982; active solar collector sales increased from $17 million in 1975 to an estimated $400 million in 1981 ....; the number of solar collector manufacturers has increased from 50 in 1975 to more than 3000 in 1982; buildings with active solar systems increased from 30,000 in 1978 to 400,000 today.
>
> (SEIR 1982, p. 144)

But there is little consensus about the ability of important solar technologies to sustain themselves now, if federal subsidies are eliminated. Nor do formal forecast of solar's future role provide much foundation for choice among different views of market growth. The uncertainty in current models is illustrated by the great variation in past estimates of future solar markets. In his survey of 38 reports on solar's future,

John Holdren (1980) found forecasts as low as 0.1 and as high as 25 quads of renewable energy by the year 2000.

Designing appropriate federal subsidies for renewable energy requires that fedral agencies become more adapt at discerning each technology's future prospects. Fortunately, the information to do that is already available, even though it is still impossible to use it in making precise predictions of the future. In this paper we draw on that body of information to construct a new model of factors governing long-term growth in solar markets.

Holdren's survey and the contrasting quotes cited above point to real uncertainties about the behavior of solar energy markets. But it is possible to improve substantially on the simple model of solar markets used to justify the administration's current policies. There is growing consensus on nature of the individual factors that govern growth in the use of renewable energy technolgies. There have been several extensive, empirical analyses of considerations that influences consumer's decisions to purchase solar systems (Scott 1977, Leonard-Barton 1980, Farhar-Pilgrim and Unseld 1982, and OR/MS 1980). The latter reference is of special interest; it summarizes data of 24 empirical surveys of solar systems consumers. Added to these findings have been the insights developed through numerous, detailed case studies of market penetration by specific solar technologies.

From the work of several studies, including (Vescuso 1981), (Amlin 1980), (Vescuso 1982), (Marshall 1981), (Marshall 1982), and (Mitchiner 1982) we found that eight factors governed the impact of federal subsidies on a technology's potential for long-term, self-sustained growth:

- policies governing investment in production capasity of the solar technology,
- economies of scale in manufactoring,
- learning curves in production and installation,
- shifts in the marginal value of new installation with increasing market saturation,
- awareness by consumers of their solar alternatives,
- competence of marketing and repair services during periods of rapid sales growth,
- resistance by established suppliers of conventional energy, and
- improvements in the technology available from investments in R&D.

By assessing the effects of these factors it becomes easier to judge which of the four curves in Figure 2 is more likely to characterize a spesific technology's response to federal subsidies.

2. Purpose of this paper

Several of the eight factors in the list above have similar effects on long-term growth prospect for a renewable energy technology. Thus it is only necessary to consider a subset of them to understand the causes of the four growth patterns

in Figure 2. In this paper we examine the influence of the first five factors.

Our analysis takes form of a generic model decribing market penetration by a characteristic renewable energy technology. The model shows how different combinations of technological features, market characteristic, and federal policies can produce different growth modes.

The purpose of this analysis is neither to forecast the precise market share of a specific technology, nor to calculate the exact amount of oil that would be saved by a particular program of federal subsidies, but rather to demonstrate how federal incentives interact with free market forces to determine long-term growth for infant, renewable energy technologies.

The work has been supported by the Solar Energy Research Institute as a basic research effort to overcome the shortcomings in many of the established forecasting models. Most extrapolations of solar markets simply incorporate some variant of the logistic curve, a function whose form corresponds rather well with observed patterns of market penetration in mature technologies. But this approach does permit one to examine explicitly the interaction of federal programs with the economic, technical, psychological, regulatory, and social factors that govern consumers' choices among energy options. Thus we have taken a different approach.

The model characterized technology by its associated capital investment, economies of production scale, learning curves, benefits as a function of market penetration, and advertising consumer awareness. We are interested only in understanding the dynamics of long-time growth in renewable energy markets.

The generic model we present contains elements we have found to characterize all renewable energy technologies. It omits details that are unique to a specific solar technology, and its coefficients have not been adapted to represent any particular device or system.

The model constitues a framework within which to assess the possible secondary consequenses of alternative federal programmes. It provides a badly needed basis for identifying the longer-term consequences of short-term policies.

