Cost-Effective Allocation of Public Funding
to Promote the Commercialization of Renewable Energy Technology

by

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Abstract

The need for new Renewable Energy Technologies (RETs) is growing with the challenge of providing affordable electricity under increasing environmental and public health constraints while promoting energy security and improved energy access. Governments have chosen to intervene in the commercialization process to overcome market failures that distort private investment in new technologies to ensure the provision of these technologies. Both technology-push and demand-pull policies are necessary to accelerate commercialization of renewable energy technologies, but the optimal balance of these strategies is not understood.

This thesis investigates the most cost-effective allocation of public funding, provided through a portfolio of commercialization policies, to ensure technologies bridge the valley of death. Case studies of photovoltaic technology promotion in the United States, Germany, and Japan provide examples of commercialization policy portfolios with varied results. Distilling the key funding flows and the resulting technology, product, and market development from the historical data provides a basis for a system dynamics model that simulates a firm commercializing a single technology from research and development through deployment. Different policy portfolios are tested to determine the most cost-effective distribution of commercialization support. The Japanese example suggests providing balanced support throughout research and development, demonstration, and deployment is more cost-effective than the either the US research-focused approach or the German market stimulation strategy. Similarly, the simulation model shows that providing funding through all phases of commercialization is more cost-effective than an unbalanced strategy that relies predominately on technology-push or market-pull strategies.

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1 Introduction

Society faces growing challenges associated with the provision of electricity. These challenges stem from new constraints such as avoiding climate change, assuring energy security and dual goals such as increasing electricity access and maintaining air quality for public health. By introducing new renewable energy technologies (RETs) and commercializing them for widespread use, electricity can continue to fuel economic growth without damaging security, health, or the environment. Unfortunately, commercialization of RETs is slow and uncertain. Due to a number of market failures the private sector does not invest the economically optimal amount in the development of RETs (Arrow, 1962; Arrow, 2007, Jaffe et. al, 2005). When the government withdraws public funding and the private sector is not yet ready to invest, many technologies remain undeveloped in the valley of death (PCAST, 1997). Although commercialization is typically viewed as the responsibility of the private sector, the importance of providing these technologies suggests a need for public intervention. Accordingly, governments have responded with policy to promote the commercialization of RETs by advancing cost reductions, technological improvements, and technological innovations.

Current policies are often insufficient to ensure commercialization (Murphy & Edwards, 2003). RETs that do not obtain enough support lay dormant in what is referred to as the “valley of death” (Branscomb & Auerswald, 2002). The most cost-effective allocation of public funding to bridge this valley of death, through government policy, remains unclear. This thesis will make recommendations on how governments should allocate their limited funding to the breadth of commercialization policies through a comparative case study analysis of commercialization policy and a system dynamics simulation model to compare different public policy strategies. Specifically, I will argue that the most cost-effective
portfolio provides balanced funding via policies throughout the process of commercialization: technology development, product development, and market development. A strategy that provides consistent, long-term funding will most effectively manage technology development and induce private sector investment to carry out the critical, later phases of commercialization.

Historically, support for RETs has come in the form of research and development (R&D) funding and market stimulation. Research and development has the potential to deliver revolutionary technological innovations that have higher performance or are fundamentally lower in cost. Either of these outcomes will lower the overall cost that determines how competitive a new technology can be with incumbent energy technologies. A country that focuses on R&D will achieve a broad technology array that will allow future deployment of the technology in markets with differing technical needs and costs. In addition to a significant amount of installed capacity, deployment support through market stimulation induces learning and economies of scale, which can also increase performance or lead to lower costs (Isoard & Soria, 2001). A market provides the opportunity to test a technology and reveal areas for improvement that can lead to incremental innovations that are likely to further contribute to cost reductions, which reinforce adoption.

Both R&D and market stimulation have a definite but narrow impact on the overall commercialization process. There is a clear tradeoff between emphasis on R&D and emphasis on deployment. The strategy determines the future technology profile, the future installed capacity, and the overall technology cost. Although R&D provides a diverse set of technologies for the future, the lack of deployment hinders product development and industry creation. Market stimulation policy will drive installations of the currently prevailing technology, but may not stimulate technological breakthroughs.
Technology-push working with market-pull is critical for commercialization (Mowery & Rosenberg, 1979; Norberg-Bohm 2000, 1999; Lund, 2007). Experience shows that weak market stimulation strategies or no demand stimulation risks wasting the public R&D monies spent on RETs (Loiter & Norberg-Bohm, 1999). Market incentives alone are too slow to induce the innovation needed to bring about new technologies (Bonvillian, 2009c). However, even when both policies are employed together, commercialization is uncertain in part because there is insufficient understanding of innovation in the commercialization process (Holdren, 2008). Complementary policies are not effective unless they are woven together to ensure that the effect of one smoothly transitions to the influence of the other (Lund, 2006). Poor understanding of the feedbacks between various stages and the blurry boundaries between phases complicates policymaking (Holdren, 2008). For example, both R&D and market stimulation policies only peripherally address product development, so the use of an additional policy can better induce the necessary change. Some countries have introduced an intermediate demonstration phase to improve the transition from publicly funded technology development to privately sponsored deployment (Rothwell, 1994).

The portfolio of commercialization policy reflected in the budgets allocated to each phase has significant impacts on the process of commercialization. Currently the debate is limited to “How much R&D money is required?” or “What size subsidy is best?” Both are very important questions, but little is being done to address what is the best balance between the two. Understanding the proper balance between policies that affect commercialization in each development stage is critical.

Through a combination of historical data and simulation this thesis seeks to illuminate the proper balance between potential policies by providing evidence suggesting the most cost-effective policy portfolio solutions. I will use (1) case studies to survey the breadth of policies that have been used and determine a rough estimate of cost-effectiveness of the
strategies coupled with (2) a system dynamics model that will provide a more generic understanding of the cost-effectiveness of public support through the stages of technology transformation. The case studies specifically evaluate key policies used to support photovoltaics in the United States, Germany, and Japan and the effects of these policies on stakeholders and outcomes related to the technology to be commercialized. A system dynamics simulation model that eliminates the country specific attributes of policy and models the overall funding scheme is used to evaluate the effect and cost of various policy portfolios.

To achieve the end goals of mitigating climate change, providing widespread electricity access, and improving air quality, technologies need to be deployed rapidly to achieve scale and to reduce costs. However, deployment now cannot come at the expense of developing technologies that will be necessary for the future. The case studies show an over-emphasis on R&D may lead to stunted deployment, which diminishes the cost reductions that can be achieved from economies of scale or learning. An overemphasis on market stimulation, may limit diversity and the long-term potential of breakthrough technologies. By examining the impacts of various policy regimes, we show that a singular emphasis falls short of the goal while a balanced approach achieves both short-term and long-term goals at the lowest cost.

Chapter 2 provides background in commercialization and motivations for government intervention. Chapter 3 describes the cash flow “valley of death” facing new technologies during commercialization. Chapter 4 presents a comparative case study analysis of photovoltaic commercialization support. Chapter 5 presents the system dynamics model and results. The final chapter concludes that a strategy that balances funding through technology development, product development, and market development is the most cost-effective
portfolio of commercialization policies because it provides financial support during the transformation and induces private investment.
2 Commercialization and Government Intervention

Commercialization is a complex process through which consumers gain access to new technologies through developing and deploying a new technology (Grubler et al., 1999). In practice the necessary innovations arise through research, development, demonstration, and deployment. Energy research often begins with breakthroughs in the basic sciences of chemistry, physics, and materials science. The research phase gives birth to new technologies that apply new scientific understanding or generate improvements in existing technologies because of better understanding of scientific systems. Development furthers the invention by applying it to a narrow technology and expanding the manufacturing and other processing techniques for the technology. The development stage furthers the embodiment of the invention in a more manufacturable form and begins to bring the cost down. Demonstration is a stage often overlooked, but increasingly recognized for its importance in exposing the operational weaknesses of the technology (IEA, 2008a pp. 172). During demonstration, pilot plants are constructed and small installations are built to confirm that the technologies work together properly to deliver the expected benefit. When sponsored by the government, demonstration provides a financial stimulus through project cost sharing and promotes the exchange of information that can improve the product and reduce the perceived risks involved with the manufacture and installation of a technology. Deployment begins with the initial introduction of a new technology and continues until the market is self-sufficient. Initially the technology may be restricted to a niche market, but as production expands, economies of scale are achieved, learning by the engineers occurs, and consumers provide feedback to improve the product. These cost reductions, technology improvements, and product improvements help drive the product into larger markets.
Part of the challenge of influencing commercialization is the difficulty in defining a useful metric (Gallagher et al., 2006). Each country depending on their R&D efforts or RET deployment efforts may view the success differently, but generally commercialization can be evaluated through its inputs and results (Gallagher et al., 2006). Both public and private R&D investments are relevant inputs to commercialization. Private R&D investment data is challenging to access because much of the information is proprietary (Gallagher, 2006; Margolis, 2002; Nemet, 2006). Public R&D information is easier to access, but is difficult to identify because R&D that contributes to innovation is a combination of applied energy R&D, energy science R&D, and basic science R&D. Outcome metrics relevant to commercialization describe the development of new technology (ex. number of patents), the market penetration (ex. cumulative installed capacity), and the industry strength (ex. production, number of firms). All of these metrics reveal an aspect of the commercialization process, but none absolutely indicate commercialization success.

Commercialization occurs spontaneously so it is commonly held that government should leave commercialization to the private sector. The private sector is well positioned to make decisions about what investments will be profitable because of their acute understanding of the market (Kammen & Margolis 1999). Additionally, it is often argued that the government plays a detrimental role in commercialization by “picking winners” (Roessner, 1984; Nelson, 1982 pp. 469-470). Despite these beliefs, governments have opted to intervene in the commercialization of RETs (IEA, 2008a pp. 178).

Government intervention in commercialization is often justified as an attempt to correct market failures (Jaffe et al., 2005). There are two commonly understood market failures implicated in the under-provision of RETs. First, R&D into RETs is under provided by the private sector because of the positive spillover externality associated with innovation. Firms investing in R&D are likely to produce innovations that cannot be entirely appropriated
to the firm. Competing firms are then likely to benefit from the innovation without contributing to the development cost (Mowery & Ziedonis, 2001). This knowledge spillover discourages firms from investing in R&D.

The second market failure that causes the under provision of RET is the negative externalities associated with traditional energy sources. Traditional energy sources have environmental, public health, and energy security costs that are not levied on the producers because there is no established market for those impacts (Tietenburg, 2006). The price of this traditional energy is lower than at an economically efficient level. Until the negative externalities, especially the health and environmental costs, are applied to traditional energy conversion technologies, RET will have a difficult time entering the energy supply market (Awerbuch, 2000). This is particularly true because energy is typically considered a commodity good. To most consumers there is no differentiation between an electron produced by a coal plant and one produced by a wind turbine, although there has been limited success offering green power to cater to those who will pay a premium for electricity generated from renewable sources (Bird & Sweezy, 2005). In general, this market combined with high entry costs and capital investment costs and a rigid, established infrastructure is not obviously appealing for investment (SET-Plan, 2007).

There are several options for government intervention to counteract the described market failures. Most commonly, R&D funding and market incentives are used1. Research and development programs act as a wellspring of new technologies and drive down costs of existing technologies. These new technologies by their sheer merit tend to push themselves into the market. Although public funding for R&D in energy technologies overall has fallen almost 50% since its peak in the 1980s, nominal funding for RET has remained relatively constant, but overall a small fraction of total energy R&D (IEA, 2008a pp. 172). Funding for

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1 Details of structuring energy R&D policy are provided in the Appendix.
energy R&D worldwide is suboptimal (IPCC 2007). According to Davis & Owens (2003), R&D funding of RETs in the US is one quarter of what is optimal to protect against uncertainty in the energy sector. The Stern (2006) report recommends a doubling in energy R&D. Others recommend increases as great as 3 to 10 times current levels (Nemet & Kammen, 2007). Market stimulation policies take a variety of forms\(^2\). Direct incentives include renewable portfolio standards, procurement policies, and building obligations. Indirect incentives include feed-in tariffs, tax credits and subsidies. These direct and indirect incentives stimulate demand in the product that will pull technologies through development to satisfy customer needs.

In the past decade it has been recognized that both a technology-push policy and a market-pull policy are necessary, but not sufficient for advancing commercialization of new technologies (Dosi, 1982; Mowery & Rosenberg, 1979). The key to successful commercialization is having many technologies in the pipeline and then subjecting them to several consistent policies to reduce their cost. The effect of a portfolio of commercialization policies can impact the technology transformation synergistically as shown in Figure 2.1.

\(^2\) A more detailed explanation of the market stimulation policies is provided in the Appendix.
Figure 2.1 Interaction of government commercialization policies and technology transformation
3 The “Valley of Death”

Despite the implementation of technology-push and demand-pull policies many RETs are not being commercialized quickly enough to become significant players in addressing current energy challenges. Murphy & Edwards (2003) attribute this to an unsuccessful transition from public support during R&D to private support in the market. The failure or delay in commercialization is often attributed to the “valley of death.” Energy technologies are particularly susceptible to the valley of death because of the long lead times and the need for considerable technology and manufacturing technology development required to successfully commercialize the invention (Norberg-Bohm, 2002).

It is most accurate to frame the valley of death as the cash flow valley of death as shown in Figure 3.1. The curve represents the total cash flow of the firm over time. Initially cash levels are high as the government is funding high-risk technology development. As the technology moves closer to commercialization government funding begins to decline. Cash flows are significantly low for a time until private investment is secured. Early stage private investment, like venture capital and angel investments, is not widely available (Gompers & Lerner, 2001). Over time, as the firm begins to become profitable, the cash flow begins to rise and venture capitalists exit as the firm can be supported through more traditional private capital (Moore, 1999; Roberts, et. al, 2000).
It is also important to understand the cash flow valley of death in terms of risk and development. The private sector is influenced by risk; government support of the development of the technology, product, and market can reduce this risk. As shown in Figure 3.2, having sufficient cash provides opportunity for technology transformation, which reduces risk and leads to outside investment.

Figure 3.2 Valley of death can be explained through a variety of lenses because of a reinforcing connection

Solutions for the valley of death require the entire portfolio of RD³ policies to align with the private sector to induce investment (IEA, 2008a pp. 169). This is challenging because the public and private sectors have different perspectives. The public sector is interested in the development of technological innovations and, thus, focuses on technology performance and cost reductions primarily in the early, high-risk stages (Murphy & Edwards,
Private investors, on the other hand, are not attached to a particular technology, but are instead interested in products and large markets to satisfy their underlying need for profit (Murphy et. al, 2002). The market can be pushed by the technology or driven by customer need as long as the potential payoff of the market is sufficient to warrant the risk involved in the initial investment, according to venture capitalist H. Anderson (personal communication, February 24, 2009).

The academic literature suggests three general approaches to overcoming the valley of death, shown in Figure 3.3, including (1) managing risk, (2) encouraging a transition from technology development to product development, and (3) fostering cooperation of the public and private sectors (Murphy & Edwards, 2003; Goldman et al., 2005; IEA, 2008a).

Figure 3.3 Managing risk, accelerating the shift to product development, and public-private partnerships can help to overcome the valley of death

The first approach requires the public sector to reduce risks stifling RET firms. Government sponsored research and technology development reduces technology risk, and setting a framework for a stable, robust market reduces market risk (deJager & Rathmann, 2008). A second approach is to ensure that some product development has occurred prior to
private sector involvement by reinforcing existing development and demonstration policies (Murphy & Edwards, 2003). An accelerated shift from a technology focus to a market focus can be fostered by changing public funding assessments to include an element of product development so that government funds and the private sector rewards the same companies (Murphy & Edwards, 2003). Finally, the two sectors can work together through co-investment partnerships to contribute uniquely to technology development and to reduce risk by reducing information asymmetries (Gompers & Lerner, 2004). By facilitating early action between technologists and investors, governments increase the chance that new technologies will be properly positioned to acquire the necessary capital and the private sector can tap a revenue stream that was previously not accessed.
4 Case Studies

Introduction

The main findings of comparative country-case studies are used to explore real practices of various countries' response to commercialization. To provide sufficient depth, the case studies focus on the development of solar photovoltaics (PV). The first modern photovoltaic research began in 1954 at Bell Labs and continues all over the world. Following the surge in RET development after the first oil shocks of the 1970s, many countries began pursuing photovoltaic technology more intensely. Figure 4.1 shows the increases in PV champion-cell efficiency over time and highlights the differences in technology.

![Figure 4.1 The increase of PV cell efficiencies by technology from 1975-2005 (Kazmerski, 2005)](image)

Photovoltaics, as a family, are currently in different stages of the commercialization process. Figure 4.2 below shows a clear distinction between the generations of technologies determined by the production cost of the technology and the power efficiency of the device.
First generation photovoltaics are made of single crystal or multi-crystalline wafers. The efficiency of such cells is limited by the Shockley-Quisser limit. As shown in Figure 4.2, second generation cells are also limited by this physical phenomenon. However, the materials used allow high-throughput, low-material production methods, which significantly lowered the cost per square meter. The third generation of technologies will likely incorporate nanomaterials or new light capturing techniques. There are two potential strategies that could succeed as third generation PV. The first is sacrificing high conversion efficiencies for extremely low cost production methods, high throughput, and minimal material cost. These technologies may include organic photovoltaics, dye solar cells, or quantum dot solar cells. Another third generation strategy is to develop cells that can overcome the Shockley-Quisser limit. Production costs may be considerable, but much less area would be needed to produce the same amount of electricity. Potential technologies include quantum wells, tandem structures, and multiple exciton generation. Firms attempting to commercialize potentially third generation PV technologies have received some initial private funding (Wesoff, 2008).

Figure 4.2 PV generations distinguished by cost per Watt (UNSW, 2008)

The future market of PV technologies is likely to have a mixed composition with a few dominant technologies, much like “batteries and bicycles”, according to US DOE photovoltaic expert S. Stephens (personal communication, March 23, 2009). But for now, the world production of photovoltaics is more than 85% first generation. Each technology
generation projects cost reductions in the future. A major source of cost reductions will come from technology solutions such as an increase in efficiency or cheaper manufacturing, but other gains may be made in product features related to installation and balance of system costs.

The United States, Germany, and Japan have implemented a variety of photovoltaic commercialization policies and have emerged as leaders in the industry. The expenditures and outcomes of each country’s policies provide information about the cost-effectiveness of each approach.

**Policies and Expenditures**

The US, Germany, and Japan began their support of PV technology in the early 1970s. Since that time all three countries have continued some form of support, but have developed distinctly different policy frameworks. Important policies in each country are shown below in Figure 4.3.

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3 Several other countries could be pursued in the future. At first glance, lessons from other countries reinforce the lessons from the US, Germany, and Japan.

4 A detailed summary of support in the US, Germany, and Japan is provided in the Appendix.
Germany begins R&D 1970
US begins R&D 1973
Japan begins R&D through the Sunshine Project 1974


US PV Manufacturing Technology Project 1991
Japan begins Demonstrations and Field Tests 1992
US Thin Film Partnership 1994 - 2007
Japanese Residential Subsidy Program 1997 - 2005
German Hundred Thousand Rooftops Program 1999 - 2003
German EEG 2000
US Energy Policy Act 2005

Figure 4.3 Research, Development, Demonstration, and Deployment activities in the United States, Germany, and Japan (PVPS National Reports, 2000-2007; IEA, 2007a; IEA, 2007b; IEA, 2008b)
The US began its PV R&D program in 1973, and picked up speed with the Solar Photovoltaic Research and Development Act of 1978. In the 1990s the US initiated two cost-shared, public-private R&D partnerships between what is now the National Renewable Energy Laboratory (NREL) and small and large firms developing photovoltaic technology: the Photovoltaic Manufacturing Technology project (PVMaT) and the Thin Film Partnership Program (TFPP). Both programs were well-structured public-private partnerships that divided risk through cost sharing, increased information flows, and increased the knowledge in academia, national labs, and the private sector. Public support in these partnerships leveraged private investment in R&D when outside or internal funding was otherwise hard to obtain. Overall the programs sped up the pace of development and encouraged more private investment into R&D (Margolis, 2002). In 2005, the Energy Policy Act introduced a 30% investment tax credit for PV system that has since been modified to make it more accessible. In the face of dismal domestic demand, the success of the US R&D projects is in part due to the international market created through Germany and Japan's subsidy programs.