It shows the different modes of growth that can characterize any solar energy source: self-initiated growth, persistent stagnation, early success followed by failure in competitive markets after the loss of subsidies, or subsidies leading to self-sustained growth in competitive markets. With the model we can demonstrate the feature of a technology that may predispose it to exhibit one or another of these growth patterns. The analysis demonstrates that for some classes for renewable

energy, incentives are now adequate to provide for the necessary rates of growth. Technologies with slightly different features in our model are never able to sustain themselves in the market, no matter what federal subsidies they receive. A third group of solar technologies still needs support, even though it will evolve to become very competitive in the market without any subsidies as little as a decade from now. Relatively modest federal supports of these technologies now can bring them quickly to levels where they are economically, environmentally, and socially attractive energy options that provide significant oil savings. For these technologies federal support through initial stages of commercialization would be appropriate.

3. <u>The Causes of Market Growth</u>

The current price of energy available from a technology is a dominant influence on its acceptance. But empirical surveys of consumer behavior reveal that other considerations are important as well. Dorothy Leonard-Barton found in her study (Leonard-Barton 1980) that factors such as reliability, aesthestics, and availability of financing were among solar home owners concern before their decision to purchase renewable energy systems.

The longer-term price of an energy source govern its success in future markets; that price depends on a complex set of relationships governing technological advance, corporate promotion, investment in production capacity, consumer attitudes, and the establishment of adequate sales, service, and maintenance institutions. From our surveys of the literature

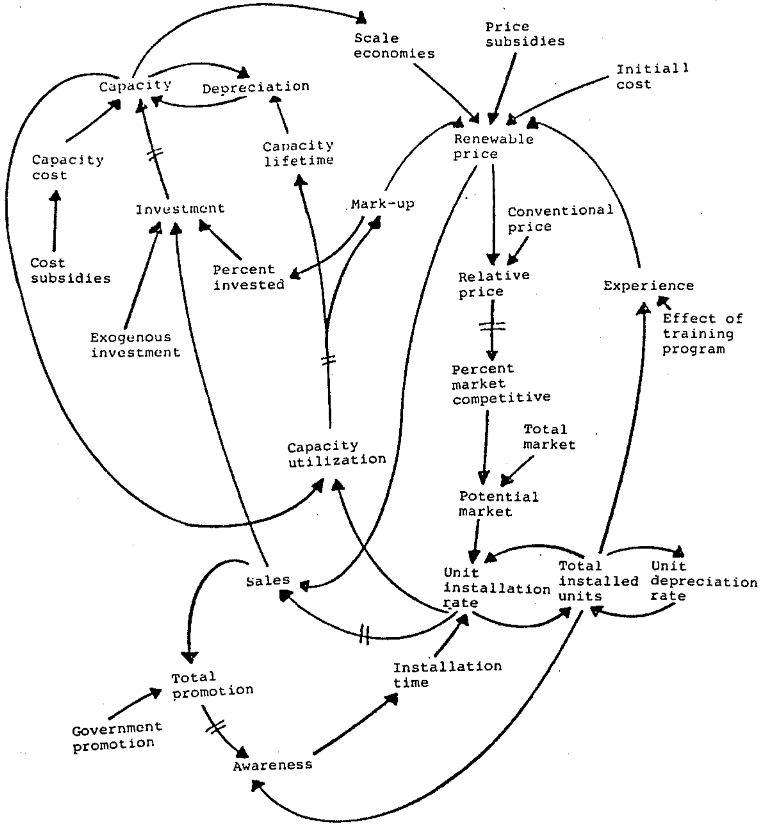


Figure 3: Diagram of the important cause-effect mechanisms in SOLMARK.

we have identified 28 factors that are important determinants of a technology's long-term markets share. In figure 3 we list them and show their interrelationships.

The complexity of the interactions in Figure 3 combines with uncertainty in the precise nature of the functional relationships among the elements and with doubt about the exact numerical values in the system to prevent the development of precise predictions. Nevertheless, one can determine some possible consequenses of a change in one factor by tracing out its impacts throug the web of causal influences that link it, ultimately, with most other elements in the systems.