The German PV program began with a heavy emphasis on R&D following the oil crisis of 1973. Cultural support for increasing the use of renewable energy led to the Thousand Solar Rooftops Program. The demonstration program offered subsidies for the purchase and installation of a PV system in return for participation in a five-year monitoring project. The success of this demonstration led to a larger Hundred Thousand Solar Rooftops Program and a Renewable Energy Law (EEG). The EEG raised the existing feed-in tariff (FIT) to an attractive level and created a stable environment to assure investors of the continuity of the market. The FIT, which is complemented by low-interest loans, has resulted in a large base of distributed, grid-connected PV installations.

Japanese funding for PV R&D began with the Sunshine Project in 1974 and has continued since that time. From 1994 through 1997 in exchange for participating in a
monitoring program, residents or public facilities were eligible for a subsidy covering half of the cost of installing a PV system. Using a public-private partnership scheme, the Ministry of Economy, Trade, and Industry (METI) ran a Field Test Project on New PV Power Generation Systems for Industrial and Other Applications from 1998 through 2003. The project served to prove the efficacy of PV systems and to standardize the technologies for future, widespread deployment. The Field Test programs have been greatly expanded in number and in budget in recent years. Japan has several subsidy programs for different sets of consumers, the most successful of which was the Subsidy Program for Residential PV Power Generation Systems that ran from 1997-2005 and will be reinstated in 2009.

Examining only the rhetoric behind each country’s policy portfolio, each country performs activities from R&D through market stimulation. However, from examination of the budgets, shown in Figure 4.4, it is evident that each country has a different policy emphasis. Research and development, which includes work on cells, modules, inverters, building integration, and system development, has been the focus of US spending. Germany has spent the vast majority of its money on market stimulation in the form of a feed-in tariff to remunerate electricity production from photovoltaic systems. Japan is notable because it is the only country with a sizeable demonstration expenditure. The Japanese emphasis on demonstration is consistent with the historical cooperation between the government and large corporations to undertake industrial development (Bonvillian, 2009b). The cost of the PV promotion program in Japan has been fairly stable. For example, in 2005 the funding level was the same as it was in 1994, however, the annual installation increased from 1860kW to 130 MW (PV Upscale, 2006).
From the policy and budget description it is reasonable to generalize the US policy as supply-push, the German policy as demand-pull, and the Japanese policy as a combination of the two with the addition of demonstration. The outcomes resulting from these historical budgets reveal how each policy strategy shaped the overall process of commercialization in each country. Trends in deployment, industry, technology development, and costs provide insight into the overall commercialization goal.

**Installations**

Deployment of a technology is an important step in the commercialization process because it yields incremental improvements in the product and technology and reduces unit costs at scale. The case studies suggest that as long as there is a pull from a market that is stable, transparent, long-term, and technology specific with minimal administrative and other non-economic barriers working contrary to market stimulation that the pull is sufficient to fuel commercialization (Watanabe et al, 2000; Watson, 2008; Loiter & Norberg-Bohm, 1999).
As shown in Figure 4.5, Germany dominates annual and cumulative installation. The annual installation rate increased dramatically in response to the FIT restructuring in 2004. The German incentive delivers guaranteed annual payment for generation as compared to the US tax credit and the Japanese capacity subsidy. Through the combination of a growing German market and a stagnating Japanese market, Germany overtook Japan in 2005 as the leader. Annual installation began declining in Japan in 2005 at the conclusion of the residential subsidy program. While in effect, the Japanese subsidy was successful because grid parity could be achieved through the high cost of grid electricity and the subsidy payment. Installations in the US have been slowly increasing, though concentrated in regions with high electricity prices and suitable state or local subsidies to complement the more meager federal subsidy.

![Figure 4.5 Annual and cumulative installed capacity between 1996 and 2007 (PVPS Annual Trends, 2007)](image)

Judged only by installation success, the German strategy, although expensive, is clearly the most effective. However, installation only captures well-constructed deployment policies, and cannot definitively recommend a commercialization portfolio. Installation success ignores the effectiveness of the strategy to generate new technologies or develop industry. Much of the installed capacity in Germany is first generation technology and many
of the installed modules are imported from other parts of the world. Because of the long life
time of photovoltaic technologies installation of one generation can dampen installation of
the newer improved technology. Manufacturing cannot be easily converted to produce
another technology so foreign competitors could overshadow the domestic industry by
providing these advanced technologies. Despite Germany’s overall dominance in annual
installations, Figure 4.6 reveals that Japan’s commercialization policy has actually been more
cost-effective. For each dollar spent Japan has been able to install as much as twice the
amount of capacity. Considering the superior solar resource in Japan, electricity generation
in Japan per installed MW is also higher than in Germany. Figure 4.6, which includes both
state and federal US market incentives, demonstrates little about the cost-effectiveness of the
US portfolio because much of the installation has occurred in a few states with extensive
incentives applied in addition to the federal tax credit. However, excluding state support
leads to a false conclusion that the US policy is efficient (Ricaud, 2000).

\[
\text{Figure 4.6 Annual installations per annual policy portfolio expenditure provides some}
\text{indication of cost-effectiveness (PVPS Annual Trends, 2003-2007)}
\]

The German FIT approach is considerably more expensive than the Japanese subsidy
approach (PV Upscale, 2006 pp. 33) especially considering that the payments from FITs will
continue to accrue for the next 20 years. However, it is difficult to directly infer that the
German program is wasteful because the price of electricity in Germany is not as high as in Japan so it requires more incentives to compete with grid electricity.

**Production**

A commercialization policy can also be judged by its ability to stimulate industry. Table 4.1 shows that of the top 16 firms worldwide three are American, three are German, and four are Japanese firms. Overall, production in Germany has increased dramatically. Production in Japan has also increased, although it slowed in 2006 and 2007. Changes in US production have been steady but modest. Figure 4.7 shows that out of almost 4500 MW of production worldwide in 2007 the US produced almost 300 MW and Germany and Japan each produced more than 900 MW.

<table>
<thead>
<tr>
<th>Company</th>
<th>2007 Cell Production (MW)</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Q-cells</td>
<td>389.2</td>
<td>Germany</td>
</tr>
<tr>
<td>2. Sharp</td>
<td>363</td>
<td>Japan</td>
</tr>
<tr>
<td>3. Suntech</td>
<td>336</td>
<td>China</td>
</tr>
<tr>
<td>4. Kyocera</td>
<td>307</td>
<td>Japan</td>
</tr>
<tr>
<td>5. First Solar</td>
<td>200</td>
<td>United States</td>
</tr>
<tr>
<td>6. Motech</td>
<td>176.4</td>
<td>Taiwan</td>
</tr>
<tr>
<td>7. SolarWorld</td>
<td>170</td>
<td>Germany</td>
</tr>
<tr>
<td>8. Sanyo</td>
<td>165</td>
<td>Japan</td>
</tr>
<tr>
<td>9. Yingli</td>
<td>145.5</td>
<td>China</td>
</tr>
<tr>
<td>10. JA Solar</td>
<td>132.4</td>
<td>China</td>
</tr>
<tr>
<td>11. Mitsubishi Electric</td>
<td>121</td>
<td>Japan</td>
</tr>
<tr>
<td>12. BP Solar</td>
<td>101.6</td>
<td>United States</td>
</tr>
<tr>
<td>13. SunPower</td>
<td>100</td>
<td>United States</td>
</tr>
<tr>
<td>14. Ningbo</td>
<td>100</td>
<td>China</td>
</tr>
<tr>
<td>15. Isofoton</td>
<td>87</td>
<td>Spain</td>
</tr>
<tr>
<td>16. Schott</td>
<td>84</td>
<td>Germany</td>
</tr>
</tbody>
</table>

5 The Appendix contains information on the evolution of production in the top firms of each country.
6 SolarWorld also has a strong presence in the US.
7 BP solar also has a strong presence in Germany, Spain, India, and Australia.
8 Schott also has a strong presence in the US.
Diversity

Although large installation rates and a growing industry are signs of successful commercialization policy, they focus on present time success and can ignore future technology developments. Commercialization policy must continue to bring forth new technologies from the progress of R&D. A highly successful policy will therefore result in the production of different technologies. Figure 4.8 shows the composition of production in the US, Germany, and Japan compared to the global composition. Roughly 90% of the production in Germany and Japan is first generation compared to a global average of 84%. It is apparent that production in the US is much smaller in absolute terms, but 64% of production is from new second generation technology suggesting the US is poised for future improvements in cost effectiveness and scale.
Looking even further into the future, the US is already leading in third generation technology. In the last few years, venture capitalists have begun funding new technologies that show promise of evolving into a commercializable third generation PV. In the US more than a dozen such companies have received funding. In Japan a few corporations have begun to pursue development of third generation technologies, namely dye solar cells. In Germany, a single small molecule photovoltaic developer has received private investment (Wesoff, 2008). Figure 4.9 shows the number and proportions of firms pursuing each type of PV technology.

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Figure 4.8 Annual production of first and second generation technologies in 2007 (Hirshman et al., 2008)

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9 Firms funded in each country are listed in the Appendix.
The industry that resulted from each country’s commercialization path clearly relates to the portfolio of policies employed in each country. The US boasts a diverse set of technologies birthed from R&D programs, but US deployment lags, especially considering the US’s size and comparatively superior solar resource. The German industry emerged in response to the promising domestic market and a manufacturing investment tax credit used to keep the industry within the country. The strong demand created by the FIT required rapid production and installation, which favors the more familiar first generation technology. Because of the long-term nature of the FIT, the installation frenzy continues. The opportunity to extract large margins by producing a lower cost cell has encouraged a number of second-generation firms that are slowly increasing their production capabilities.

The Japanese focus on transitioning from R&D to deployment through demonstration programs and their focus on industrial R&D, including the large electronics manufacturers has led to a few large firms. These firms are continuing to focus on the crystalline silicon cells, but like in Germany, there is some activity in second generation technologies and increasing interest in third generation PV in industry labs.
Cost Reduction

Despite considerable progress in the areas of PV deployment, the PV industry, and new technologies, commercialization will only be truly successful after the technology has become widely adopted. Widespread acceptance will be the result of an attractive product offered at a suitable cost that is at or near grid parity. Research and development can reduce costs through technological breakthroughs or more incremental improvements or by increasing cell efficiency. The efficiency of a technology is a very powerful cost lever. With the same factory throughput an increase in efficiency would increase the number of MW produced each year. We see this to be the case in Figure 4.10, where initially the cost is very high, but through decades of R&D the costs are reduced. A log-log plot of cumulative production and cost in Figure 4.11 shows two regimes. In addition to cost reductions from R&D, cost reductions also arise as production increases through a phenomenon called learning (Arrow, 1962). Learning which began as strictly the cost reductions that arose from repeating the same activity repeatedly has now been extended to include several different mechanisms of cost reduction that occur during production and deployment (Sagar & van der Zwaan, 2006). Learning can lower the cost of manufacturing, installation, operation, and maintenance (Sagar & van der Zwaan, 2006). A two-factor learning rate can be used to describe the inclusion of the effect of learning-by-searching associated with R&D with the more traditional, learning-by-doing (Berglund & Soderholm, 2006). Research and development decreases module costs, while deployment can reduce both the module and non-module costs.
Figure 4.10 Evolution of cost reductions and annual production for crystalline silicon cells from 1975 to 2007 (Prometheus Institute, 2007; Rogol et al., 2008)

Figure 4.11 Photovoltaic technology learning curve (Prometheus Institute, 2007; Rogol et al., 2008)

Installed prices, of concern to the consumer, can also be decreased through deployment. A denser market and practiced installers, electricians, and buildings inspectors reduces many of the installation costs. Accordingly, we would expect the non-module prices in Germany and Japan to be lower than in the US. As we see in Figure 4.12, the US does have historically higher non-module prices. High non-module costs in an emerging market

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10 Departure from the curve at high capacity may be due to a silicon shortage in 2005-2007.
were confirmed by PV Upscale (2006) in an analysis of Spain. In a geographically dispersed market the electrician may spend most of his time driving and will get fewer projects done in a day requiring him to charge more for each project. The number of site visits decrease as there are fewer iterations between the installers and building inspectors, according to solar industry expert C. Jones (personal communication, January 15, 2009).

![Figure 4.12 Reductions in per Watt module and non-module prices from 1993-2007 (PVPS Trends, 2007)](image)

Using historical price information there is no way to see the exact cost difference because of profit margins. In Farber’s (2006) analysis of installed costs in Germany and the US he finds that overall system cost in Germany is two thirds that in the US. In the US costs of monitoring and installation are roughly equal to the combined cost of modules, inverters, and other Balance of System (BOS) costs. Although the weighted average module cost in Germany is higher because of only 10% thin film technologies (compared to 64% in the US), the reductions in non-module costs are dramatic.
Conclusions

No one country excels along the entire innovation chain; countries tend to have a single, dominant policy focus. Each policy concentration can be related to a narrow impact on photovoltaic commercialization. The result of significant federal R&D funding in the US is a variety of technologies vying for dominance. The diversity of options coupled with a strong tradition of venture capitalism has resulted in the birth of many startups. Germany’s heavy market stimulation has resulted in unrivaled cumulative installation that is dominated by first generation technology installations. Japan, before 2005, had the largest diversity of policies along the commercialization path, and provides an example of a balanced implementation of both supply-push and demand-pull policies. Japan’s New Sunshine Program contained elements of R&D, industry collaboration, and market creation (Watanabe, 1995). Overall, Japan has been the most efficient in deployment (PV Upscale, 2006) and has had a more cost-effective portfolio than either the US or Germany. By actively funding the demonstration of new technologies they have improved the technology and ensured the technology is suitable to use in the larger market. Firms know there are gains to be obtained from market learning, but the initial cost of demonstration is often preventatively high.
Industry may perceive the initial costs of market learning are too expensive and too risky. In these situations a government supported deployment program can encourage private investment and initiate the learning cycle for the entire industry (Virdis, Wene & Nilsson, 2003 pp. 42). Although some may argue that it is not the public sector’s responsibility to assist a technology so far down the commercialization path, ending public funding before private funding is sufficient increases the risk that R&D money already invested will lay fallow. Reluctance to invest in the demonstration required to tune a product and begin market development is similar to the underinvestment in R&D and may suggest reasons for government intervention. When financing is hard to come by, the government should more actively induce private investment by sharing in the risks of technology verification, product development, and market entry.

Japanese demonstration programs are stable, comprehensive programs rather than singular events as has been the case with demonstration projects conducted in European countries and the US. This structure leads to more productive industry and investor participation. Industry involvement, which has historically been accomplished through public-private partnerships, provides industry with a better knowledge of the state of the technology and an understanding of the direction of the market. Through this cooperation technologies will evolve more quickly because of more commitments to riskier, long-term projects.

Policies that relate to the neglected product development phase like demonstration should be more widely pursued. By extending public funding later in the commercialization process to support these policies private investment occurs earlier. As can be seen in Figure 4.14 this increase in funding from both sides fills in the valley of death.
Figure 4.14 More public funding of technology development and product development induces greater private funding (Adapted from Murphy & Edwards, 2003)

PV commercialization and progress to achieving a cost goal in the near future would be much improved if all policies were consistent and working in unison at each point of the commercialization path. Although technology-push and market-pull are sufficient to commercialize a technology, demonstration can reduce the friction in transition. As suggested in the literature solutions to the valley of death successful policies reduce risk through consistent support, incorporate early stakeholder involvement in technology transformation and cost reduction, and encourage product development.
5 Clean Venture Simulation Model

Understanding how a single policy may affect the complex commercialization process can be challenging because the specific impact and interaction of various policies is unobvious. I will employ a system dynamics simulation model to develop a better understanding of how flows of funding support the entire commercialization process, and how development of the technology, product, and market enhance each other. System dynamics is a computer simulation method that models conceptual interactions and clarifies feedbacks of complex systems (Sterman, 2000). By developing a model and testing different policy conditions, we can make recommendations on the most cost-effective policy portfolio. In this model, commercialization occurs when a firm, and therefore its technology, passes through the valley of death into positive cash flow. Each different public support strategy can be used to guide a technology through the valley of death, but certain strategies are more costly because of their reliance on a single policy. The most cost-effective allocation of public funding will be the strategy that requires the least public investment and still generates a successful firm.

Model Background

The model is adapted from a simulation of venture capital investment policies and firm behavior policies for a clean technology firm (Miller, 2007). The original model portrayed a clean technology firm seeking venture capital funding to continue product development and build a market for its product. The original model was adapted in a number of ways to better represent the influence of public and private funding and risk and development.
Model Structure

In the adaptation developed here the model portrays a single startup working to develop and commercialize a clean energy technology. The model reveals high-level government strategies that can induce private investment and increase the probability that a technology will successfully be commercialized. Complete documentation of the model can be found in the Appendix. The simulation begins when the firm is very young, with staff consisting of two engineers with a single RET idea and government funding for R&D. With additional funding the technology can be transformed into a product and then sold to a market. The firm is influenced by flows of funding and development. In addition to the firm, important stakeholders portrayed in the model include the government, private investors, the market, and the competition.

The technology begins in the very early stage of R&D and proceeds through to the infusion of private capital and the expansion of a customer base. As modeled, the firm’s health and existence is measured by its working capital (Figure 5.1). Working capital is increased when the product is sold and generates revenue. Expenses for operations drain working capital as the firm pays the cost of goods sold and salaries for engineers and sales personnel. Spending money for operations occurs earlier than generating positive cash flows, putting the firm in danger of bankruptcy and thus the technology in danger of lying fallow without private sector investment.

![Diagram](image)

Figure 5.1 Working capital is at the heart of a firm commercializing an RET
Before the private sector will invest in the firm, a product and a market must be developed, which requires prior technology development. Technology development initially is the role of government. Through the process of government funded research new applications of scientific understanding and revolutionary innovations result in new technologies as shown in Figure 5.2. With additional funding, this technology can be further developed to meet existing needs or create new technological opportunities. Continued funding of technology development will lead to incremental improvements, which may manifest themselves as improved performance or technology-driven cost reductions. Once a minimum technology development threshold is reached the firm can make a decision to allocate its effort between product and technology development. As technology development increases the government will provide less and less funding with the expectation that the private sector will begin to invest because the technology is nearer to being commercialized.

Figure 5.2 Government funds high-risk research and development

Still the private sector will not invest without confidence that they will receive a return on their investment, which requires evidence of a significant market and a product to serve that market (Zider, 1998; Fried & Hisrich, 1994). Risk is related to the product of the payoff and the probability of success; increasing either of these decreases the risk. The market grows as new uses are found for the technology and a more attractive product leads to
market growth as shown in Figure 5.3. Figure 5.3 aggregates all potential customers, however, in the model the sales cycle is disaggregated into the following customer stages. Potential prospects are firms capable of adopting the RET that could presumably be evaluating the entire field of RET options to replace their current fossil-fuel technologies. Prospects are all the firms capable of adopting that are aware of their options and have not ruled out purchasing the RET venture’s technology. Hot prospects are those that are actively evaluating the firm’s technology. Purchasers have purchased the technology and Adopters are actively using the technology. The progression from potential prospect is determined by the number of prospects at each stage, the average amount of time a prospect remains in a stage, the sales effort applied by the firm, and the success of the sales effort. The stock of potential prospects grows through increases in technology and features or directly through policy.