4. The Structure of the Model

For purposes of the exposition we will assign generic numbers to the parameters of the model. The precise magnitutes of the numbers in SOLMARK thus have no meaning, but the relative sizes of parameters in the model are characteristic of what has been observed in actual markets. Where it is appropriate and possible, we indicate the numerical values actually observed at present for the corresponding elements in various solar technologies.

The most important feedback loops in the model are depicted in the figure. The model consists of four sectors: sales, price, production, and promotion.

4.1. Sales Sector

In our simple model all renewable energy units are identical. Their number is increased by installation rate and reduced by the depreciation rate. Three factors influence the unit, installation rate; total installed units, installation and time and potential market. As the price of the renewable alternative becomes more and more attractive compared to conventional energy sources, the potential market increases. As the market saturates, however, total installed units increases, dimishing the number of new units left to be installed. As the average installation time grows, the installation rate is reduced. Thus sales of the renewable energy unit can be very low, if most sites have already installed solar technologies, or if low consumer awareness has raised the avarage installation time to a large value. Installation time, a delay measured in years, represents the combined effects of all factors that may slow a consumer's response to new, but economically attractive solar energy technologies - low familiarity with the option, lack of confidence in its reliability, poor access to financing, slow delivery, installation delays, lags that come from desires to amortize the established energy system, and psychological resistance to becoming dependent on an unfamiliar technology.

During the early stages of growth for new technologies each of these may individual pose problems for the fledgling

industry. We simplify in SOLMARK by assuming that installation time depends on society's overall awareness of the option.

Consumers do not respond instantly to a change in the relative price of the renewable energy source; there is a perception delay of several years. The perceived economic savings from solar technologies do not affect all consumers equally. In our total market of 10.000, some sites will be far from the established sources of conventional energy. For them decentralized renewable sources will be very attractive, even the cost of the renewable energy technology exceeds by 50 percent or more the avarage market price of conventional alternatives in the whole region.

Other consumers will have strong attitudes against solar sources; they are not an effective part of the competitive market even the renewable source is half or less the cost of its convential competitors.

Increasing unit installation rate gives rise to more sales, which provide increased incentives and resources for manufacturers to invest in advertising and in other promotional activities that affect consumer awareness. Growing sales also lead to increased investment.

4.2. Price Sector

The economic index of interest to consumers is the price of renewable source compared to the price of its conventional competitors. The conventional price is specified as an exogenous, time-dependent variable. The renewable price is affected by several factors.

It has been widely observed that a product's costs tend to decline as the work force accumulates experience with the tools and procedures that are involved in its production and installation. This learning curve phenomenon is represented in the model as an experience multiplier on cost. Experience rises with growth in the number of total installed units and with the effects of any relevant training programs that may be initiated by industry, or labor unions.

The renewable price may be altered up or down by the mark-up. Producers manipulate price to hold their production rate near the capacity of their manufactoring facilities. Here we make the size of the price mark-up a function of average capacity utilization. The ratio of unit installation rate to production capacity shows the prevailing capacity utilization. The renewable price may also be reduced by scale economies.

It is widely observed in manufacturing processes that the production cost per unit falls as the size of a manufacturing facility rises up to some point of dimishing returns set by physical or managerial limits. In SOLMARK we assume implicitly that growth in the total production capacity of the industry signifies larger individual factors, hence economies

scale.

4.3. Production Sector

Capacity in the model refers to the total stock of physical capital and personnel involved in design, manufacture, sales, and service of the renewable energy devices. The capacity is increased by investment and reduced by depreciation. Depreciation is numerically equal to the ratio of the capacity to the capacity lifetime. As the lifetime increases, the rate of depreciation declines. This lifetime depends on the average utilization of the capacity.

Investment in SOLMARK has two components. The first, most important in the early years of the industry, is transferred into the renewable energy market from revenues that firms earn in other markets. The major investments in photovoltaic production capacity by Mobil Oil and ARCO Corporation are examples of exogenous investment. The second, dominant as the renewable energy industry matures, is investment from profits earned through the sale of the device. In SOLMARK, a variable percent of sales revenue is reinvested in the industry. This endogenous component is the principal source of investment today for residential woodstove manufacturers.

The actual cost of capacity can be reduced by federal subsidies, for example, through investment tax credit or accelerated depreciation allowances.

The percent of gross sales income invested in new production capacity depends upon the mark-up earned by the industry. When the sales price is marked up significantly above manufacturing costs, the producers are earning attractive profits, and there is substantial incentive to expand production. The percent invested will rise.

4.4. Promotion Sector

Increasing sales of the solar device increase the total promotion. The promotion is the sum of all government and corporate investments designed to create a favorable and well-informed view of solar energy options among prospective consumers.

The promotion has a positive influence on the awareness. The latter include the extent to which all those influences the sale of the solar device hold informed and positive views of it consumer attitudes, the extent and the tone of media coverage, social option, the disposition of lenders, the outlook of insurers, and the orientation of builders - all of these are subsumed in awareness. In addition to the promotional efforts, the awareness is also influenced by the number of installed units. The awareness increases when total installed units starts to accumulate.

In the next section we illustrate the use of the model by presenting and discussing some runs of the relationships described above.

5. The relation of federal subsidies to market growth

In this section we present seven computer simlation runs of SOLMARK to illustrate the different behavior modes of the model. While it is not possible to predict intuitively the precise behavior of the relationships discussed above, a basic understanding of our model gives good insights into the behavior modes it may exhibit. In SOLMARK the number of sites that will ultimately install a renewable energy unit depends solely on the ratio of the renewable to the conventional energy price. There is assumed to be increasing marginal installation costs and dimishing marginal value for the new units as market saturation progresses. However, the rate of market saturation varies greatly depending on the awareness of the market.

The initial price of the renewable source starts at two times the conventional price. Federal subsidies may reduce the renewable price:

- through reductions in the cost of new production capacity,
- through tax credits that reduce the consumers' renewable energy purchase price,
- by investment in training programs for those who install and maintain the devices, and
- with direct investments in production capacity.

The ratio of prices may also be reduced by industry through:

- investments in greater production capacity, affording economies of scale,

- reductions in the mark-up, and
- by accumulating experience in the installation and maintenance of the renewable devices.

Finally, the ratio of the two prices may be shifted by growth in the price of convential energy sources.

When there is a potential market for the renewable devices, it may be realized more quickly through corporate and public promotional activities which reduce the average installation time. Of course promotion does little good in SOLMARK, if the price disadvantage of the renewable source leaves it without a potential market.

In this paper, we will illustrate the ability of the model to reproduce each of the modes shown in Figure 2. Extensive sensitivety analyses must still be conducted in order to identify the full range of parameters that will produce each of the four shown in that figure.

5.1. MARKET STAGNATION: In Figure 4, the reference run, the renewable price is two times that of the conventional sources (assumed constant throughout this run), and there is no exogenous investment or federal subsidies of the price. Thus the potential market is zero, and there is no sales income. Without investment or accumulated experience there is no mechanisms to attain price reductions, and sales are zero throughout the run.

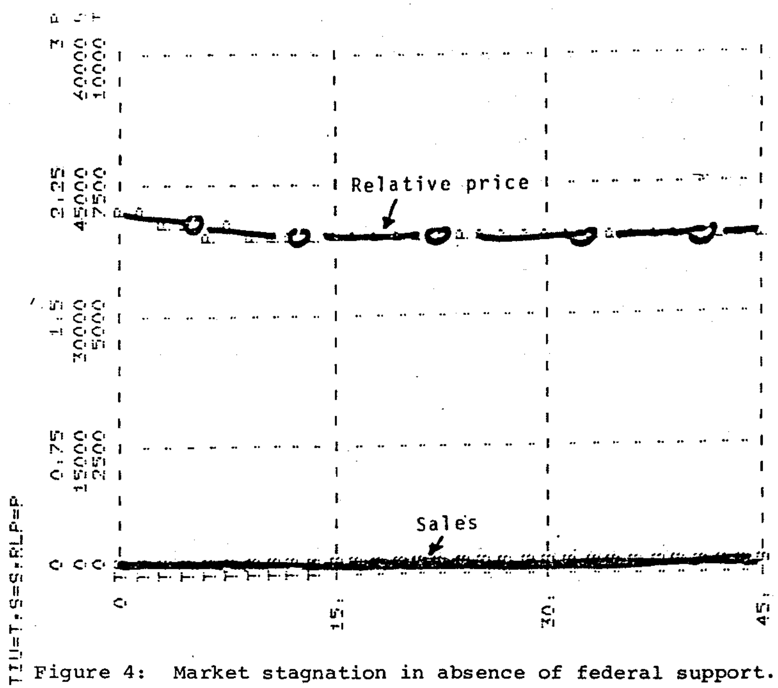


Figure 4: Market stagnation in absence of federal support.