![Technology development creates a new market to be served](image)

After sufficient technology development, one of three things may happen. First, technology development may drive the cost of the technology down to a point where it has a significant advantage over the market incumbents (in this case, traditional power producers and electric utilities). Alternatively, technology development may lead to a technology that far exceeds the functionality that can be provided by competitors. Finally, technology development may yield a profitable niche market that is currently underserved or not served
at all. If any of these three conditions are met, investors will take an interest in the firm because of its potential profitability. A combination of these events reduces the risk related to an investment in the firm; when the market, product, and technology risk is low enough, the private sector invests. Because a technology alone is not sufficient to capture a market, private funding will be channeled towards product development as shown in Figure 5.4 (Murphy & Edwards, 2003).

![Figure 5.4 A potential market induces the private sector to invest in technology and product development](image)

Technology and product development accumulates and the firm becomes increasingly successful finding adopters for their product. As shown in Figure 5.5, as the number of adopters increases, learning reduces the cost of the product, which improves the attractiveness of the product and in turn continues to enlarge the market and further decrease costs. Together these induce more private investment. As sales increase and revenue is generated, the firms can continue to invest in technology and product development. Eventually, a firm's role in the market will be firmly established and the technology can be considered commercialized.
Figure 5.5 Cost reductions continue to drive the commercialization process

**Policy**

Policies are available to influence the technology transformation, as shown in Figure 5.6. In addition to traditional public funding for high-risk R&D and common market incentives this model also incorporates a more progressive development policy: public-private partnership cost-share agreements. These agreements extend public funding past the high-risk stage and contribute to manufacturing R&D, process R&D, and pilot projects. In these partnerships the public sector and private sector both agree to fund a portion of the project cost. As the technology is closer to commercialization the government will fund a smaller and smaller fraction of the total cost.
Traditionally, to prevent the government from becoming too involved in commercialization, public funding for R&D may only be used for technology development (Gompers and Lerner, 2001). In this model, government funding for R&D can only be spent on technology development. Cost-share monies, private investment, and any revenues can be used to pay for customer service, marketing, sales, and product development.

Market development support is incorporated in this model as an indirect market stimulation policy, which lowers the price of the product so that it becomes more attractive in comparison with the price of the technology offered by the competitor. A common example of an indirect market stimulation policy is a subsidy or a rebate.

A carbon price may also be imposed to stimulate the market. In this model a carbon price is represented as an increase in the price of the competitor’s technology. Here we assume that the cost per ton of carbon, which typically relates to an increase in the cost of electricity generation from fossil fuels, can also be represented as an increase in the cost of the generation technology. This is a reasonable assumption because after a carbon price is put in place additional increments of carbon-emitting generation will be accompanied with a
cost of abatement or a permit/tax cost. With a known capacity factor, efficiency, and resulting emissions a carbon price can be back-calculated into an increase in technology cost.

Due to many factors external to the firm, successful commercialization is not assured (Miller, 2007), but to improve the provision of affordable, clean energy in the coming decade governments should consider several complementary policies that are highly cost-effective.

**Experiments and Results**

In the base case we will examine the cost and results of a portfolio in which the government only funds R&D. The initial values are shown below in Table 5.1, and the necessary maximum public funding for R&D is adjusted (to the nearest $50,000) until the firm can succeed during the first 60 years of the technology.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Potential Technology Adopters</td>
<td>1 million</td>
<td>People</td>
</tr>
<tr>
<td>Engineers</td>
<td>2</td>
<td>People</td>
</tr>
<tr>
<td>Sales Force</td>
<td>0</td>
<td>People</td>
</tr>
<tr>
<td>Average Salary</td>
<td>17,000</td>
<td>Dollars/Person*Month</td>
</tr>
<tr>
<td>Initial Technology Development</td>
<td>1</td>
<td>Technology</td>
</tr>
<tr>
<td>Theoretical Maximum Technology Development</td>
<td>300</td>
<td>Technologies</td>
</tr>
<tr>
<td>Technology Development Threshold to begin Product Development (fraction of theoretical maximum)</td>
<td>.25</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Initial Product Development</td>
<td>0</td>
<td>Features</td>
</tr>
<tr>
<td>Multiple of Incumbent Functionality Threshold (how much better RET must be over incumbent)</td>
<td>2</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Initial Cost per Unit</td>
<td>2 million</td>
<td>Dollars/Unit</td>
</tr>
<tr>
<td>Initial Competitor Cost per Unit</td>
<td>100,000</td>
<td>Dollars/Unit</td>
</tr>
<tr>
<td>Decrease in Costs per Doubling of Purchases</td>
<td>0.10</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Decrease in Costs per Doubling of Technology Development</td>
<td>0.18</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Minimum Market Size for Private Financing</td>
<td>300 million</td>
<td>Dollars</td>
</tr>
<tr>
<td>Minimum Private Investment</td>
<td>100,000</td>
<td>Dollars</td>
</tr>
<tr>
<td>Frequency of Private Investment</td>
<td>36</td>
<td>Months</td>
</tr>
<tr>
<td>Frequency of Public Funding</td>
<td>36</td>
<td>Months</td>
</tr>
</tbody>
</table>
In the base case public R&D funding is given to the firm every three years for technology development until the technology development reaches half of its theoretical potential, as shown in Figure 5.7. In the first year, the firm is given the maximum public funding for R&D, which is $16.55 million. Over thirty years, as technology development occurs, the public sector provides less and less money annually to support development. Discounted at an annual rate of 2\%\textsuperscript{11}, the total public cost of the R&D-only policy is $31.12 million. If the R&D had been funded by a single grant, rather than over thirty years, it would require an $81.35 million investment. Without government funding no technology development would occur at all.

![Annual Total Cash Flow from Public Funding](image)

**Figure 5.7 Profile of annual public R&D funding in the base case when R&D is the only commercialization policy employed**

As the technology develops and the potential market grows the private sector invests in the firm. The technology becomes more than three times superior to the competing technology, and the population that is capable of adopting the product increases. The combination of a better technology and a more lucrative market induces a nominal total of

\textsuperscript{11} Discount rates of 1\%, 2\%, and 3\% are examined. These discount rates reflect federal discount rates over a long period of time.
$38 million of private investment in the firm, as shown in Figure 5.8. If private investment had not occurred because technology development or product development did not improve enough to reduce the risk of investment then the public funding would eventually be consumed and the technology would fail as shown in Figure 5.9.

![Annual Cash Flow from Private Investment](image1)

**Figure 5.8 Profile of annual private investment when R&D is the only commercialization policy employed**

![Working Capital](image2)

**Figure 5.9 Without private investment the RET will stagnate in the “valley of death”**
With the combined public and private investments shown in Figure 5.10 the firm does not become independent for almost 50 years after the technology was first invented. The valley of death lasts roughly six years. A summary of the results for the base case and the following policy cases is provided in Table 5.2.

Figure 5.10 Working capital comprised of both public and private investment
Table 5.2 Summary of case inputs and results

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Policy Case 1</th>
<th>Policy Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Public Research and Development Expenditure (Million $)</td>
<td>16.55</td>
<td>12.75</td>
<td>9.5</td>
</tr>
<tr>
<td>Maximum Cost-Share Available (Million $)</td>
<td>0</td>
<td>0</td>
<td>250</td>
</tr>
<tr>
<td>Subsidy (%)</td>
<td>0</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total Discounted Public Cost (1% discount rate) (Million $)</td>
<td>42.45</td>
<td>34.06</td>
<td>27.87</td>
</tr>
<tr>
<td>Total Discounted Public Cost (2% discount rate) (Million $)</td>
<td>31.12</td>
<td>24.67</td>
<td>19.19</td>
</tr>
<tr>
<td>Total Discounted Public Cost (3% discount rate) (Million $)</td>
<td>26.30</td>
<td>20.95</td>
<td>16.38</td>
</tr>
<tr>
<td>Years to Market (first commercial sale)</td>
<td>46.5</td>
<td>38</td>
<td>30.5</td>
</tr>
<tr>
<td>Profit in Year 60 (Billion $)</td>
<td>0.4387</td>
<td>3.193</td>
<td>6.935</td>
</tr>
<tr>
<td>Cumulative Purchases</td>
<td>8,123</td>
<td>35,499</td>
<td>63,019</td>
</tr>
<tr>
<td>Years to Private Investment</td>
<td>21</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Total Private Investment (Million $)</td>
<td>38.16</td>
<td>44.61</td>
<td>25.42</td>
</tr>
</tbody>
</table>

In addition to R&D, other policies can promote commercialization. In two different policy cases we will examine how the cost of crossing the valley of death changes with additional policies in the portfolio. In the first policy case, an indirect market stimulation policy, reduces the price of the firm’s RET by 20%, which changes the timing of investments and reduces the overall public cost of commercialization. The higher value of a potential market induces earlier private investment in the firm and larger investments in each round as shown in Figure 5.11. This private infusion of capital reduces the maximum public funding for R&D to $12.75 million.
In the second policy case, a public-private cost sharing agreement is coupled with the R&D and market incentives. Cost-sharing increases the productivity of private investment through government dollar matching and further reduces the initial R&D investment required to create a successful firm to $9.5 million. Because of the fund matching nature of the cost-sharing program, the private sector injects about half the amount of money as it did without cost-sharing.

These two cases and the R&D base case all lead to a successful firm, but at different costs. The R&D only case is the most expensive, followed by the combined R&D and market stimulation case. Achieving a successful firm purely through R&D requires a considerable amount of funding to be committed to reach technology development levels that on their own are high enough to induce private investment. The addition of the market stimulation policy relaxes the need to rely on technology development because it creates a comparatively larger population of potential adopters because of the lower price. Cost sharing further reduces the overall portfolio cost because it contributes to technology and product development. Unlike R&D funding that is extinguished before the technology is
ready for market, cost sharing can provide funding in what may otherwise be the critical valley of death period. With less capital committed to this technology, more technologies can be supported. Less private investment may be socially optimal because of the opportunity cost of that money.

In addition to affecting the cost of crossing the valley of death, implementing policies to complement R&D decreases the amount of time a firm has negative or very low cash flows. Figure 5.12 shows that the market stimulation policy decreases the time in the “valley of death” by almost ten years. The combination of cost-sharing and market stimulation allows the firm to emerge from the valley of death in 35 years. Each additional policy increased the total technology development marginally because of higher levels of cash available from sales to be reinvested in technology development.

![Log of Working Capital](image)

*Figure 5.12 Increasingly positive working capital indicating successful commercialization occurs at different times under each policy portfolio*

The growth in working capital is driven by increasing sales. The difference in purchases is shown in Figure 5.13 below. The differences in capacity are extremely important for working toward the climate change mitigation goal. First, the sooner clean
energy technologies are deployed the sooner they can displace greenhouse gas emitting alternatives. Installations far in the future are not as valuable for carbon mitigation as those deployed now. Second, the earlier commercialization is achieved the sooner production can be scaled up. At a future date cumulative deployments will be higher for a technology that began production earlier. Finally, due to the feedbacks between operating revenues and technology development and its affect on the market size, the rate of adoption is different in the three cases. For all three of these reasons, the portfolio employing cost-sharing in addition to market stimulation and R&D funding is the superior strategy.

Figure 5.13 The start of purchasing, the cumulative amount purchased, and the rate of purchasing differ for each of the policy portfolios

Employing all three policies is also beneficial for achieving cost reductions that are important for widespread adoption. Clean, affordable electricity is directly tied to the unit cost of RETs. As shown in Figure 5.14, the policy portfolios reach different ultimate unit costs because of the differences in learning that drive down costs when production experience accumulates. These policy portfolios have the same cost reduction due to technology development, the earlier regime. The kink in each cost curve occurs when cost reductions due to cumulative production occur in addition to the cost reductions from technology...
development. When working capital is positive and there is sufficient private investment, marketing begins. The marketing creates potential customers who are persuaded to purchase the technology.

![Cost Per Unit Graph](image)

**Figure 5.14** Unit costs decrease differently in each policy portfolio due to differences in production

Predictions of adoption and firm success depend largely on the price of the product. The cost of the product decreases over time through two mechanisms: technology development and experience (Berglund & Soderholm, 2006). The cost of the technology has a significant impact on the purchases, working capital, and total private investment so it is difficult to predict the success of commercialization without strong evidence of cost reduction to be expected per doubling. Learning rates are different for every technology and are not necessarily constant overtime (Sagar & van der Zwaan, 2006). In a two-factor learning rate assumptions made about each learning rate have a different effect. Figure 5.15 and Figure 5.16 show that the cost reductions due to a doubling in technology development have a much greater influence on the cost of the technology. The result, shown in Figure 5.17 and Figure 5.18, is that projections about working capital are much more susceptible to uncertainty about cost reduction through R&D than through deployment.
Figure 5.15 Sensitivity of unit cost to cost reduction due to doubling of technology development. Varied uniformly between 0.05 and 0.35 around 0.18.

Figure 5.16 Sensitivity of unit cost to cost reduction due to doubling of cumulative purchases. Varied uniformly between 0.05 and 0.35 around 0.18.
Another strategy to induce development and deployment of RETs is to place a price on greenhouse gas emissions. By increasing the cost of traditional technologies, either by emission control devices or emission permits, the population of potential RET adopters increases. In this model a 30% increase in the competitor’s cost is caused by a $30/ton
carbon tax\textsuperscript{12}. The increase in competitor price drives up adoption and profits of the RET as shown in Table 5.3. The difference in purchases also causes a difference in cost per unit due to learning, which further promotes adoption of the RETs. Changes in the carbon price reveal that the successful commercialization of RETs is highly sensitive to carbon prices as shown by the increased purchase rates in Figure 5.19.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
 & \textbf{Base Case} & \textbf{10\%} & \textbf{30\%} & \textbf{50\%} \\
\hline
\textbf{Total Discounted Public R&D Cost (2\% discount rate) (Million \$)} & 31.12 & 26.11 & 21.52 & 18.88 \\
\hline
\textbf{Years to Market (first commercial sale)} & 46.5 & 40.5 & 34 & 29 \\
\hline
\textbf{Profit in Year 60 (Billion \$)} & 0.4387 & 2.093 & 7.371 & 15.24 \\
\hline
\textbf{Cumulative Purchases} & 8,123 & 23,749 & 47,996 & 70,788 \\
\hline
\textbf{Years to Private Investment} & 21 & 18 & 18 & 15 \\
\hline
\textbf{Total Private Investment (Million \$)} & 38.16 & 45.49 & 37.33 & 64.78 \\
\hline
\end{tabular}
\caption{Summary Results of Carbon Policies}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{cumulative_purchases.png}
\caption{Deployment of the technology occurs significantly earlier when carbon pricing increases competitor's costs}
\end{figure}

\textsuperscript{12} I assume the electricity generation mix is 50\% coal, 25\% natural gas, and 25\% carbon free (nuclear, hydro, renewable). Using a generation weighted levelized cost of electricity before and after a $30/ton carbon tax, I find that the cost of the alternative to the RET increases by 30\% (Lazard, 2009). This estimate is rough because it does not account for feedbacks in the generation mix or adaptation under a carbon price.
Although effective, the cost of a carbon policy to society is a complex issue. Further understanding of the impact of a carbon price is needed to determine if it is more cost-effective than a pure R&D regime or a strategy with a diverse set of commercialization policies. The cost and value of a price on carbon is being debated because of uncertainty surrounding how much a carbon policy may increase the cost of fossil-fuel based electricity generation technologies. Internalizing the emission externality in a carbon price will undoubtedly raise the cost of electricity and force out some traditional generation. It is unknown whether new RETs can fill in the deficit. Figure 5.20, showing the sensitivity of purchases to increases in competitor price caused by a carbon policy, suggests that the size of the carbon price strongly influences the success of RET technology commercialization. With adequate R&D funding a carbon policy also shortens the valley of death causing the RET to be deployed earlier and allowing a larger cumulative installed capacity over time.

![Figure 5.20 Sensitivity of cumulative purchases to carbon prices](image)
Conclusions

I have examined the impact of various funding strategies on firm survival, which has served as a proxy for successful technology commercialization. Employing a balanced combination of R&D spending, public-private cost sharing, and indirect market stimulation was more cost-effective than a strategy leaving out one of these policies. A balanced portfolio, one that provides funding to a technology over its lifetime, develops the technology, product, and market alike and so benefits from the feedback between each stage of development and deployment. Balancing the tradeoff between investing in R&D and learning through deployment improves technological capabilities and reduces cost through multiple avenues. The proper balance of funding depends on the private investment that can be leveraged. The attention to the entire technology transformation reduces risks in multiple ways and induces private investment in commercialization.

The balanced policy strategy also accelerated deployment and increased the overall capacity deployed. These benefits are currently not priced and so cannot be included in a measure of cost-effectiveness, but they are critical for avoiding climate change. Future work could monetize the deployed capacity benefits for a more in depth comparison of the costs and benefits of the different portfolio schemes.

The model is limited in content and scope, and could be improved with additional complexity. Future work should remove simplifying assumptions to provide a more detailed understanding of the industry dynamics. For example, R&D actors, private investors, and market stimulation policies could be disaggregated. Other policies such as non-economic barrier removal, loan guarantee programs, and customer financing programs could be included. For many clean energy technologies the model could be made more complete by including the cost and activities associated with manufacturing. A more detailed private investment decision-making method could be improved by evaluating the size and frequency
of investment and limiting private investment so as not to dilute the firm’s ownership. Future work could also collect more detailed empirical evidence to further understand the costs and benefits of each policy portfolio for specific technologies.

The scope of the model could also be expanded; the analysis examines a single country and a single technology individually. The model is not complex enough to understand the global implications of different policies in different regions of the world interacting though trade and multinational corporations. Due to a given country’s resources, demand, and national strengths it may be rational to have an unbalanced public funding portfolio, but this model is not equipped to look at the aggregate effectiveness of different countries pursuing different strategies.
6 Conclusion and Recommendations

New RETs must be commercialized to provide affordable and increasingly accessible electricity in a carbon-constrained world. Due to positive spillover externalities in the development of RETs and the negative environmental externalities associated with existing fossil fuels, the private sector underinvests in the commercialization of new RETs, justifying government intervention to correct these market failures. Commercialization requires new technologies to be adopted, which in turn requires lower product costs and increased functionality. Because of the complexity of commercialization and its feedbacks a number of policies can stimulate the process. A well designed R&D portfolio supplies new technology innovations and lowers the cost of existing technologies through technology breakthroughs like improved performance, new materials, and new manufacturing techniques. Market stimulation policies of all kinds induce deployment of the technology. Deployment also leads to technology improvements and cost reductions, but they are of a different kind and magnitude. Rather than revolutionary innovations, deployment causes evolutionary innovations that arise through customer and supply chain feedback.

Despite a policy portfolio that in name includes technology-push and demand-pull policies, the case studies show that governments tend to emphasize one policy or the other. Some success is achieved because either of the two traditional commercialization policies promote new technology, technology improvements, and cost reductions in a limited capacity. However, frequently this unbalanced portfolio of funding causes commercialization to fail as technologies are trapped in the valley of death. R&D does provide a variety of potential technologies for the future, but without a market new technologies may not transform into marketable products. Conversely, a strong market induces considerable deployment, but has a limited effect on creating new and better technologies that may be
cheaper and more efficient in the longer term. Since it is impossible to know the optimal technology portfolio over the long-term, countries must choose a balanced funding strategy that achieves near term goals and provides for the future simultaneously.

An additional policy phase of demonstration can improve the commercialization process even more by lubricating the transition from public to private support. The government can induce private investment by bearing a fraction of the cost and assuming a fraction of the technology and market risk. By extending public funding and inducing earlier private funding the valley of death can be filled in. Investment in market learning is often too expensive for a single firm and is subject to the same spillover externalities as R&D, but demonstration projects serve to prove technological performance, validate the desirability of the product, and ensure the stability of the market.