5.2. SMALL EXOGENOUS INVESTMENT: In Figure 5 the previous conditions are changed only by adding modest levels of exogenous investment over the first decade. This provides increased production capacity, hence modest economies of scale. But the reductions in price are small. Thus the installation rate never becomes significant, there are no gains from accumulated experience, industry has no incentive to sustain investment in production and promotion, and the industry disappears once exogenous investments are discontinued,

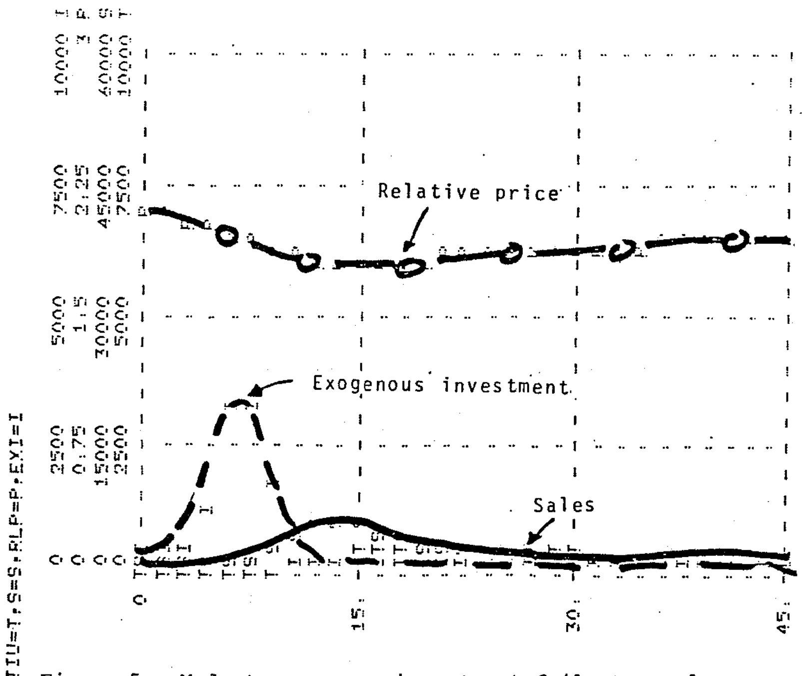


Figure 5: Modest exogenous investment fails to produce growth.

5.3. LARGE EXOGENOUS INVESTMENTS: The Administration's proposal for amounts to programs that should provide significant levels of exogenous investment to the renewables industry. But in SOLMARK, the problems seen above are not alleviated even by much larger infusions of money to fund productive capacity. Figure 6 exhibits market decline after the incentives for outside investment are removed around year 10.