The case studies show that the funding decisions implicitly make a tradeoff between the types of technologies that are available and the strength of the commercializing industry and deployment. Strong R&D created a variety of technologies and reduced the technology cost of the product. Strong deployment policies resulted in considerable annual installation and annual production and reduced the product cost. The development of strong industry was also supported by stable deployment policies. Japan achieved low module and non-module (technology and product) costs by funding both R&D, a subsidy program, and ensuring the transition through extensive field-testing. As a result of their balanced policy portfolio, they have been the most cost-effective achieving both new technologies and installed capacity.

The system dynamics simulation model shows that the timing of funding over the lifetime of technology commercialization has considerable impact on the time to success and the social cost. Each policy portfolio can be used to commercialize a technology, but they differ in terms of overall public cost and the length of time to cross through the valley of
death. If commercialization relies only on R&D funding then commercialization comes at a considerable expense and takes a comparatively long time to be successful. Similarly, if the focus is on market development support, then the size of the market induces private investment and less public funding is needed. A stable market induces an initial amount of private investment, which can be used in cost-shared partnerships to reduce the burden of technology development cost and free up private capital for product development. Cost-shared funding for the technology transformation reduces the cost to commercialize and the amount of time in the valley of death is reduced.

The debate over technology-push and demand-pull policies is limited. This thesis shows that a reliance on one of these policies is costly despite its potential effectiveness. An unbalanced policy portfolio results in an unbalanced result both in terms of technological progress and implementation. It is critical to have a portfolio of policies influencing the short and long-term commercialization path of a technology. To address all of the problems, climate change especially, development of breakthrough technologies should be coupled with deployment of existing technologies. Deployment takes action now and provides lessons for future technology generations.
7 Case Studies

United States

Figure 7.1 Timeline of US photovoltaic commercialization policy (IEA, 2007b)

Research and Development

Due to the influence of Vannevar Bush after the Second World War, there is a strong R&D focus in the United States (Bonvillian, 2009a; Bush, 1945). Research and development of RETs was initiated in 1973 as a reaction to the oil crisis, as shown in Figure 7.1. The budget and support for photovoltaics has fluctuated since that time as shown in Figure 7.2. Starting in 1978 the Solar Photovoltaic Research and Development Act laid out a ten-year plan to promote RD&D for PV. The law placed considerable emphasis on commercialization especially through publicly visible demonstration projects. Most of the funding for the National Photovoltaic Program went to R&D despite its original emphasis on demonstration and commercialization because the administration in the 1980s slashed the budget leaving funding only for basic R&D. Luckily, the funding for basic R&D remained relatively stable and was able to build industry knowledge that contributed to developments when demonstration support began. The long-term experience made it easier to transition to commercialization in the 1990s. Since competitiveness with the grid was farther away, US
firms, compared to Japanese firms for example where the cost of electricity is high, tended to divert resources to activities that would lead to radical innovation (Rogol, 2007).

![United States (DOE) Photovoltaic R&D Expenditures](image)

**Figure 7.2 Research and development funding for photovoltaics in the US through the US Department of Energy (IEA, 2009)**

The US pursued two very successful applied R&D programs in the 1990s. The first of these programs, the Photovoltaic Manufacturing Technology project (PVMaT) began in 1991. Through phases of (1) problem identification, (2) process-specific manufacturing and teamed research on generic problems, and (3) product driven PV module manufacturing technology and PV system components research, the program sought to identify and solve PV manufacturing issues. Specifically the goals were to improve manufacturing processes and equipment, accelerate cost reductions from manufacturing, improve performance and reliability, and lay the groundwork for scaling up the industry. Each phase of participation was competitive and offered a bigger investment by the public sector. Goal setting was done with industry and government collaboration. The independent teams had heavy industry representation that were aware of the market when allocating funds to projects. Cost sharing was used to share risk between the public and private sector. The cost system was multi-tiered so large firms assumed 50% of the cost burden compared to 30% by small firms. Information sharing between the private sector, academia, and the public sector at annual
review meetings was one benefit of the program. Information sharing was also encouraged through “generic-teamed” research collaborations. Participation in these collaborations reduced cost-sharing requirements and promoted longer-term, higher-risk research collaborations (Margolis, 2002).

The PVMaT program brought success to individual firms, and overall the program resulted in cost reductions and increased manufacturing capacity in the industry. These successes were both incremental development and due to the manufacturing breakthroughs that occurred through risky or peripheral R&D projects that would not have been undertaken but for the risk sharing of the cost-shared partnership (Margolis, 2002).

The second landmark R&D program in the US was the Thin-Film PV Partnership. It was a descendent of earlier a-Si projects and ran from 1994 to 2007. The goal was to move specific thin-film PV technologies from R&D to demonstration, specifically from prototype to pilot production. The program was structured as a multi-tiered cost share where the government percentage reflects the distribution of risk between the private and public sector. The research goals were set in regular meetings between industry, university, and an NREL monitor. Some of the cost shared funds were required to go to team projects to both encourage participants to be more collaborative and less secretive and to reduce duplication among participants.

The program resulted in an increase in the efficiency of thin film cells and the success of technology transitions from laboratory experiments to pilot production. For example, United Solar Systems Corp and BP Solar successfully developed their a-Si technologies and Siemens Solar Industries developed its CIS technologies.

In 2007 the Thin-Film Partnership Program was phased out along with the PV Manufacturing R&D Project and the University and Exploratory Research Program. These
projects were reorganized under Technology Pathway Partnerships (TPP) and the PV Incubator Project under the Solar America Initiative.

Another innovative research program was the Jet Propulsion Laboratory’s (JPL) Flat-Plate Solar Array Project. It was a boost to the industry for several reasons. First, it served as an initial market by purchasing 5 kW modules from each PV manufacturer. Second, it performed testing and standard setting for the industry. Finally, it provided firms with feedback as to how to improve the reliability of their modules. Overall, it revealed the products that were effective in a real world environment.

Currently PV RD&D falls under the Solar America Initiative (SAI), which is part of the Advanced Energy Initiative that began in 2006. The majority of the funding is for cost shared research and commercialization projects in collaboration with the private sector to enhance the cross over from R&D to commercialization. Through Technology Pathway Partnerships (TPP) projects to achieve a PV system that meets the cost goals of SAI are funded. This industry-lead, public-private partnership specifically seeks to develop technologies that may be cost competitive as early as 2015. The research is broken up into several sub categories: component development, systems development, and technology evaluation. Special PV incubator activities fund development of system components (US DOE, 2008).

The initiative has also established a lab for both private and public researchers to standardize their processes. The lab is called the Process Development and Integration Laboratory and it is hosted at NREL. The initiative conducts the work that was done under the Thin-film partnership and the PV Manufacturing R&D project in the past. More fundamental research on semiconductor properties, device mechanisms, and fabrication processing to improve efficiency, stability and reduce cost is performed under the Advanced Materials and Devices branch of SAI.
**Demonstration**

Solar America Cities were established in 2007 under the Solar America Initiative. In 2007 thirteen Solar America Cities were chosen, and twelve more were chosen in 2008. Through the partnership local governments are given funding and technical and regulatory assistance to install photovoltaics (US DOE, 2008).

**Deployment**

The US has a relatively weak federal deployment policy. In 1978, the US passed the Public Utilities Regulatory Policies Act, PURPA. PURPA required renewable generation to be purchased by electric utilities at the “avoided cost” of electricity based on energy and capacity costs that the utility would otherwise incur by generating the power itself or purchasing it from another traditional generator. PURPA did much to stimulate low-cost renewable generation like wind power, but was little incentive for more expensive photovoltaic installations.

Also in 1978, the Energy Tax Act established a 10% tax credit for residential solar installations. The Energy Policy Act of 1992 extended the 10% business tax credits for solar installations indefinitely. The Energy Policy Act of 2005 increased the solar investment tax credit to 30% with a cap of $2,000 until the end of 2008. The Emergency Economic Stabilization Act of 2008 extended the 30% investment tax credit eight years, removed the $2,000 cap, and made public utilities eligible to receive the tax credit. In addition to the investment tax credit, the Energy Policy Act of 1992 also established a 1.5 cent/kwh renewable energy production incentive (REPI) for state and local governments.

Currently, the federal government has set no renewable energy targets. Many of the states have set targets, many of which are substantiated with renewable portfolio standards. Some states have building obligations, system benefits charges, green power funds, net
metering, rebates, and roof programs that may be coupled with the federal tax credit (Energy Policies of the USA, IEA 2007).

The federal government has begun a new Loan Guarantee Program. It has the potential to provide renewable energy firms with low-cost capital. Congress has allocated $60 million dollars for which PV projects would be eligible.

Despite weak demand enhancements, 830.5 MW of grid-connected distributed PV was installed in the US in 2007 as shown in Figure 7.3. However, the US should no longer rely on international demand, but should develop policies to create demand nationally (Margolis, 2002). “The U.S. fascination with factors such as patents as stimulators of technological innovation ignores the need for other kinds of market-enhancing policies” (Rycroft & Kash 1999).

![Figure 7.3 Annual and cumulative installed capacity in the United States (PVPS National Reports, 2000-2007)](image)

**Figure 7.3 Annual and cumulative installed capacity in the United States (PVPS National Reports, 2000-2007)**

*Industry Development*

The example of the US in the 1970s and 1980s shows the importance of multiple policies working together and the importance of demonstration and market stimulations. In
the 1970s with a broad set of policies linking demand-pull, supply-push, and public sector involvement the US PV industry grew causing decreases in cost and increases in production. In the 1980s when the demonstration and commercialization budget was severely cut and demand-pull policies were removed the costs of PV did not decline as rapidly. The 1990s saw a return to private sector collaboration including the PVMaT project and the Thin-Film PV Partnership Project- this boost coupled with a growing international market to substitute for adequate demand-pull policies improved the growth of the PV industry (Margolis, 2002 pp. 97,98) Production in the US is steadily increasing. In 2007, 273 MW of cells were produced in the US as shown in Table 7.1.

Table 7.1 Annual Cell Production (MW) in the United States (Prometheus Institute, 2007; Hirshman et al., 2008)

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>BP Solar</td>
<td>20.5</td>
<td>25.5</td>
<td>31</td>
<td>13.4</td>
<td>14.2</td>
<td>22.6</td>
<td>25.6</td>
<td>27.7</td>
</tr>
<tr>
<td>Evergreen</td>
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<td></td>
<td>2.8</td>
<td>6</td>
<td>14</td>
<td>13</td>
<td>16.4</td>
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<td>20</td>
<td>60</td>
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<td>Global Solar</td>
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<td>1</td>
<td>2.5</td>
<td>3</td>
<td></td>
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<tr>
<td>Schott</td>
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<td>5</td>
<td>5</td>
<td>4</td>
<td>10</td>
<td>13</td>
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<td>52</td>
<td>62</td>
<td>42</td>
<td>35</td>
<td>35</td>
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<tr>
<td>United Solar</td>
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<td>7</td>
<td>14</td>
<td>22</td>
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<td>19.5</td>
<td>27.3</td>
<td>32.2</td>
<td>18.8</td>
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<td>24.5</td>
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</tr>
<tr>
<td>Total</td>
<td>75</td>
<td>100.6</td>
<td>120.6</td>
<td>103</td>
<td>138.7</td>
<td>153.1</td>
<td>201.6</td>
<td>272.7</td>
</tr>
</tbody>
</table>

Table 7.2 shows the diversity of the US photovoltaic industry. Annual production is comprised of both the proven silicon technologies and the more recent thin film technologies. As a result of considerable R&D, the number of firms commercializing each generation of technology is large. Exciting new PV technologies continue to be developed in the US and more and more are receiving financing to begin production. Unfortunately, without a strong domestic market demand, firms are left to compete for market share in the German and Spanish PV market. State renewable initiatives, such as the RPS laws, may begin to provide a substantial domestic market for PV depending on the technology differentiation.
Table 7.2 Diversity of photovoltaic technology in the United States is reflected in the production and number of firms for each generation (Hirshman et al., 2008; Wesoff, 2008)

<table>
<thead>
<tr>
<th></th>
<th>First Generation</th>
<th>Second Generation</th>
<th>Third Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell production in 2007 (MW)</td>
<td>98</td>
<td>173</td>
<td>0</td>
</tr>
<tr>
<td>Number of firms in 2007</td>
<td>7</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

Sources:
PVPS National Reports, 2003-2007
Germany

Figure 7.4 Timeline of German photovoltaic commercialization policy (IEA, 2007a)

Research and Development

Germany began investigating photovoltaics and other sources of renewable energy in 1970, as shown in Figure 7.4. Since that time Germany has established itself as a leader in the promotion of renewable energy generation. The Federal Ministry of Education and Research (BMBF) is responsible for institutional funding of basic research at research centers while the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is specifically responsible for renewable energy R&D. From 1974 to 1992 the PV program had a heavy emphasis on R&D. There is still a strong focus on PV R&D, within the 5th Energy Research Program, as it receives the most R&D funding among the RET. Public funding for R&D over the last 35 years is shown in Figure 7.5 below.

To achieve the maximum effect and to accelerate market uptake, those projects that are undertaken through collaboration between industry and researchers are given special preference to receive both national and state research funds. There is also project funding
available specifically to fund research projects that focus on technologies that are close to market readiness. Research programs are constantly evaluated by industry and researchers.

In addition to university work, the Center for Sun Energy and Hydrogen Research Baden-Wuerttemberg and the Fraunhofer Institute for Solar Energy Systems (ISE) conduct cutting edge research. Research ranges from basic materials and optics research to more applied energy systems and energy technology research.

An incentive for private renewable energy R&D investment is available through a tax reduction for renewable energy R&D.

![German Photovoltaic R&D Expenditures](image)

**Figure 7.5 Research and development funding for photovoltaics in Germany (IEA, 2009)**

**Demonstration**

Germany has had little activity in the realm of demonstration projects. The Thousand Solar Rooftops program is an exception. From 1991-1994 the program gave a 50%-60% subsidy for the purchase and installation cost of a PV system. Participation in the program required a five-year monitoring and evaluation component.

**Deployment**

Germany’s presence in PV is primarily because of their successes in incremental innovation of photovoltaics driven by lessons from deployment. Germany is most well-known for their market stimulation strategy which began in 1990 with the establishment of
Stromeinspeisegesetz (StrEG) or the Electricity Feed in Law. StrEG required utilities to pay a fixed rate of 65% to 80% of the retail price for electricity generated by renewable energy sources. The law was in effect from 1991 to 2000. It provided the same tariff for all RETs so it did not stimulate PV installations because of PV’s comparatively higher costs.

From 1999 through 2003, the government ran a Hundred Thousand Rooftop program to stimulate 300 MW of investment in decentralized PV systems with an average size of 3 kWp. The program provided soft loans from the state bank, KfW, to the public. The loans effectively acted as a 40% direct subsidy. In 1999 the program was put on hold so the program only achieved 9MW of its 18MW goal for the year. The program was rather unsuccessful until the start of the EEG in 2000, which offered a 0.50 €/kWh FIT for a duration of 20 years. Unfortunately the combination of the EEG and the loan created extremely favorable conditions that caused a rush for PV installations forcing the program to be paused again in 2000.

The Renewable Energy Law (EEG) enacted in 2000 marks the beginning of the highly discussed market stimulation through a feed-in tariff. The law included a number of important details including: fixed payment for new installations; rate differentiation by technology, location, and size; a 20 year FIT lifetime; a technology specific degression rate; shallow grid connection costs for renewable energy developers; priority grid access; a utility purchase obligation; and an exemption from grid imbalance settlement payments. All of these features reduce the renewable energy developer’s risk and encourage investment in renewable energy. It is important to note that this policy is funded by all electricity consumers via the transmission grid operators.

The EEG was amended in 2004 and again in 2007. The amendments arising from the 2007 evaluation will be enacted in 2009. A major change to the tariff will be an increase in the tariff degression rates. Currently, the degression rate for roof top installations is 5% and
for ground level parks it is 6.5%. Under the new law the tariff for rooftop installations will be reduced annually by 8% from 2009 to 2010 and then by 9% annually from 2011 onwards. Ground level solar park rates will increase to 10% annually in 2009 and 2010.

Since the conclusion of the Hundred Thousand Rooftop program in June 2003, rooftop installation support has come from soft loans from KfW. The KfW provides loans through the Umwelt Program, the ERP Program, and the Solar Power Generation Program. The Umwelt Program provides 10 to 20 year, low-interest loans to private companies covering up to 75% of the investment costs. The ERP Program provides 75% of the financing for small and medium enterprises for 10 to 15 years. The ERP and Umwelt program funding can be combined by eligible parties. The Solar Power Generation Program or Solarstromerzeugen has provided soft loans for PV since January of 2005. It finances up to 100% of the project to a maximum of 50,000€ for PV investment.

Other funding for PV is also available. Federal states provided PV support to complement national deployment funds. The CO2 Building Rehabilitation Program, which began in 2000, also provides subsidies that can be used for PV installations.

Germany has targets for both the proportion of TPES generated by renewables and the amount of RES-E penetration. Their current goal is to achieve 4.2% of TPES with renewable sources by 2010. This percentage will increase to 10% by 2020. Specific to electricity supply, Germany plans to generate 12.5% of its electricity needs by 2010 and 20% of its electricity needs by 2020 with renewable energy. As Germany adapts to meet the goals of the EU 20-20-20 directive, this target will be increased to 25%-30% of electricity from renewable sources in 2020.

As a result of the feed-in tariff, Germany is currently the largest market in the world and has the largest installed capacity of 3635 MW in 2007, predominately in grid-connected, decentralized locations. The annual and cumulative installed capacity is shown in Figure 7.6.
The photovoltaic industry in Germany is strong. The EEG has undoubtedly created a stable investment climate facilitating 916 MW of cell production in 2007. Annual production is summarized in Table 7.3. Table 7.4 shows that most of this production is the conventional crystalline silicon cell, but an increasing number of firms are emerging to begin production of second generation, thin film technologies.
Table 7.3 Annual Production of major German companies (Prometheus Institute, 2007; Hirshman et al., 2008)

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<td>4.5</td>
<td>11</td>
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<td>Wurth Solar</td>
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<td>2.4</td>
<td>15</td>
<td></td>
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<tr>
<td>Other</td>
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<td>3</td>
<td>3.5</td>
<td>4</td>
<td>5</td>
<td></td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>13.3</strong></td>
<td><strong>25.7</strong></td>
<td><strong>58</strong></td>
<td><strong>125</strong></td>
<td><strong>209</strong></td>
<td><strong>362</strong></td>
<td><strong>535</strong></td>
<td><strong>915.6</strong></td>
</tr>
</tbody>
</table>

Table 7.4 Diversity of photovoltaic technology in Germany is reflected in the production and number of firms for each generation (Hirshman et al., 2008; Wesoff, 2008)

<table>
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<th></th>
<th>First Generation</th>
<th>Second Generation</th>
<th>Third Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell production in 2007</strong></td>
<td>821</td>
<td>95</td>
<td>0</td>
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<tr>
<td><strong>Number of firms in 2007</strong></td>
<td>10</td>
<td>19</td>
<td>1</td>
</tr>
</tbody>
</table>

**Firms in 2007**
- Heliatek

Sources:
- PVPS National Reports, 2000-2007
- Nobuyuki, 2006
Japan

Research and Development

The Japanese government takes three approaches to PV funding: technology development, demonstration and field tests, and promotion. A timeline of these key policies is shown in Figure 7.9. Depending on the stage of development the government will fund a prescribed fraction of the project. Basic R&D projects are eligible to receive 100% government funding. As the R&D becomes more applied and closer to supporting commercialization the public funding decreases to 66%, then to 50%, and finally to 33% (IEA, 2008b). This funding structure reflects the belief that the government should perform high-risk, long-term R&D and develop infrastructure for public use. The responsibility for applied R&D shifts to the private sector as the technology becomes less risky and the research more practical. The majority of the budget funds the demonstration and field test stage unlike other developed countries.