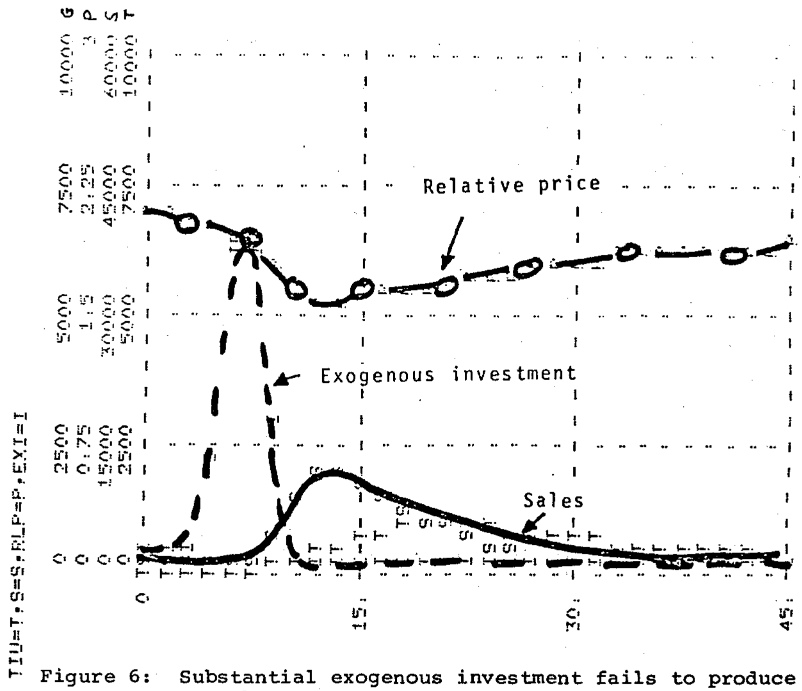


Figure 6: Substantial exogenous investment fails to produce growth.

5.4. GOVERNMENTS PROMOTION: As we have formulated the decisions of consumers, promotion does little good if there is no economic incentive to purchase renewable energy systems. In Figure 7 we add federal expenditures to the assumptions used in the reference run. The stagnation seen in that run is repeated. Government promotion can be effective, but it must be combined with subsidies that alter the economic attractiveness of the solar sources.

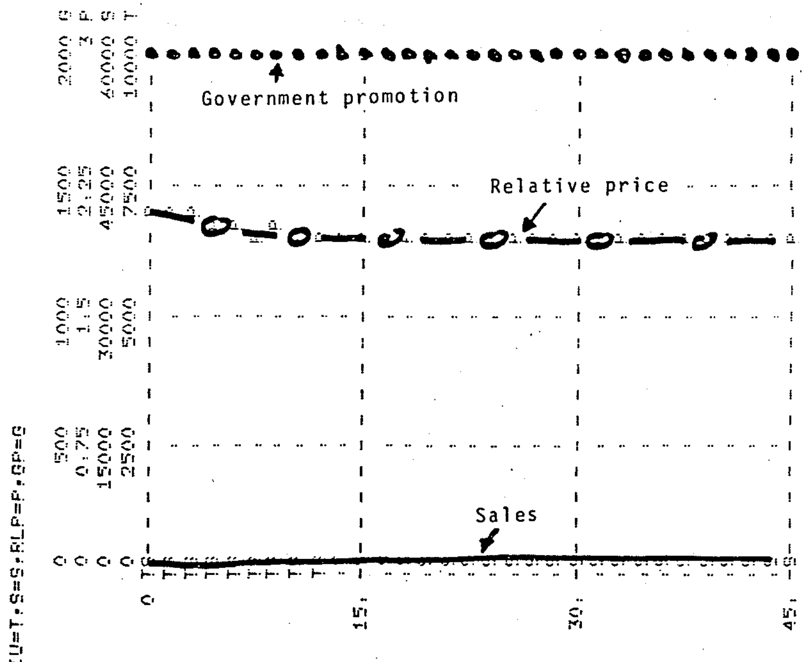


Figure 7: Government promotion alone is ineffective.

5.5. COST SUBSIDIES: In Figure 8 we represent the effects of federal programs that reduce the consumers' purchase price by 20 percent and lower the effective cost of new production capacity by a similar fraction. These policies are sustained over the course of the run, and they suffice to stimulate modest rates of growth in the sales of the renewable energy source.