In 1974, in response to the oil crisis, the Ministry of Trade and Industry (MITI which is now METI- the Ministry of Economy, Trade, and Industry) began the Sunshine Project (1974-1993) to develop specific new and RETs, including PV. With respect to PV, it primarily focused on R&D, aiming to reduce the costs of PV by a factor of 100. Over the course of the program the budget for PV grew from 3 MUSD in 1974 to 53 MUSD in 1993 with a highpoint of 73 MUSD reached in 1985. The historical budget is shown in Figure 7.7. According to Watanabe (1995) this spending induced private sector spending of an additional $70 to $120 million per year. The New Energy and Industrial Technology Development Organization (NEDO) was established in 1980 to implement the Sunshine Project by developing and promoting RETs. NEDO receives 100% funding to carry out the R&D
efforts and distributes the projects between national institutes, universities, and the private sector.

Japanese (METI) Photovoltaic R&D Expenditures

![Chart showing Japanese (METI) Photovoltaic R&D Expenditures]

Figure 7.7 Research and development funding for photovoltaics in Japan through METI (IEA, 2009)

In 1993, the New Sunshine Program (FY1993-FY2000) continued to promote advancements in PV technology. This program shifted the focus on PV technology from R&D to demonstration. It set a target of installing 400 MW by 2000 and 5000 MW by 2010. Annual funding for PV under this program reached 113 MUSD by 2000 at the conclusion of the project. Over the course of the Sunshine Programs both cell efficiencies and system technologies improved.

From FY2001-FY2005 the first 5-Year Plan for Photovoltaic Power Generation Technology Research and Development was instituted. Its conclusion marked the start of the 4-Year Plan for Photovoltaic Power Generation Technology Research and Development (FY2006-FY2009), which was developed from the 2030 roadmap. Other recent support of energy R&D has come from the Third Science and Technology Basic Plan released in 2006 and the 2007 Basic Energy Plan. There remains a strong focus on PV as it receives the highest amount of funding amongst the RETs. (In 2006, PV was 64% of renewables R&D funding).

Research and development projects are reviewed every few years. In addition to a technical and time schedule review, there is a review of the necessity of government
participation and a review of the R&D operations structure which includes an evaluation of the leadership ability of the project leaders and of the cooperation between industry, academia, and the public sector. The market prospective of the project and the success in increasing the awareness of the public and stakeholders are also evaluated.

On its own initiative, the private sector organized PVTEC, the Photovoltaic Power Generation Technology Research Association to do collaborative work. The public sector attempts to engage the private sector in R&D by clearly setting the long-term direction of technology advances. Roadmaps like the *PV Roadmap Toward 2030* and a general energy technology roadmap for 2030 released in April 2007 are an example of this long-term planning. In 2004, Japan developed an R&D roadmap extending to 2030. The roadmap is to be reviewed regularly, with the first scheduled review in 2009. The PV specific roadmap is technology differentiated, outlines short-term and long-term goals, and aims to develop more market-driven R&D. The roadmap is designed to maintain a position of world leadership based on technology advances and cost reductions in cells, modules, BOS, and generated electricity. At the time the roadmap was produced, Japan was the PV production leader and the installed capacity leader. They have since fallen to China and Germany respectively. Japan could benefit from a long-term, transparent policy and funding roadmap to accompany the R&D/technical roadmap. The influence and success of the technical PV roadmap should be evaluated for its potential in the US.

R&D has been successful because “as the government plans and directs the long-term R&D scheme continuously and consistently, the talents from the private sector, universities and national institutes can be gathered to engage in their respective research and there has been a sufficient government budget (largest in the world) to cover the R&D projects, and projects are evaluated appropriately, and flexibly modified” (Virdis, Wene & Nilsson, 2003). Recognizing the diversity of technology needs, R&D has and will continue to focus on
reducing costs, stabilizing grids, and improving PV system performance. Below is a list of R&D done under each of the overarching energy R&D policies discussed above.

Under the Sunshine Programs (FY1974-FY2000)

Development of Technology for Practical Application of Photovoltaic Power Generation Systems
- 1974-1997
- 100% government funded
- Aims to improve manufacturing to lower costs and advance system technology

Development of a Low-energy Consumption Manufacturing Process for Solar Grade Silicon
- 1997-2000
- 66% government funded
- Reducing the cost of solar grade silicon raw material and ingots

Development of Practical Technology for High Efficiency Multi-crystalline Silicon Solar Cells
- 1999-2002
- 100% government funded

Development of Advanced Manufacturing Technology for Photovoltaic Power Generation Systems
- 2000-2004
- 50% government funded
- Transferring and improving manufacturing and mass production technology from NEDO to private sector

Under the first 5-Year Plan for Photovoltaic Power Generation Technology Research and Development (FY2001-FY2005)

Development of Advanced Solar Cells and Modules
- FY2001-FY2005
- Aimed to establish short-term basic technologies that would reduce PV power generation costs and more quickly commercialize developed technologies

Development of PV System Technology for Mass Deployment
- FY2001-FY2005
- Aimed to develop common infrastructure technologies to support large-scale PV deployment

Investigation for Innovative Photovoltaic Power Generation Technology
- FY2001-FY2005
- Aimed to improve the performance and lower the costs of PV power generation through new materials over the long-term

Development of Technology to Accelerate the Dissemination of Photovoltaic Power Generation Systems
• FY2001-FY2005
• Aimed at developing technologies for industries supporting PV cell and module production
• Followed by the PV Systems Advanced Practical Technology

Under the 4-Year Plan for Photovoltaic Power Generation Technology Research and Development began FY2006-FY2009 based on the 2030 roadmap

R&D for Next generation PV Systems
• FY2006-FY2009
• Aimed at creating basic technologies to meet 2030 roadmap goal- higher efficiencies, lower costs, improved durability

Development of PV Systems Technology for Mass Deployment, Phase II
• FY2006-FY2009
• Aimed at developing evaluation technologies for performance and reliability of cells/modules, manufacturing, disposal, and LCA

PV Systems Advanced Practical Technology
• FY2005-FY2007
• Advances industrial technology to accelerate practical application of R&D developments

Demonstration

The PV industry in Japan has experienced continued government funding and presence through the demonstration phases. Unlike other developed countries, the majority of Japan’s public funding is spent on demonstration projects and field tests. The installations from the demonstrations are significant, for example, the cumulative installed capacity from field tests FY1992-FY2007 is expected to be about 90 MW. However, the demonstration also serves to involve other stakeholders in the process and reduce risk.

Below is a description of different demonstration programs conducted by NEDO (PVPS National Reports, 2003-2007).

PV System Monitoring Program
• FY1994-FY1997
• 50% government funded
• Program expanded under the New Energy Law as the Subsidy Program for Residential Photovoltaic Power Generation Systems

Field Test Project on New PV Power Generation Systems for Industrial and other Applications
Field Test on New Photovoltaic Power Generation Technology
- FY2003-present
- 50% of the installation cost is subsidized
- Trials medium to large scale advanced technology installations at public and industrial sites to improve performance and decrease costs
- Private businesses, local authorities and organizations are eligible
- Subsidy recipients must collect performance data of the PV system for 4 years and demonstrate the performance of the PV system as part of the field test
- Originally only supported projects of 10 kW or more, but in FY2008 it will be extended to 4 kW or more for a new module type and 3 kW or smaller systems that have multiple connections, like what would be needed in collective housing

Demonstrative Project on Grid-Interconnection of Clustered Photovoltaic Power Generation Systems
- FY2002-FY2007
- Trials household, grid-connected PV systems with batteries to research large-scale and extensive introduction of PV to the grid

Demonstrative Project of Regional Power Grids with Various New Energies
- FY2003-FY2007
- Trials PV systems paired with other distributed generation technologies to study the issues surrounding electricity quality of distributed power sources

Verification of Grid Stabilization with Large-scale PV Power Generation Systems
- FY2006-present
- Demonstrative research to establish a system for stabilizing the output from MW-scale PV systems while maintain the grid’s electricity quality

Development of an Electric Energy Storage System for Grid-Connection with New Energy Resources
- FY2005-FY2010
- Developmental research on electricity storage technologies

International Cooperative Demonstration Projects for Stabilized and Advanced Grid-connection PV Systems
- Demonstrative research of micro-grids with large capacities of PV systems
- Collaboration with China, Thailand, Vietnam, Nepal, Mongolia, Myanmar, Cambodia, Laos, Malaysia

International Cooperative Demonstration Projects Utilizing Photovoltaic Power Generation Systems
- FY2006-present
- Improving the reliability of PV systems
- Collaboration with China, Thailand, Indonesia, Malaysia
Deployment

In 2007, the Revised Basic Energy Plan was released which specified the expansion of RETs as a priority. Photovoltaics are viewed as a viable energy source in the present and a key long-term solution to energy supply. Japan is aware of the need for a full portfolio of policies and accordingly broken down government support measures into six different categories.

1. Support for basic technological development
2. Creating initial demand
3. Technology introduction by the public sector
4. Support for market expansion
5. Creating a supporting-industry structure
6. Building awareness

An extensive portfolio of market stimulation policies are employed simultaneously including RPS, net billing, tax incentives, Green Power Funds, low-interest loans, and subsidies by the national and regional governments.

There are many targets for renewable energy deployment in Japan. In 1997, the Law Concerning Special Measures to Promote the Use of New Energy, also called the New Energy Law, set a target of 3.1% renewable energy contribution to total primary energy supply by 2010 (excluding hydroelectric and geothermal). The Special Measures Law on Promoting Use of New Energy by Electric Enterprises, also called the RPS Law, sets a target of 1.35% of electricity by 2010. The Law Concerning Promotion of the Development and Introduction of Alternative Energy sets a PV specific target of 5000 MW or 12200 Gwh by 2010, which has been extended to 16000 Gwh by 2014 or 1.63% of electricity sales.

Utilities are active in offering their own incentives to meet the RPS. Net metering has been available to buy back household surplus electricity over a contract period of 15 to 17 years since 1992. Since 2000, utilities have also participated in a Green Power Fund to develop renewable energy projects. By the end of 2006, 15 MW of photovoltaic modules were installed through voluntary contributions under the program.
Generation of renewable electricity also generates "unbundled" renewable energy credits. Details of the law allow banking and borrowing of these credits. To balance the cost disadvantage that PV has compared to other renewable sources, METI allows the double counting of electricity generated from PV. In other words, when a PV system generates 1 kWh of electricity it is treated as if it had generated 2 kWh.

Financial incentives include a property tax reduction offered by the national government to corporations or individuals who install a PV system and low-interest loans for PV projects offered by commercial banks.

Regional governments are also involved in PV promotion. Three hundred forty-four local governments have support programs including investment subsidies, production subsidies, and preferential loan programs. In addition to subsidies offered by regional governments, subsidies and other promotional programs are hosted by a number of Japanese ministries. These are listed below.

By METI

Subsidy Program for Residential Photovoltaic Power Generation Systems
- FY1997-FY2005
- Aimed to create a self-sustaining PV market through subsidies to residential PV installations
- Paid 33-48% of installation and purchasing costs
- Results – in 2005 when program ended it was responsible for 932 MW of the 1421 installed (65.5%)

Local Introduction of New Energy Promotion Project
- FY1997- present
- 50% government funding originally and now can be between 50% and 33% (in 2006)
- Promote the use of photovoltaic systems in regional governments and nonprofit organizations
- For a minimum of four years after the system becomes fully operational the utilization status of the system is recorded
- About 25 MW will be installed between FY2008 and FY2010

Project for Supporting New Energy Operators
- FY1998-present
- Originally a maximum of 50% subsidy and guaranteed debt
- Since 2007, a 1/3 subsidy and 90% guaranteed debt
• Aims to accelerate the private businesses that launch the introduction of new energy—
most installations have occurred at factories
• Between FY 1998 and FY2006 986 MW of PV have been approved

By MoE
Solar Promotion Program
• FY 2006 – present
• A variety of projects that promote the introduction of PV

Community Model Project of a Virtuous Circle for Environment and Economy
• FY2004- present
• City planning efforts which include introduction of PV systems

By MILT
Guidelines for Planning Environmentally-friendly Government Buildings

By MEXT
Eco-school Promotion Pilot Model Project
• FY1997- present
• Subsidy for planning investigations
• Subsidy covering half the cost of new construction of the school and one third of the cost for rebuilding or retrofitting
• Ministry of Agriculture, Forestry, and Fisheries (MAFF) joined in FY 2002
• MoE joined in FY 2005

Other promotional activities include Cool Earth 50, which began in 2008 and provides an energy technology innovation plan leading up to 2050. The plan identified PV technology as a priority technology for meeting greenhouse gas emission reductions and set a goal of 40% conversion efficiency by 2050. PV is also promoted under the Kyoto Protocol Target Achievement Plan established in 2005. METI has also established a new energy planning office made up of several working groups. The goal of the office is to study new ways to promote PV systems to give new energy to the Japanese PV market. There are also an increasing number of financial institutions that are financing environmental activities and providing preferential, low-interest rate loans to install a PV system or on homes that have PV systems.

The combination of market stimulation policies, especially the residential subsidy, established a grid-connected, decentralized installation niche market. In 2007, 1919 MW
were installed of which 85.8% were residential, grid-connected, distributed PV systems. The annual and cumulative installations are shown in Figure 7.8. Residential subsidies have been very successful for developing a PV market for a number of reasons. First, as private companies increased production they gained economies of scale, which led to PV system price decreases. The subsidy offered each year was decreased to maintain equality with already high grid electricity prices in Japan, creating an instantly viable market. The focus on standardized systems made it easier for suppliers and consumers to make transactions. What resulted from the sustained and balanced promotion program is a comprehensive industry chain and standardized, familiar technology for residential installations. These programs have also increased public awareness leading to further interest and further opportunities. For example, programs to buyback surplus power and policies like the Building Standards Law, which acknowledged PV cells as architectural materials, led to more installations by housing manufacturers. Installations are now common on private houses, prefabricated houses, collective housing, apartment houses, public, industrial, and commercial facilities and buildings.
Currently Japan falls behind Germany in terms of cumulative installed capacity and behind China in terms of annual production. However, Japan was once the leader in terms of both installed capacity and production. Unfortunately, the residential subsidy may have been removed too quickly. In 2006, after the end of the Residential PV System Dissemination Program, the annual PV market growth stagnated. Regional government subsidies and major developers who now employ PV systems in pre-fabricated homes are responsible for a large portion of the installations since the national subsidy scheme ended. Major capacity installations now are from the Field Test Project on New Photovoltaic Power Generation, the Project for Supporting New Energy Operators, the Verification of Grid Stabilization with Large-Scale PV Power Generation System, and the Utility RPS and Green Power Funds. In 2007 for the first time the annual installed capacity in Japan decreased. The decrease in annual demand may be an artifact of the dried up domestic demand from the conclusion of the subsidy or other external factors. Installation decreases may be due to production
decreases attributed to a shortage of silicon or a result of more exports to strong German and Spanish markets. It is unclear whether European demand held the Japanese industry up in 2007 or if the foreign markets out competed the domestic markets. Regardless of the cause, the Japanese government is reinstating the subsidy in 2009.

Industry Development

The geographical and cultural elements coupled with strong policy contributed to a strong PV industry. With high energy prices and few natural resources, Japan did not need an exorbitant subsidy to match the cost of grid-electricity. Japan has a history of industrial innovation and government-corporation cooperation (Bonvillian, 2009b). Through the Japanese PV roadmap they targeted the already successful electronics industry and focused on ways to improve manufacturing. Manufacturing decisions by Japanese firms was highly influenced by the demand-side policies (Rogol, 2007). The market stimulation policies made investment in more manufacturing capacity economic and so drove supply-side scale up which led to reductions in the price of the technology, which then stimulated increased demand. Despite the per watt subsidy decreasing, installations continued because the production cost was dropping (Rogol, 2007). The stability of the market support measures was critical because manufacturers made their investment decisions based on the belief that the subsidy would remain in place. Without this stability, investments would not have been made and prices would not have dropped (Rogol, 2007).

At the conclusion of the subsidy, Japan used its experience as an island nation to generate wealth through export. The Japanese PV industry continued despite lack of strong market support, and in 2007, 932 MW of photovoltaic cells were produced. More detailed information about annual production by Japanese firms is shown in Table 7.5.
Table 7.5 Annual production of major Japanese companies (Prometheus Institute, 2007; Hirshman et al., 2008)

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<td>Mitsubishi</td>
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<td>125</td>
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<tr>
<td>Sharp</td>
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<td>75</td>
<td>123.1</td>
<td>197.9</td>
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<td>1.5</td>
<td>1.5</td>
<td>2.5</td>
<td>5</td>
<td>5.5</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>128.6</strong></td>
<td><strong>171.2</strong></td>
<td><strong>251.1</strong></td>
<td><strong>363.9</strong></td>
<td><strong>601.5</strong></td>
<td><strong>833</strong></td>
<td><strong>927.5</strong></td>
<td><strong>932</strong></td>
</tr>
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</table>

Japan has a number of firms in the PV industry as shown in Table 7.6 but is clearly dominated by a few large corporations. Most cell manufacturers produce c-Si, but there are an increasing number of a-Si manufacturers. Some of the large crystalline silicon manufacturers are expanding their business to include thin film technology. The commercial production of CIS began in 2007. There is no production of CdTe modules; they are banned by law because of fears of toxicity. In addition to cell and module manufacturers, there are several silicon feedstock producers, several Si-ingot and wafer producers, and inverter manufacturers. There has also been dramatic growth in the number of PV integrators.
Table 7.6 Diversity of photovoltaic technology in Japan is reflected in the production and number of firms for each generation (Hirshman et al., 2008; Wesoff, 2008)

<table>
<thead>
<tr>
<th></th>
<th>First Generation</th>
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<tr>
<td>Cell production in 2007</td>
<td>835</td>
<td>97</td>
<td>0</td>
</tr>
<tr>
<td>Number of firms in 2007</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Firms in 2007</td>
<td>Clean Venture</td>
<td>Honda Motor,</td>
<td>Aisian Seiki,</td>
</tr>
<tr>
<td></td>
<td>21, KIS, Kyocera,</td>
<td>Fuji Electric,</td>
<td>Sony</td>
</tr>
<tr>
<td></td>
<td>Mitsubishi</td>
<td>Kaneka, Mitsubishi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electric, Sanyo,</td>
<td>Heavy, Showa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sharp</td>
<td>Shell</td>
<td></td>
</tr>
</tbody>
</table>

Sources:
Energy Policies of Japan 2008, IEA
PVPS National Reports, 2003-2007
NEDO, 2004
Kurokawa & Ikki, 2001
Watanabe, Wakabayashi et al. 2000
PV Upscale, 2006
Figure 7.9 Timeline of photovoltaic commercialization policy in Japan (IEA, 2008b)
8 Appendices

Policy Details

Government intervention has proved to be necessary to commercialize RET because of common market failures. Government sponsored research and development to overcome the private sector’s underinvestment in R&D creates technology improvements and reductions in cost. Demonstration projects can contribute to product development by building a customer base and providing some experience with the technology, market, and regulations. Market stimulation creates niches in which a product can improve from customer feedback and cost reductions through learning and economies of scale from which a self-sustaining part of the economy can be created.

Research and Development

Research and development as a whole is intended to develop technology and lower costs. It is well established that an R&D portfolio is necessary to provide an adequate technology-push. The portfolio should have a balanced set of projects addressing short, medium, and long-term technologies. For example, with respect to PV, R&D should be performed on many potential materials and device structures. Complementary technologies like the balance of systems in PV systems and enabling technologies like grids and storage should be included in the portfolio. Different PV systems are in different phases of development and will likely serve different markets, but they should all have stable R&D funding so that new options continue to move through the pipeline.

A more progressive supply-push policy is an R&D partnership. Partnerships involving government, industry, universities, and international players are becoming widely used (Gallagher, 2006). The government-industry partnership has been successful in both wind and solar technologies because the government takes on some of the risk and cost
involved in funding a public good, and industry is around to steer the direction of the work. The spread risk and spread cost allows firms to undertake R&D that is riskier or peripheral, to capture knowledge spillovers, and often to maintain intellectual property rights. Government interest in a technology often sends a signal to industry management and financiers that the technology is worth further investment.