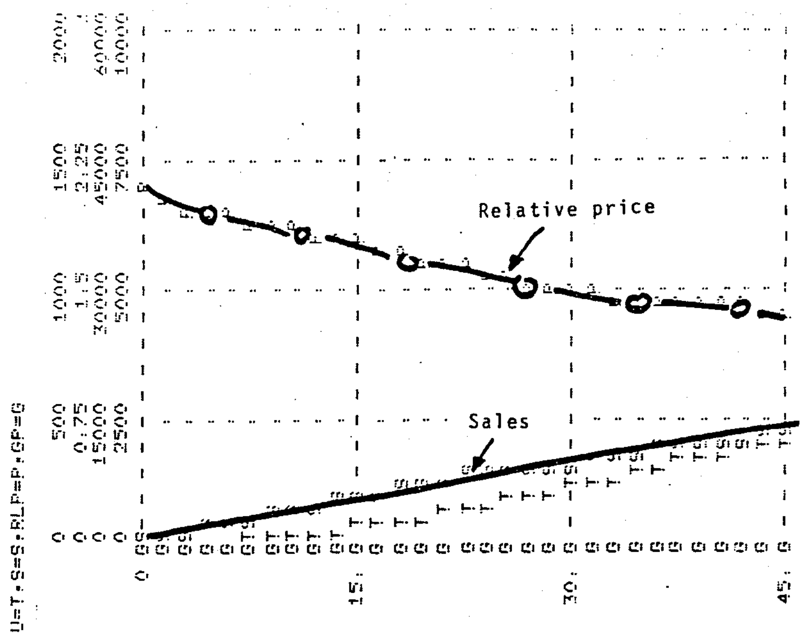


Figure 8: Federal supports to reduce capacity cost and lower initial cost produce modest growth.

5.6. COST SUBSIDIES COMBINED WITH PROMOTION: Federal promotion policies that were ineffective when pursued alone, become of great significance when combined with the two initiatives represented in the last run. Now promotion serves to reduce the time consumers spend in installing the units that are economically competitive. This raises the sales rate and provides more income to be used in investment. With greater productive capacity, the scale economies become more important, driving prices down even more and opening up new markets. With a greater base of installed units, the experience effects become important, and they permit further

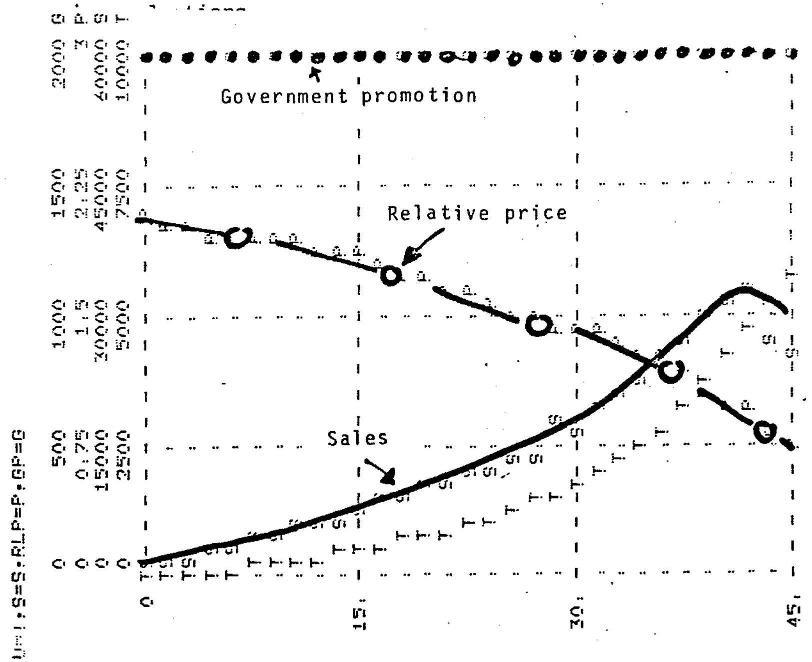
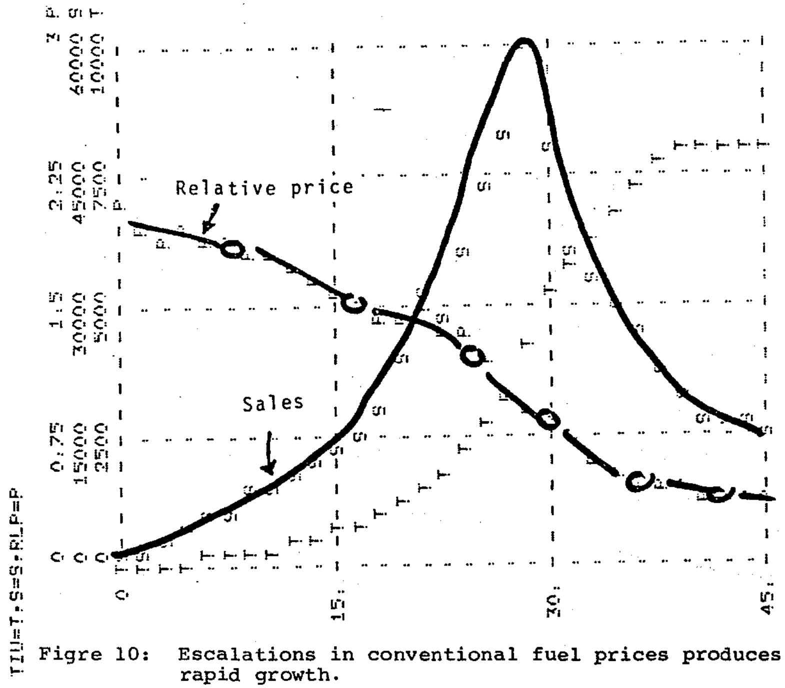