**Demonstration**

In technology transformation it is clearly the function of R&D to create and develop a technology. Equally obvious is the role of demand-pull in market development. The critical failure in this transformation is often product development. The technology and the market may exist, but without successfully molding a product around that technology and aligning it with the market there is still a failure to commercialize. Failure to develop a product by demonstrating the role of RETs in the future energy system will “send the wrong signal to governments and private investors and will have the potential to inhibit future investment in RETs (RETD, 2006).” Therefore, in addition to R&D and market incentives, governments are increasingly turning to demonstration projects. The demonstration phase is an excellent learning experience for industry because it allows feedback from customers, engineers, and installers that can be integrated into product design. Small changes and details to tailor the technology to the market reinforce the product development. The technology may also be improved or become cheaper through learning.

For investors, the demonstration phase can be an excellent way to reduce risk. The chance to observe the technology performing will increase the information they have as to the technology’s shortcomings and successes. Their perceived technology risk will be reduced. Their perceived market risk will also be reduced because demonstration will provide an opportunity to verify the niche market. To some extent demonstration may also reduce the regulatory risk. Although demonstration cannot change poor policies or guarantee that
policies will not change in the future, it can confirm which policies are working smoothly and where problems could arise in future projects.

**Market Stimulation Incentives**

In the case of PV, where high costs prevent a spontaneous market, there are many market stimulation policies to choose from. Direct incentives increase the number of units of a RET that are purchased. A *procurement* policy requires the government to purchase a predetermined number of units. Procurement creates an instant market that can influence the entire commercialization chain (Virdis, Wene & Nilsson 2003). It is designed to reduce the cost by forcing the technology down the learning curve (Gruebler, Nakicenovic, & Victor, 1999). Other regulations that force adoption of a technology are obligations imposed by the government on other parties. A *building standard* requires new buildings of a certain size or type to install a certain amount of RET. Obligations are also created through *renewable portfolio standards*, which require utilities to supply a predefined portion of electricity from renewable energy. Renewable portfolio standards typically apply generically to the breadth of RETs. In some cases, however, special carve outs, which are technology specific, set different goals for different RETs.

Indirect incentives increase the attractiveness of purchasing a RET by reducing the cost to the consumer. Typically, *tax credits* or cash *subsidies* are granted. The tax credit subsidy has the drawback of requiring a consumer with a large enough tax appetite to benefit from the subsidy. Either of these policies can be capacity-based or production-based. A capacity-based incentive is determined based on the upfront capital costs of the RET and is either a fixed amount or a percentage, often with a cap. A performance-based incentive on the other hand provides a fixed return on every kWh produced by the technology. A more specific type of performance-based subsidy is called a *feed-in tariff*. A *feed-in tariff*
guarantees the generator of specific types of technology a fixed return for each kWh fed into the grid. The *feed-in premium*, a derivative of the feed-in tariff, provides a fixed return on the electricity fed into the grid in addition to the market price of electricity. Feed-in laws are established by the government and carry an obligation for transmission and distribution operators to connect renewable energy generators to the grid. *Net metering* and *net billing or buy back* programs are similar. In net metering there is only one meter. During generation the meter spins backwards. At the end of the billing period the difference between consumption and production is paid to the utility at the regular residential rate. In net billing the price of the electricity consumed and produced are different. Net billing is a voluntary purchase agreement where utilities agree to purchase surplus electricity at the selling price of electricity nationwide. In a buy back scenario a utility agrees to purchase all of the generation at a fixed rate and they will also assume ownership of the Renewable Energy Credits (RECs) generated. RECs are a virtual commodity that is created for each kWh of generation. RECs may be bought and sold to meet renewable portfolio standards and provide an additional stream of funding.

Placing a price on carbon is another indirect incentive for RETs. Carbon pricing policies benefit RETs by increasing the cost of the competitor’s technology. The carbon price can be applied through a *carbon tax* or a *carbon cap and trade program*. A carbon tax is a fixed fee set by law that must be paid for each increment of emission of carbon dioxide. A cap and trade program sets a cap on the total quantity of emissions allowed in a given period of time for a given region. A permit to emit an increment of carbon dioxide must be surrendered at the end of each year for the total amount of emissions released that year. These permits are then bought and sold throughout the year as firms choose whether to purchase permits or to reduce their emissions. Both the carbon tax and the cap and trade program seek to equilibrate the marginal abatement cost.
In addition to regulatory measures, RET can be stimulated by voluntary measures. The most common of such voluntary measures is green power marketing. Utilities offer green power marketing to customers who can enroll to pay a premium on all of their electricity and in return the utility will invest in more renewable energy generation (Bird & Sweezy, 2005).

The are other tax measures such as accelerated depreciation, value added tax reductions, reductions on import duty, property tax exemptions, and tax holidays employed to support RETs.

Investment into RET can also be stimulated by reducing non-economic barriers. Those barriers include interconnection rules, siting, licensing, and permitting laws, and a variety of other potential penalties (Margolis & Zuboy, 2006). The private sector is more willing to invest if the market and regulations are clear. Information sharing can also be helpful to stimulate adoption of RET. In many cases adopters are unsure of the technological performance. If the technical performance is more certain then project financiers can more easily calculate the financial structure to guarantee a return. There are many other financial tools that can be used to make investment in RET more widely available (Haas et al., 2003; IEA, 2004).

Amidst the debates over which policies are best, the bottom line is that the details of the policy are paramount and in many cases several policies must work simultaneously to be successful. Experience with different policies and different policy combinations have revealed best practice structures for market creation policies and general qualities of policies that are crucial (de Jager & Rathmann, 2008 ch. 3).

Risk reduction is best achieved through policies that are long-term, stable (Loiter & Norbergh-Bohm, 1999), transparent (Loiter & Norbergh-Bohm, 1999), and technology-specific (Watson, 2008). "A clear, long-term vision is needed that can underpin investor confidence to
further invest in innovative technologies (IEA, 2008a pp. 127).” Stability is required to minimize the risk in investing money into a project. If there is doubt as to whether the policy will be in effect in the future firms may drag their heels hoping the policy will change. On the other hand, if the policy is perceived to be stable it may be easier to get capital from lending parties. Transparency is how closely the policy reflects the interests of the governing authority. If a particular policy directly affects the target in an unambiguous way, firms can predict future standards and take aggressive steps now rather than waiting. Policies that are not transparent may cause firms to take actions that do not achieve the environmental goals. Technology-specificity allows the entire portfolio of RETs under development to be influenced by the market. Without technology-specificity the technology closest to commercialization is the only one stimulated.

The importance of the market is to exert a pull earlier in the commercialization chain that acts as a stimulus to researchers, investors, and industry to innovate to capture some of the market. A potentially lucrative market encourages researchers to innovate to develop a low cost technology that will return higher profits. A current example is the surge in development and success of thin film PV technologies. These thin film technologies are significantly less expensive to produce and yet they are still eligible for the feed-in tariff that was designed to support the more expensive silicon cells. Incremental innovations are commonly discovered as the technology is tested as a product. The market also provides learning opportunities and a chance to achieve economies of scale in production and installation as shown in. Cost reductions through economies of scale clearly require product production. A market is a rational reason for industry and investors to spend the money required to start large-scale production. A market that supports the technology at its present cost can unlock the potential to drive down future costs. The assumptions that must be met to
price below current costs may not be met with RETs because of the amount of competition and non-appropriability of the technology (Spence, 1979).
Model Documentation

Abandonment Rate \([\text{company, featuretype}]\) = 0
Units: Features/Month
Rate at which feature ideas are abandoned

Abandonment Rate 1 \([\text{company, featuretype}]\) = Feature Devl Rate 1 \([\text{company, featuretype}]\) * Feature Abandonment Fraction 1 \([\text{company, featuretype}]\)
Units: Features/Month
Rate at which feature ideas are abandoned in 1st stage of product development

Abandonment Rate 2 \([\text{company, featuretype}]\) = Feature Devl Rate 2 \([\text{company, featuretype}]\) * Feature Abandonment Fraction 2 \([\text{company, featuretype}]\)
Units: Features/Month
Rate at which feature ideas are abandoned in 2nd stage of product development

Abandonment Rate 3 \([\text{company, featuretype}]\) = Feature Devl Rate 3 \([\text{company, featuretype}]\) * Feature Abandonment Fraction 3 \([\text{company, featuretype}]\)
Units: Features/Month
Rate at which feature ideas are abandoned in 3rd stage of product development

Accounts Receivable = INTEG (Billing-Cash Received From Customers-Defaults on AR,0)
Units: Dollars
Revenue waiting to be received in cash

Additional Increment of Adopters = ((Purchasers-Dummy Purchasers)/TIME STEP) * Increase Adopters Switch
Units: Prospects/Month
The additional number of adopters induced from direct market stimulation policy

Adjustment for Eng Vacancies = (Desired Eng Vacancies - Eng Vacancies)/Eng Vacancy Adjustment Time
Units: Persons/Month
Adjusts eng vacancy creation to have the desired number of vacancies.

Adjustment for Engineers = (Indicated Desired Engineers-Engineers)/Engineers Adjustment Time
Units: Persons/Month
Adjusts the desired hiring rate of engineers to bring the number employed to the desired level.

Adjustment for FUD \([\text{company, featuretype}]\) = (Desired FUD \([\text{company, featuretype}]\) - Product Features Under Development \([\text{company, featuretype}]\))/FUD Adjustment Time \([\text{company, featuretype}]\)
Units: Features/Month
How many features per month we need to add (or subtract) from FUD

Adjustment for Sales Force = (Indicated Desired Sales Force-Sales Force)/Sales Force Adjustment Time
Units: Persons/Month
Adjusts the desired hiring rate of sales people to bring the number employed to the desired level.

Adjustment for Sales Vacancies = (Desired Sales Vacancies - Sales Vacancies)/Sales Vacancy Adjustment Time
Units: Persons/Month
Adjusts sales vacancy creation to have the desired number of vacancies.

Adjustment for Technology Under Development \([\text{company}]\) = (Desired Technology Under Development \([\text{company}]\) - Technology Features Under Development \([\text{company}]\))/Technology Under Development Adjustment Time \([\text{company}]\)
Units: Features/Month
How many features per month we need to add (or subtract) from TFUD
Adopter Increase Ramp Time = 3
Units: Months
Time it takes for policy to take full effect

Adopter Increase Start Time = 0
Units: Months
Time at which policy starts having an effect

Adopter Loss Fraction = Normal Adopter Loss Fraction * Effect of Customer Support on Adopter Loss Fraction
(Normalized Cust Support) * Effect of Features on Adopter Loss Fraction (Normalized Features) * Effect of Technology on Adopter Loss Fraction (Normalized Technology)
Units: 1/Months
What fraction of adopters we lose every month

Adopter loss rate = Adopters * Adopter Loss Fraction
Units: Prospects/Month
Rate at which adopters stop using the product

Adopters = INTEG (+Adoption Rate - Adopter loss rate, Initial Adopters)
Units: Prospects
Prospects who are now using the product

Adoption Capab Increase Ramp Time = 3
Units: Months
Time it takes for policy to take full effect

Adoption Capab Increase Start Time = 0
Units: Months
Time at which policy starts having an effect

Adoption Productivity Of Sales Effort = MIN(Max Adoption Productivity From Sales, Sales Experience
Productivity Multiplier * Max Adoption Productivity From Sales * Effect Of Customer Support On
Adoption Efficiency * Effect Of Features On Adoption Efficiency * Effect Of Technology On Adoption
Efficiency)
Units: Prospects/(Person*Hour)
The decision rate of sales effort as effected by price, features, cust support (for trials), and word-of-
mouth

Adoption Rate = IF THEN ELSE(Norm Adoption Rate > 0, Norm Adoption Rate * Prospect Conversion Fn
(ZIDZ(Potential Adoption From Sales Effort, Norm Adoption Rate)), 0)
Units: Prospects/Month
The rate at which purchasers start to use the product

Adoption Sales Effort = Fraction effort for adoption * Sales Effort
Units: Persons*Hours/Month
Total number of hours spent by the sales force on decisions per month

Allow Layoffs = 1
Units: Dmnl
Whether or not to allow layoffs to occur (0=no, 1=yes)

Annual Cash Flow from Private Investment = SAMPLE IF TRUE(Reset Switch = 1, Annual Cash Flow from
Private Investment Stock, Cash Flow from Private Investment * Reset Interval)
Units: $
Annual cash from private sector plotted to scale

Annual Cash Flow from Private Investment Stock = INTEG (Cash Flow from Private Investment - Reset Annual
Cash Flow from Private Investment, 0)
Units: $
Annual private investment accumulates revenue inflows from the beginning to the end of a year.
Annual Cash Flow from Public RD Funding = \( \text{INTEG} \) (Cash Flow from RD Funding - Reset Annual Cash Flow from RD Funding, 0)
Units: $
Annual public R&D funding accumulates revenue inflows from the beginning to the end of a year.

Annual Cash Flow from RD for Display = SAMPLE IF TRUE (Reset Switch = 1, Annual Cash Flow from Public RD Funding, Cash Flow from RD Funding * Reset Interval)
Units: $
Annual public R&D funding accumulates revenue inflows from the beginning to the end of a year.

Annual Discount Rate = 0.02
Units: Dimensionless
Discounting the value of money over time

Annual Total Cash Flow from Public Funding = SAMPLE IF TRUE (Reset Switch = 1, Annual Total Cash Flow from Public Funding Stock, Total Cash Flow from Public Funding * Reset Interval)
Units: $
Annual cash from public plotted to scale

Annual Total Cash Flow from Public Funding Stock = \( \text{INTEG} \) (Total Cash Flow from Public Funding - Reset Annual Total Cash Flow from Public Funding, 0)
Units: $
Annual public funding accumulates revenue inflows from the beginning to the end of a year.

Appropriable Feature Development Fraction = 1 - Nonappropriable Feature Development Fraction
Units: Dimensionless
Fraction of development effort applied to approbriable features

Available Private Investor Financing = IF THEN ELSE (Indicated Private Investment Win Fraction > 1, Minimum Private Investor Financing * Indicated Private Investment Win Fraction, 0)
Units: Dollars
The highest amount of funding the investors will provide considering the size of the market and the competitiveness of the technology (cost and functionality)

Average Layoff Time = 2
Units: Months
The average time required to lay off an engineer

Avg Engineer Experience = ZIDZ (Engineer Experience, Engineers)
Units: Hours
How many hours of experience the avg engineer has

Avg Experience Of New Eng Hires = 2000
Units: Hours \([0,10000,35]\)
Average relevant experience of new engineering hires

Avg Experience Of New Sales Hires = 1000
Units: Hours
Average relevant experience of new sales hires

Avg Feature Devl Time[company, featuretype] = 2, 12; 4, 24;
Units: Months \([0,50]\)
How long, on average, does it take to develop a feature, regardless of how many engineers are working on it

Avg Feature Lifetime[company, featuretype] = 10000
Units: Months \([0,10000]\)
Avg amount of time a feature is useful for
Avg Hot Prospect Lifetime=4
Units: Months [1,?] 
Minimum amount of time it takes to persuade a prospect to trial the product

Avg Potential Prospect Lifetime=6
Units: Months [1,?] 
Average amount of time it takes for a potential prospect to become aware of product and become a prospect

Avg Prospect Lifetime=1
Units: Months [1,?] 
Average amount of time it takes to persuade a prospect to seriously consider purchasing

Avg Purchaser Lifetime=1
Units: Months [1,?] 
Minimum amount of time it takes to persuade a purchaser to start using product

Avg Receivable Delay=1.5
Units: Months [0.1,12,0.1] 
How long it takes on average to get paid

Avg Salary=17000
Units: Dollars/(Person*Month) 
Average loaded salary across all employees (includes office and admin costs)

Avg Sales Experience=ZIDZ(Sales Experience, Sales Force)
Units: Hours 
Avg hours of experience of sales force

Avg Technology Devl Time[company]=6, 12
Units: Months [0,20] 
How long, on average, does it take to develop a technology regardless of how many engineers are working on it

Avg Technology Lifetime[company]=10000
Units: Months 
Avg amount of time a technology is useful for

Avg Time to Fill Eng Vacancies=2.5
Units: Months 
The average time required to fill an engineering vacancy

Avg Time to Fill Sales Vacancies=2.5
Units: Months 
The average time required to fill a sales vacancy

Bankrupt Switch= IF THEN ELSE(Working Capital<=0, 1, 0) 
Units: Dmnl
If cash goes to 0 (or less!), then company is bankrupt

Begin Counter=Total Population*Increase In Addressable Market*Fraction Of Firms Capable Of Adopting
Units: Prospects/Month 
Tracks increase in size of potential market by fraction of total firms that we are able to address that are capable of adopting product per time period if there is no increase in adopters policy: All shadows in this stock and flow chain are set up to determine the number of adopters in the absence of a direct market incentive to determine the cost of the policy

Billing=Quantity Per Purchase*Adoption Rate*Initial Payment+Maintenance Billing
Units: Dollars/Month 
Amount of money customers obligated to pay
Burn Rate = IF THEN ELSE(Cash Flow From Operations < 0, -Cash Flow From Operations, 1e-007)
   Units: Dollars/Month
   If cash flow is negative, burn rate is simply the inverse, otherwise we're not burning money, but set the
   burn rate to very low number so as not to divide by 0.

Carbon Policy Effect on Comp Cost = 0.3
   Units: Dimensionless [0,1,0.01]
   What fraction initial competitor cost will change based on carbon policy (0.1 = 10% increase, 1 =
   double, -1 means it goes to 0)

Carbon Policy Ramp Time = 10
   Units: Months
   Time it takes for carbon policy to take full effect

Carbon Policy Start Time = 0
   Units: Months
   Time at which carbon policy starts having an effect

Carbon Policy Switch = 0
   Units: Dimensionless [0,1,1]
   Whether's there's a carbon policy or not that will effect competitor's prices

Cash Flow From Operations = Cash Received From Customers - Outflows Of Capital
   Units: Dollars/Month
   The amount of cash left over after salaries and COGS are paid

Cash Flow from Private Investment = Funds Raised From Private Investors
   Units: Dollars/Month
   Private Investment as inflow to annual revenue accumulator.

Cash Flow from RD Funding = Public RD Investment
   Units: Dollars/Month
   Revenue as inflow to annual revenue accumulator.

Cash for Firm Operations = INTEG (Inflows Of Capital - Outflows Of Capital, 0)
   Units: Dollars
   Amount of money venture has available to spend. Increased by investments and revenue, and decreased
   by spending on salaries and COGS.

Cash Received From Customers = Accounts Receivable / Avg Receivable Delay
   Units: Dollars/Month
   Amount of cash coming in from customers

Cash Restricted for Technology Development = INTEG (Inflow of Technology Development Funding - Outflow
   of Technology Development Funding, 0)
   Units: Dollars
   Cash that because of government restrictions may only be used to fund technology development

Change in Burn Rate Required = IF THEN ELSE(Months of Runway > Min Runway In Order To Hire, Months of
   Runway / Min Runway In Order To Hire, IF THEN ELSE( Months of Runway < Min Runway, Months
   of Runway / (Min Runway + 1), 1))
   Units: Dmnl
   If we have more than enough months of capital to bum, we can adjust the bum up, but if we have less
   than the min runway months of capital, we must adjust the bum down, otherwise don't adjust the bum

Change in Salary Required = Burn Rate * (Change in Burn Rate Required - 1)
   Units: Dollars/Month
   How much to adjust salary payments to make the required adjustment in burn rate
Change in Workforce Required = Change in Salary Required / Avg Salary
Units: People
How many people do we need to lay off to change salary payments by the required amount

COGS = Product COGS + Maintenance COGS
Units: Dollars/Month
Total cost of goods sold

Units: Dimensionless
If there's a carbon policy, then effect on competitors cost will ramp up to its full effect starting at start time and taking the amount of time specified by ramp time.