Figure 9: Governments promotion combined with reduced capacity cost and lower initial cost produce rapid growth.

5.7. GROWTH IN CONVENTIAL ENERGY PRICES: Federal subsidies are not required in SOLMARK to sustain growth, if convential energy prices growth rapidly. In the last run we assume a 40 percent increase, over the first few years of the run. That

suffices to stimulate self-sustained growth in the use of the renewable source until the market is saturated.



Figre 10: Escalations in conventional fuel prices produces rapid growth.

6. Conclutions

A set of plausible assumptions about the behavior of markets for renewable energy sources reveals a variety of conditions in which federal subsidies are required to initiate growth, even for technologies that have the potential to compete in free markets. The many omissions in the Administration's model of markets make it quite unsuited for deciding whether subsidies are justified. SOLMARK is not a form that will let it pinpoint the technologies that are best candidates for federal support, but it certainly suggests that there are many.

REFERENCES

(Amlin 1980) Amlin, Jeff, "Economic and Technical Determinants of Small-scale Hydropower Development in New England", DSD-181, Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, 1980.

(Farhar-Pilgrim and Unseld 1982) Farhar-Pilgrim, Barbara and Charles T. Unseld, Consumers and Residential Solar Energy: Findings from the National Study, Praeger Press, New York, NY, in press.

(Fjellså & Meadows 1982) Fjellså, Olav and Meadows, Dennis. "Dynamics of Growth in Solar Markets - A New Perspective on the Debate over Federal Incentives" GRS-469, Resource Policy Group, Oslo, Norway, 1982.

(Holdren 1980) Holdren, John P., "Renewables in the U.S. Energy Future: How Much, How Fast?". No. ERG-WP-80-13, Energy And Resources Group, University of Calfornia, Berkley, CA, December 1980.

(Leonard-Barton 1980) Leonard-Barton, Dorothy, "The Diffusion of Active Residential Solar Energy Equipment in California", in The Diffusion of Solar Energy Innovation, Avraham Shama (Ed.), Praeger Press, New York, NY (page reference is to the draft chapter, book page number will differ).

(Marshall 1981) Marshall, Norman L., "The Dymanics of Residential Wood-Energy Use in New England, 1970-2000", DSD-363, Resource Policy Center, Thayer School of Engineering, Hanover, NH, 1981.

(Marshall 1982) Marshall, Norman L., "WOODSTOV: A U.S. Regionally-disaggregated Model of Residentail Wood-energy Use 1970-2000", DSD-447, Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, May 1982.

(Mitchiner 1982) Mitchiner, John L., "The Role of Government in Encouraging the Market Penetration of Newly-Emerging Technologies: A Parabolic Trough Case Study", DSD- , Resource Policy Center, Thayer School of Engineering, Hanover, NH, January 1982.

(OR/MS 1980) "A Market Assessment for Active Solar Heating and Cooling Products - Category B: A Survey of Decision-makers in the HVAC Marketplace, Final Report", OR/MS Dialogue, Inc., Cambridge, MA, September 1980.

(Scott 1977) Scott, J., "Solar Water Heating Economic Feasibility, Capture Potential, and Incentives", Delaware University, 1977.

(SEIR 1982) Solar Energy Intelligence Report, Vol. 8, No. 18, Business Publishers, Inc., Silver Spring, MD, May 3, 1982.

(Vescuso 1981) Vescuso, Peter, "A Summary of Eleven Solar Market Penetration Models", DSD-411, Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, June 1982.