Competitor Margin = Max Competitor Margin - Competitor Margin Adjustment Fn(Delay3i(Normalized Price, Competitor Margin Adjust Time, 1)) * (Max Competitor Margin - Min Competitor Margin)
Units: Dimensionless
Competitor will charge their max margin unless our price is below theirs in which case the Competitor Margin Adjustment Fn will determine how far to move towards the min margin they could charge

Competitor Margin Adjust Time = 3
Units: Months [0.1, 36, 0.1]
How long it takes for competitor to adjust their margin in response to venture's change in price

Competitor Margin Adjustment Fn = [(0.5, 0) - (1, 1), (0, 1), (0.5, 1), (0.620795, 0.907895), (0.69419, 0.754386), (0.75, 0.5), (0.799694, 0.232456), (0.874618, 0.109649), (1, 0), (1000, 0)]
Units: Dimensionless
Input is ratio between price and competitor's price and output is how much to adjust competitor's margin. If ratio >= 1, then no need to adjust at all, and if ratio <= 0.5 (competitor is charging twice as much) then adjust the maximum amount, and s-shaped curve in between

Competitor Price = (Initial Competitor Cost Per Unit * Competitor Cost Adjustment Fraction Due To Policy) / (1 - Competitor Margin)
Units: Dollars/Unit
How much competitor charges (reference price)

Constrained Eng Hiring Rate = Desired Eng Hiring Rate
Units: People/Month
If we want to hire more people than we could afford, then if we don't want to hire anyone else, we can hire the maximum allowed number of engineers, otherwise we hire the proportional number we're allowed

Constrained Sales Hiring Rate = Desired Sales Hiring Rate
Units: People/Month
If we want to hire more people than we could afford, then if we don't want to hire anyone else, we can hire the maximum allowed number of sales people, otherwise we hire the proportional number we're allowed

Contact Rate = 0.25
Units: 1/Month
Rate of contact between adopters and potential prospects (relatively high)

Cost Per Unit = (Initial Cost Per Unit * ((Cumulative Purchases / Reference Production for Initial Cost)^((LN(1 - Decrease in Costs per Double Purchases) / LN(2))) * (ZIDZ(Cumulative Technology Development, Reference Technology Development for Initial Cost)^((LN(1 - Decrease in Costs per Double Technology Development) / LN(2))))))
Units: Dollars/Unit
Cost to manufacture/produce/provide product to purchasers
Cost Share Amount = \(\frac{\text{Indicated Cost Share Amount}}{\text{TIME STEP}} \times \text{PULSE TRAIN}(0,0,\text{Funding Frequency}, \text{FINAL TIME})\) 
Units: Dollars/Month 
The amount of cost shared public funds instantaneously pulsed in

Cost Share Switch = 0 
Units: Dimensionless [0,1,1] 
When switch is on firm recieves money for cost sharing development and demonstration.

Cum Prob of Failure Based on Hazard Rate = \(\text{INTEG} (\text{Hazard Rate Incr},0)\) 
Units: Dimensionless 
The cumulative probability of the investors or entrepreneurs giving up on the venture based on the accumulation over time of a hazard rate of failure

Cumulative Profit = \(\text{INTEG} (\text{Net Income},0)\) 
Units: $ 
The total profit a firm accumulates

Cumulative Purchases = \(\text{INTEG} (\text{Purchase Rate},1)\) 
Units: Prospects 
Total number of purchases made (regardless of how purchases used)

Cumulative Technology Development = \(\text{Technology Development}[\text{self}]\) 
Units: Features 
Total technology development over time

Cumulative Ticks = \(\text{INTEG} (\text{Ticks} - \text{Reset ticks},0)\) 
Units: Month

Cust Support Needed = \(\text{Adopters} \times \text{Cust Support Needed per Adopter} + \text{Purchasers} \times \text{Cust Support Needed Per Purchaser}\) 
Units: Persons*Hours/Month 
Total cust support needed for customers who have purchased and adopted the product (includes time needed to deliver the product)

Cust Support Needed per Adopter = 8 
Units: ((Person*Hours)/Month)/Prospect 
Person-Hours needed per month needed to support each adopter

Cust Support Needed Per Purchaser = 40 
Units: Hours*Person/(Month*Prospect) 
Person-Hours needed per month needed to support each purchaser (in process of adoption)

Decision Productivity Of Sales Effort = \(\text{MIN}(\text{Max Decision Productivity From Sales, Sales Experience Productivity Multiplier} \times \text{Max Decision Productivity From Sales} \times \text{Effect Of Features On Decision Efficiency} \times \text{Effect Of Price On Decision Efficiency} \times \text{Effect Of Word Of Mouth On Decision Efficiency} \times \text{Effect Of Customer Support On Decision Efficiency} \times \text{Effect Of Technology On Decision Efficiency})\) 
Units: Prospects/(Person*Hour) 
The decision rate of sales effort as effected by price, features, cust support (for trials), and word-of-mouth

Decision sales effort = \(\text{Fraction effort for decision} \times \text{Sales Effort}\) 
Units: Persons*Hours/Month 
Total number of hours spent by the sales force on decisions per month

Decrease in Costs per Double Purchases = 0.1 
Units: Dmnl 
Fractional decrease in costs to produce the products per double the amount produced (i.e. sold)
Decrease in Costs per Double Technology Development = 0.18
Units: Dmnl
Fractional decrease in costs to produce the products per double the technology development over time

Default Rate = Normal Default Fraction * Effect of Cust Support on Default Rate Fn(Normalized Cust Support) * Effect of Cust Financial Condition on Default Rate Fn(Normalized Cust Fincd Condition)
Units: 1/Month
Rate at which customers are defaulting based on our cust support and their financial condition

Defaults on AR = Accounts Receivable * Default Rate
Units: Dollars/Month
Dollars per month we're losing due to customer defaults on their bills

Desired Eng Hiring Rate = MAX(0, Adjustment for Engineers + Eng Attrition Rate)
Units: Persons/Month
Hire enough people to replace expected attrition and adjust number of engineers to the desired level (and if need to reduce them, then do so through attrition)

Desired Eng Lay Off Rate = Allow Layoffs * MAX(0, -Constrained Eng Hiring Rate)
Units: Persons/Month
If hiring rate is negative, means we want to get rid of engineers

Desired Eng Proportion = ZIDZ(Desired Eng Hiring Rate, Desired Hiring Rate)
Units: Dimensionless
Proportion of all new hires we want for engineering

Desired Eng Vacancies = MAX(0, Expected Time to Fill Eng Vacancies * Constrained Eng Hiring Rate)
Units: People
Number of engineering vacancies needed to generate the desired hiring rate, given the expected time required to fill an engineering vacancy.

Desired Eng Vacancy Cancellation Rate = MAX(0, -Desired Eng Vacancy Creation Rate)
Units: Persons/Month
The desired rate of engineering vacancy cancellation, given by the desired vacancy creation rate whenever that rate is negative.

Desired Eng Vacancy Creation Rate = Constrained Eng Hiring Rate + Adjustment for Eng Vacancies
Units: Persons/Month
Create enough engineering vacancies to result in the desired hiring rate, adjusted to bring the stock of vacancies in line with the desired level.

Desired Engineering Effort for Cust Support = Cust Support Needed
Units: Persons*Hours/Month
Assume for now that we desire engineers just for the customer support that's needed now

Units: Persons*Hours/Month
How many person hours are needed to develop the features we desire

Units: Persons*Hours/Month
How many person hours are needed to develop the features we desire
Desired Engineers = xIDZ((Desired Engineering Effort for Feature Development + Desired Engineering Effort for Cust Support + Desired Engineering Effort for Technology Development), Productive Eng Work Month, 100)
Units: People
How many Engineers we need to make up the feature shortfall, based on their productivity and how many hours are needed for cust support (current engineering) (but can’t be negative if too many features)

Units: Features/Month
How many features we’d like to develop per month to obtain stock of features we’d like (taking into account features we’re losing from obsolescence) -- allowed to go negative

Desired Feature Development Rate[company, featuretype] = MAX(0, Desired Feature Completion Rate[company, featuretype] + Abandonment Rate[company, featuretype] + Adjustment for FUD[company, featuretype])
Units: Feature/Month
At what rate do we want to be starting feature development, taking into account the features already under development, and the ones being abandoned

Desired Feature Ratio[self, appropriable] = 1.25
Desired Feature Ratio[self, nonappropriable] = 1.25
Desired Feature Ratio[competitor, featuretype] = 1.1, 1.1
Units: Dmnl [0, 8, 0.05]
Desired ratio between our features and competitors features (to drive product attractiveness)

Desired Features[self, featuretype] = IF THEN ELSE (Switch for Product Development = 0, 0, Features[competitor, featuretype] * Desired Feature Ratio[self, featuretype]) * Desired Features[competitor, featuretype] = Features[self, featuretype] * Desired Feature Ratio[competitor, featuretype]
Units: Features
How many features we desire (based on how many features competitors have, and how we want to compare to competitors)

Desired FUD[company, featuretype] = Desired Feature Completion Rate[company, featuretype] * Avg Feature Devl Time[company, featuretype]
Units: Features
How many features we need under development to maintain the rate of feature development we desire

Desired Hiring Rate = Desired Eng Hiring Rate + Desired Sales Hiring Rate
Units: People/Month
The total amount of hires we desire to make per month

Desired Marketing Effort = IF THEN ELSE (Cash for Firm Operations <= 0, 0, Min Marketing Effort * Portion of Min Effort for Marketing Fn (Prospect to Population Ratio))
Units: Person*Hours/Month
Devote at least min hours, or the multiple of the min effort determined by the function

Desired Sales Effort = IF THEN ELSE (Cash for Firm Operations <= 0, 0, Desired Sales Hours/Time to Apply Effort)
Units: Person*Hours/Month
How many person-hours of effort do we want the sales force to apply per month

Desired Sales Force = (Desired Sales Effort + Desired Marketing Effort) / Sales Work Month
Units: People
How many people do we want for sales and marketing
Desired Sales Hiring Rate = \text{MAX}(0, \text{Adjustment for Sales Force} + \text{Sales Attrition Rate}) \\
\text{Units: Persons/Month} \\
\text{Hire enough people to replace expected attrition and adjust number of sales people to the desired level} \\
\text{(and if need to reduce them, then do so through attrition)} \\

Desired Sales Hours = Z:\text{IDZ}(\text{Potential Prospects}, (Z:\text{IDZ}(\text{Knowledge Productivity Of Sales Effort}, \text{Effect Of Features On Knowledge Efficiency}))) + Z:\text{IDZ}(\text{Prospects}, (Z:\text{IDZ}(\text{Persuasion Productivity Of Sales Effort}, \text{Effect Of Features On Persuasion Efficiency}))) + Z:\text{IDZ}(\text{Hot Prospects}, (Z:\text{IDZ}(\text{Decision Productivity Of Sales Effort}, \text{Effect Of Features On Decision Efficiency}))) + Z:\text{IDZ}(\text{Purchasers}, (Z:\text{IDZ}(\text{Adoption Productivity Of Sales Effort}, \text{Effect Of Features On Adoption Efficiency}))) \\
\text{Units: (Person*Hours)} \\
\text{How many person-hours of sales effort do we need based on our sales productivity and the number of prospects at each stage of the sales cycle} \\

Desired Sales Lay Off Rate = Allow Layoffs \times \text{MAX}(0, -\text{Constrained Sales Hiring Rate}) \\
\text{Units: Persons/Month} \\
\text{If hiring rate is negative, means we want to get rid of sales people as long as we’re willing to make layoffs} \\

Desired Sales Proportion = Z:\text{IDZ}(\text{Desired Sales Hiring Rate}, \text{Desired Hiring Rate}) \\
\text{Units: Dimensionless} \\
\text{Proportion of all new hires we want for sales} \\

Desired Sales Vacancies = \text{MAX}(0, \text{Expected Time to Fill Sales Vacancies} \times \text{Constrained Sales Hiring Rate}) \\
\text{Units: People} \\
\text{Number of sales vacancies needed to generate the desired hiring rate, given the expected time required to fill a sales vacancy.} \\

Desired Sales Vacancy Cancellation Rate = \text{MAX}(0, -\text{Desired Sales Vacancy Creation Rate}) \\
\text{Units: Persons/Month} \\
\text{The desired rate of sales vacancy cancellation, given by the desired vacancy creation rate whenever that rate is negative.} \\

Desired Sales Vacancy Creation Rate = \text{Constrained Sales Hiring Rate} + \text{Adjustment for Sales Vacancies} \\
\text{Units: Persons/Month} \\
\text{Create enough sales vacancies to result in the desired hiring rate, adjusted to bring the stock of vacancies in line with the desired level.} \\

Desired Technology Completion Rate[\text{company}] = \text{Technology Shortfall[company]} / \text{Desired Time to Catch Up Technology[company]} + \text{Perceived Technology Obsolescence Rate[company]} \\
\text{Units: Features/Month} \\
\text{How much technology we’d like to develop per month to obtain stock of technology development we’d like (taking into account technology we’re losing from obsolescence) -- allowed to go negative} \\

Desired Technology Development Rate[\text{company}] = \text{MAX}(0, \text{Desired Technology Completion Rate[company]} + \text{Technology Abandonment Rate[company]} + \text{Adjustment for Technology Under Development[company]}) \\
\text{Units: Feature/Month} \\
\text{At what rate do we want to be starting technology development, taking into account the technology already under development, and the ones being abandoned} \\

Desired Technology Under Development[\text{company}] = \text{Desired Technology Completion Rate[company]} \times \text{Avg Technology Devl Time[company]} \\
\text{Units: Features} \\
\text{How much technology we need under development to maintain the rate of technology development we desire} \\

Desired Time to Catch Up Features[\text{company, featuretype}] = 2, 4, 6, 12; \\
\text{Units: Months} [0, 80, 0.1] \\
\text{How soon we’d like our features to reach the desired level}
Units: Months [0,80,0.1]
How soon we'd like our technologies to reach the desired level

Dummy Adopter loss rate = Dummy Adopters * Adopter Loss Fraction
Units: Prospects/Month
Shadow of Adopter loss rate

Dummy Adopters = INTEG (+ Dummy Adoption Rate - Dummy Adopter loss rate, Initial Adopters)
Units: Prospects
Shadow of Adopters

Dummy Adoption Rate = IF THEN ELSE (Norm Adoption Rate > 0, Dummy Norm Adoption Rate * Prospect Conversion Fn(ZIDZ(Potential Adoption From Sales Effort, Dummy Norm Adoption Rate)), 0)
Units: Prospects/Month
Shadow of Adoption Rate

Dummy Hot prospect loss rate = MAX(0, Dummy Norm Decision Rate - Dummy Purchase Rate)
Units: Prospects/Month
Shadow of Hot prospect loss rate

Dummy Hot Prospects = INTEG (Dummy Persuasion Rate - Dummy Hot prospect loss rate - Dummy Purchase Rate, Initial Hot Prospects)
Units: Prospects
Shadow of Hot Prospects

Dummy Knowledge Rate = Dummy Norm Knowledge Rate * Prospect Conversion Fn(ZIDZ(Potential Knowledge From Sales Effort, Dummy Norm Knowledge Rate))
Units: Prospects/Month
Shadow of Knowledge Rate

Dummy Lost Prospects = INTEG (Dummy Adopter loss rate + Dummy Hot prospect loss rate + Dummy Potential Prospect Loss Rate + Dummy Prospect Loss Rate + Dummy Purchaser Loss Rate - Dummy Prospect Regain Rate, 0)
Units: Prospects
Shadow of Lost Prospects

Dummy Norm Adoption Rate = Dummy Purchasers / Avg Purchaser Lifetime
Units: Prospects/Month
Shadow of Norm Adoption Rate

Dummy Norm Decision Rate = Dummy Hot Prospects / Avg Hot Prospect Lifetime
Units: Prospects/Month
Shadow of Norm Decision Rate

Dummy Norm Knowledge Rate = Dummy Potential Prospects / Avg Potential Prospect Lifetime
Units: Prospects/Month
Shadow of Norm Knowledge Rate

Dummy Norm Persuasion Rate = Dummy Prospects / Avg Prospect Lifetime
Units: Prospects/Month
Shadow of Norm Persuasion Rate

Dummy Persuasion Rate = IF THEN ELSE (Norm Persuasion Rate > 0, Dummy Norm Persuasion Rate * Prospect Conversion Fn (ZIDZ(Potential Persuasion From Sales Effort, Dummy Norm Persuasion Rate)), 0)
Units: Prospects/Month
Shadow of Persuasion Rate
Dummy Potential Prospect Loss Rate = MAX(0, Dummy Norm Knowledge Rate - Dummy Knowledge Rate)
Units: Prospects/Month
Shadow of Potential Prospect Loss Rate

Dummy Potential Prospects = INTEG (Begin Counter + Dummy Prospect Regain Rate - Dummy Knowledge Rate - Dummy Potential Prospect Loss Rate, Initial Potential Prospects)
Units: Prospects
Shadow of Potential Prospects

Dummy Prospect Loss Rate = MAX(0, (Dummy Norm Persuasion Rate - Dummy Persuasion Rate))
Units: Prospects/Month
Shadow of Prospect Loss Rate

Dummy Prospect Regain Rate = Dummy Lost Prospects / Lost Prospect Lifetime
Units: Prospects/Month
Shadow of Prospect Regain Rate

Dummy Prospects = INTEG (Dummy Knowledge Rate - Dummy Persuasion Rate - Dummy Prospect Loss Rate, Initial Prospects)
Units: Prospects
Shadow of Dummy Prospects

Dummy Purchase Rate = IF THEN ELSE (Norm Decision Rate > 0, Dummy Norm Decision Rate * Prospect Conversion Fn(ZIDZ(Potential Decision From Sales Effort, Dummy Norm Decision Rate)), 0)
Units: Prospects/Month
Shadow of Purchase Rate

Dummy Purchaser Loss Rate = MAX(0, Dummy Norm Adoption Rate - Dummy Adoption Rate)
Units: Prospects/Month
Shadow of Purchaser Loss Rate

Dummy Purchasers = INTEG (Dummy Purchase Rate - Dummy Adoption Rate - Dummy Purchaser Loss Rate, Initial Purchasers)
Units: Prospects
Shadow of Purchasers

Effect of Cust Financial Condition on Default Rate Fn([(0,0)- (3,10)], (0,100), (0.1,10), (0.25,4), (0.33,3), (0.5,2), (0.75,1.33), (1,1), (2,0.1), (100,0.01))
Units: Dmn
If customers are bankrupt, then 100* default rate, and if customers have tons of cash, then 1% of default rate, and asymptotic in between

Effect of Cust Support on Default Rate Fn([(0,0)(5,20)], (0,1000), (0.05,20), (0.1,5), (0.2,3.25), (0.5,2), (0.7,1.3), (1, 1), (5,0.5), (100,0.25))
Units: Dimensionless
With no customer support at all, all customers default, with norm cust support, defaults are normal, and with maximum customer support, curve is asymptotic to one quarter the default rate

Effect of Customer Support on Adopter Loss Fraction([(0,0)(3,10)], (0,10), (0.06,5.5), (0.125,3.5), (0.25,2.25), (0.5,1.5), (1,1), (1.44037,0.473684), (2,0.1), (100,0.1))
Units: Dmn
If no cust support we lose everyone, and if great cust support we lose much fewer adopters than normal, and asymptotic curve in between

Effect Of Customer Support On Adoption Efficiency = 1 + Effect Of Customer Support On Adoption Efficiency Fn(Normalized Cust Support)
Units: Dmn
How the efficiency of implementation is affected by the level of customer support
Effect Of Customer Support On Adoption Efficiency $\text{Fn}([0,0)-(1.1)],(0,0),(1,1])$
Units: Dmnl
Assuming cust support is needed to help purchaser to use product, linear relationship between cust support and adoption efficiency

Effect Of Customer Support On Decision Efficiency $= 1 + \text{Effect Of Customer Support On Decision Efficiency}$
$\text{Fn}(\text{Normalized Cust Support})$
Units: Dmnl
How the efficiency of sales at the decision stage is affected by the level of customer support

Effect Of Customer Support On Decision Efficiency $\text{Fn}([0,0)-(10,10)],(0,0.5),(1,1),(10,1))$
Units: Dmnl
Assuming only a portion of hot prospects are trialing, 0 cust support will only cut decision productivity in half, and then it will rise linearly to 1

Effect of Features on Adopter Loss Fraction $\text{Fn}([0,0)(3,100)],(0,100),(0.06,32),(0.125,16),(0.25,8),$ $(0.5,2),(1,1),(1.44037,0.473684),(2,0.1),(100,0.1))$
Units: Dmnl
If no features, we lose everyone, and if great features we lose much less, and asymptotic curve in between

Effect Of Features On Adoption Efficiency $= \text{Effect Of Features On Adoption Efficiency}$
$\text{Fn}(\text{Normalized Features})$
Units: Dmnl [0,1]
How the efficiency of sales at the adoption stage is affected by normalized features

Effect Of Features On Adoption Efficiency $\text{Fn}([0,0)-(1,1)],(0,0),(0.5,0.5),(1.5,0.9),(2,1),(100,1))$
Units: Dmnl
No features still equals no sales, but given that they've already purchased, lack of some features will have less of a negative effect

Effect Of Features On Decision Efficiency $= \text{Effect Of Features On Decision Efficiency}$
$\text{Fn}(\text{Normalized Features})$
Units: Dmnl [0,1]
How the efficiency of sales at the decision stage is affected by normalized features

Effect Of Features On Decision Efficiency $\text{Fn}([0,0)(1,1),(0,0),(0.125,0.02),(0.25,0.1),(0.375,0.2),(0.5,0.5),$ $(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1)],(0,0),(0.25,0.02),(0.5,0.1),(0.75,0.2),(1,0.5),(1.35,0.8),(1.5,0.9),$ $(1.75,0.98),(2,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Features On Fraction of Firms Capable of Adopting $= \text{Effect Of Features On Fraction of Firms Capable}$
of Adopting $\text{Fn}(\text{Normalized Features})$
Units: Dmnl [0,1]
How the efficiency of sales at the knowledge stage is affected by the normalized features

Effect Of Features On Fraction of Firms Capable of Adopting $\text{Fn}([0,0)-(10,1)],(0,0),(0.125,0.02),(0.25,0.1),$ $(0.375,0.2),(0.5,0.5),(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1)],(0,0),(0.25,0.02),(0.5,0.1),(0.75,0.2),(1,0.5),$ $(0.9,0.8),(1,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Features On Knowledge Efficiency $= \text{Effect Of Features On Knowledge Efficiency}$
$\text{Fn}(\text{Normalized Features})$
Units: Dmnl [0,1]
How the efficiency of sales at the knowledge stage is affected by the normalized features
Effect Of Features On Knowledge Efficiency \( F_n([0.5, 0](1, 0.5), (0, 0), (0.125, 0.02), (0.25, 0.1), (0.375, 0.2), (0.5, 0.5), (0.625, 0.8), (0.75, 0.9), (0.875, 0.98), (1, 0)], [0, 0], (0.25, 0.02), (0.5, 0.1), (0.625, 0.8), (0.75, 0.9), (0.875, 0.98), (1, 0.1), (100, 1))
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Features On Persuasion Efficiency = Effect Of Features On Knowledge Efficiency \( F_n(\text{Normalized Features}) \)
Units: Dmnl \([0, 1]\)
How the efficiency of sales at the persuasion stage is affected by normalized features

Effect Of Features On Persuasion Efficiency \( F_n([0, 0], (1, 1), (0, 0), (0.125, 0.02), (0.25, 0.1), (0.375, 0.2), (0.5, 0.5), (0.625, 0.8), (0.75, 0.9), (0.875, 0.98), (1, 1)], [0, 0], (0.25, 0.02), (0.5, 0.1), (0.625, 0.8), (0.75, 0.9), (0.875, 0.98), (1, 0.1), (100, 1))
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Features on Private Investment Win Fraction = Function for Effect of Features on VC Win Fraction (Normalized Features/Functionality Threshold as a Multiple of Incumbent Functionality)
Units: Dmnl
The multiple that investors is willing to invest because of superiority of features

Effect of Functionality on Private Investment Win Fraction = Effect of Features on Private Investment Win Fraction \( \times \text{Effect of Technology on Private Investment Win Fraction} \)
Units: Dimensionless
The fraction of funding a VC is willing to invest because of technology and features functionality

Units: Dimensionless
The multiple of funding a VC is willing to invest because of market size

Effect of Marketing Effort on Market Size \( F_n([0, 0], (100, 0.06)), (0, 0), (1, 0.001), (4, 0.00578947), (10, 0.01), (17, 0.0147368), (26, 0.02), (40, 0.0612), (30, 0.0310526), (58, 0.156), (0.0413158), (76, 0.1468), (0.0463158), (100, 0.05) \)
Units: 1/Month
No marketing effort has 0 effect, normalized has a tenth of a percent, and the most effect we can have is 5% (with hundreds of marketing people) and asymptotic in between

Effect Of Marketing On Knowledge Efficiency = 1 + Effect Of Marketing On Knowledge Efficiency \( F_n(\text{Normalized Marketing}) \)
Units: Dmnl
How the efficiency of sales at the knowledge stage is affected by marketing

Effect Of Marketing On Knowledge Efficiency \( F_n([0, 0], (10, 10)), (0, 0), (1, 1) \)
Units: Dmnl
If no marketing, cuts sales productivity in by 90%, then linear up to 1

Effect Of Marketing On Persuasion Efficiency = 1 + Effect Of Marketing On Persuasion Efficiency \( F_n(\text{Normalized Marketing}) \)
Units: Dmnl
How the efficiency of sales at the persuasion stage is affected by marketing

Effect Of Marketing On Persuasion Efficiency \( F_n([0, 0], (10, 10)), (0, 0.5), (1, 1) \)
Units: Dmnl
If no marketing, cuts sales productivity in half, then linear up to 1

Effect Of Price On Decision Efficiency = Effect Of Price On Decision Efficiency \( F_n(\text{Normalized Price}) \)
Units: Dmnl \([0, 1]\)
How the efficiency of sales at the decision stage is affected by normalized price
Effect Of Price On Decision Efficiency Fn((0,0),(0.5, 0.92), (1, 0.75), (1.25, 0.5), (2.32416, 0.315789), (3.42508, 0.162281), (5.50459, 0.0614035), (7.82875, 0.0438596), (10.581, 0.0219298), (50, 0))
Units: Dmnl
S-curve, If price is 0, get 100% sales efficiency, if it's normal, get 75% efficiency, and as price approaches 10x normal, efficiency goes to 0

Effect Of Price On Fraction of Firms Capable of Adopting = Effect Of Price on Fraction of Firms Capable of Adopting Fn(Normalized Price)
Units: Dmnl [0, 1]
How the efficiency of sales at the knowledge stage is affected by normalized price

Effect Of Price On Fraction of Firms Capable of Adopting Fn((1.0, 10.1), (0.1), (0.0733945, 0.855263), (0.159021, 0.719298), (0.287462, 0.622807), (0.5, 0.5), (0.611621, 0.482456), (0.801223, 0.425439), (1.0.3), (1.25, 0.15), (2, 0.1), (3, 0.05), (5, 0.01), (7, 0.005), (10, 0.001), (50, 0))
Units: Dmnl
S-curve

Effect Of Price On Knowledge Efficiency = Effect Of Price On Knowledge Efficiency Fn(Normalized Price)
Units: Dmnl [0, 1]
How the efficiency of sales at the knowledge stage is affected by normalized price

Effect Of Price On Knowledge Efficiency Fn((0,0),(60,1), (0,1), (0.5, 0.92), (1, 0.75), (1.25, 0.5), (2.32416, 0.315789), (3.42508, 0.162281), (5.50459, 0.0614035), (7.82875, 0.0438596), (10.581, 0.0219298), (50, 0))
Units: Dmnl
S-curve, If price is 0, get 100% sales efficiency, if it's normal, get 50% efficiency, and as price approaches 10x normal, efficiency goes to 0

Units: Dmnl [0, 1]
How the efficiency of sales at the persuasion stage is affected by normalized price

Effect Of Price On Persuasion Efficiency Fn((0,0),(60,1), (0,1), (0.5, 0.92), (1, 0.75), (1.25, 0.5), (2.32416, 0.315789), (3.42508, 0.162281), (5.50459, 0.0614035), (7.82875, 0.0438596), (10.581, 0.0219298), (50, 0))
Units: Dmnl
S-curve, If price is 0, get 100% sales efficiency, if it's normal, get 50% efficiency, and as price approaches 10x normal, efficiency goes to 0

Effect of Technology on Adopter Loss Fraction= Effect Of Technology On Adopter Loss Fraction= Effect Of Technology On Adopter Loss Fraction Fn((0,0),(3,100), (0,100), (0.06, 32), (0.125, 16), (0.25, 8), (0.5, 2), (1,1), (1.44037, 0.473684), (2.0.1), (100, 0.1))
Units: Dmnl
If no technology, we lose everyone, and if great technology we lose much less, and asymptotic curve in between

Effect Of Technology On Adoption Efficiency = Effect Of Technology On Adoption Efficiency Fn(Normalized Technology)
Units: Dmnl [0, 1]
How the efficiency of sales at the adoption stage is affected by normalized technology

Effect Of Technology On Adoption Efficiency Fn((0,0),(1,1), (0,0), (0.5, 0.5), (1.5, 0.9), (2, 1), (10, 1))
Units: Dmnl
No features still equals no sales, but given that they've already purchased, lack of some features will have less of a negative effect

Effect Of Technology On Decision Efficiency = Effect Of Technology On Decision Efficiency Fn(Normalized Technology)
Units: Dmnl
How the efficiency of sales at the decision stage is affected by normalized technology
Effect Of Technology On Decision Efficiency $F_n(\{(0,0),(1,1),(0,0),(0.125,0.02),(0.25,0.1),(0.375,0.2),
(0.5,0.5),(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1)\},(0,0),(0.25,0.02),(0.5,0.1),(0.75,0.2),(1,0.5),(1.35,0.8),(1.5,0.9),(1.75,0.98),(2,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Technology On Fraction of Firms Capable of Adopting $F_n(\{(0,0)-(10,1),(0,0.125,0.02),(0.25,0.1),(0.375,0.2),(0.5,0.5),(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1)\},(0,0),(0.25,0.02),(0.5,0.1),(0.75,0.2),(1,0.5),(1.35,0.8),(1.5,0.9),(1.75,0.98),(2,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Technology On Knowledge Efficiency $F_n(\{(0.5,0),(1,0.5),(0,0),(0.125,0.02),(0.25,0.1),(0.375,0.2),
(0.5,0.5),(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1)\},(0,0),(0.25,0.02),(0.5,0.1),(0.625382,0.129386),(0.75,0.2),(0.874618,0.33114),(1,0.5),(1.35,0.8),(1.5,0.9),(1.75,0.98),(2,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Technology On Persuasion Efficiency $F_n(\{(0,0)-(10,1),(0,0),(0.125,0.02),(0.25,0.1),(0.375,0.2),
(0.5,0.5),(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1)\},(0,0),(0.25,0.02),(0.5,0.1),(0.75,0.2),(1,0.5),(1.35,0.8),(1.5,0.9),(1.75,0.98),(2,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Technology On Private Investment Win Fraction $= F_n(\{(0,0)-(10,10),(0,0),(0.125,0.02),(0.25,0.1),(0.375,0.2),
(0.5,0.5),(0.675,0.8),(0.75,0.9),(0.875,0.98),(1,1),(0,0),(0.25,0.02),(0.5,0.1),(0.75,0.2),(1,0.5),(1.35,0.8),(1.5,0.9),(1.75,0.98),(2,1),(100,1))$
Units: Dmnl
S curve with no features = no sales, normal features = 50% sales, double features = 100% sales

Effect Of Word Of Mouth On Decision Efficiency $F_n(\{(0,0),(1,1),(0,0),(0.125,0.02),(0.25,0.1)\},(0,0.5),(1.1),(100,1))$
Units: Dmnl
0 word of mouth will cut decision efficiency in half, and then it will rise linearly to 1
Effect Of Word Of Mouth On Knowledge Efficiency = Effect Of Word Of Mouth On Knowledge Efficiency
Fn(Normalized Word of Mouth)
Units: Dmnl
How the efficiency of sales at the knowledge stage is affected by word of mouth

Effect Of Word Of Mouth On Knowledge Efficiency Fn\([((0,0)-(2,1)),(0,0.15),(1,1),(100,1))\]
Units: Dmnl
If no word of mouth, sales productivity only 15%, then linear up to 1

Fn(Normalized Word of Mouth)
Units: Dmnl
How the efficiency of sales at the persuasion stage is affected by word of mouth

Effect Of Word Of Mouth On Persuasion Efficiency Fn\([((0,0)-(1,1)),(0,0.33),(1,1),(100,1))\]
Units: Dmnl
If no word of mouth, sales productivity only 1/3, then linear up to 1

Effective Discount Rate = 12*\(((\text{Annual Discount Rate}+1)\times(1/12))-1\)
Units: Dimensionless
Transformation of an annual discount rate into a monthly rate

Effective Engineering Effort = Engineering Effort * Engineering Experience Productivity Multiplier
Units: Persons*Hours/Month
How many productive hours engineers work

Effective Prospects = \(ZIDZ(\text{Total Prospects,Initial Potential Prospects})\)
Units: Dimensionless
Current number of prospects compared to the initial number of prospects

Eng Attrition Rate = Engineers * Fractional Eng Attrition Rate
Units: Persons/Month
Rate at which engineers leave (quit)

Eng Experience From Hiring = Eng Hiring Rate * Avg Experience Of New Eng Hires
Units: Persons*Hours/Month
Experience gain from hiring

Eng Hiring Rate = (Eng Vacancies/Avg Time to Fill Eng Vacancies) * (1 - Bankrupt Switch)
Units: Persons/Month
Hire engineers based on how many vacancies have been created and the avg time to fill them

Eng Hrs Required per Feature\[\text{self,featuretype}\]=350,35000
Eng Hrs Required per Feature\[\text{competitor,featuretype}\]=350,35000
Units: Person*Hours/Feature
How many hours it would take one engineer to develop a feature

Eng Hrs Required per Technology\[\text{self}\]=Function for Effect of Approaching Theoretical Maximum Technology Development
Eng Hrs Required per Technology\[\text{competitor}\]=Function for Effect of Approaching Theoretical Maximum Technology Development
Units: Person*Hours/Feature \([0,100000]\)
How many hours it would take one engineer to develop a technology

Eng Productivity Change Per Double Experience = 0.33
Units: Dmnl
The fractional change in productivity of engineers for every doubling of their effective experience
Eng Proportion = \frac{\text{Engineers}}{\text{Total Labor}}

Units: Dimensionless

Proportion of workforce made up of engineers

Eng Vacancies = \text{INTEG} (\text{Eng Vacancy Creation Rate} - \text{Eng Vacancy Closure Rate} - \text{Eng Vacancy Cancellation Rate}, \text{Desired Eng Vacancies})

Units: People

The number of open positions the firm seeks to fill.

Eng Vacancy Adjustment Time = 1

Units: Months

The average time over which to adjust the actual number of engineering vacancies to the desired level.

Eng Vacancy Cancellation Rate = \text{MIN}(\text{Desired Eng Vacancy Cancellation Rate}, \text{Max Eng Vacancy Cancellation Rate})

Units: Persons/Month

The rate at which to cancel existing engineering vacancies prior to filling them.

Eng Vacancy Cancellation Time = 1

Units: Months

The average time required to cancel an engineering vacancy.

Eng Vacancy Closure Rate = \text{Eng Hiring Rate}

Units: Persons/Month

Vacancies are closed when the employee is hired.

Eng Vacancy Creation Rate = \text{MAX}(0, \text{Desired Eng Vacancy Creation Rate})

Units: Persons/Month

The rate at which to create new engineering positions and begins to recruit for them.

Eng Work Month = 175

Units: Hours/Month

How many hours engineers work per month.

Engineer Experience = \text{INTEG} (\text{Increase In Eng Experience} + \text{Eng Experience From Hiring} - \text{Loss Of Eng Experience}, \text{Initial Engineers} \times \text{Initial Avg Engineering Experience})

Units: Persons*Hours

Cumulative sales experience of organization.

Engineer Lay Offs = \text{MAX}(\text{Bankrupt Switch} \times ((\text{Engineers} / \text{TIME STEP}) - \text{Eng Attrition Rate}), \text{MIN}(\text{Desired Eng Lay Off Rate}, \text{Maximum Layoff Rate}))

Units: Persons/Month

Engineers being layed off per month.

Engineering Effort = \text{Engineers} \times \text{Eng Work Month}

Units: Persons*Hours/Month

How many total hours engineers work per month.

Engineering Effort for Cust Support = \text{IF THEN ELSE} (\text{Cash for Firm Operations} \leq 0, 0, \text{MIN}(\text{Cust Support Needed, Effective Engineering Effort} \times (1 - \text{Min Development Fraction})))

Units: Persons*Hours/Month

After allocating the min percentage of engineering effort to development, then use engineering effort to satisfy cust support (current engineering) needs.

Engineering Effort Net of Customer Support = \text{Effective Engineering Effort} - \text{Engineering Effort for Cust Support}

Units: Persons*Hours/Month

The amount of engineering effort after customer service is performed that can be allocated to technology or product development.
Engineering Experience Productivity Multiplier = \( \left( \frac{\text{Avg Engineer Experience}}{\text{Engineering Experience Reference}} \right)^{\frac{\ln(1 + \text{Eng Productivity Change Per Double Experience})}{\ln(2)}} \)

Units: Dimensionless

Learning curve for productivity from experience (from Sterman pg 507, from Zangwill and Kantor (1998))

Engineering Experience Reference = 2000

Units: Hours

Normal engineering experience

Engineers = \( \text{INTEG} \) (+Eng Hiring Rate-Eng Attrition Rate-Engineer Lay Offs, Initial Engineers)

Units: Persons

Number of engineers

Engineers Adjustment Time = 6

Units: Months [0,1000,10]

The time period over which the firm seeks to bring the labor force in line with the desired level.

Exp Gain Per Adoption = 910

Units: Person*Hours/Prospect [0,6000,35]

How much of a boost in experience does each adopter provide

Exp Gain Per Purchase = 910

Units: Person*Hours/Prospect [0,6000,35]

How much of a boost in experience does each purchase provide to the sales force

Expected Time to Fill Eng Vacancies = Avg Time to Fill Eng Vacancies

Units: Months

For simplicity, assume managers know the real avg time to fill vacancies (i.e. no information delay)

Expected Time to Fill Sales Vacancies = Avg Time to Fill Sales Vacancies

Units: Months

For simplicity, assume managers know the real avg time to fill vacancies (i.e. no information delay)

Feasible Feature Devl Rate[company, featuretype] = \( \frac{\text{Product Development Effort[company, featuretype]}}{\text{Eng Hrs Required per Feature[company, featuretype]}} \)

Units: Features/Month

Given the engineering resources we have, and the amount of time it takes to develop a feature, how many features can we develop per month

Feasible Technology Devl Rate[company] = \( \frac{\text{Technology Development Effort[company]}}{\text{Eng Hrs Required per Technology[company]}} \)

Units: Features/Month

Given the engineering resources we have, and the amount of time it takes to develop a technology, how many technologies can we develop per month

Feature Abandonment Fraction[company, featuretype] = 0.099

Units: Dimensionless

Fraction of features under development that are abandoned

Feature Abandonment Fraction 1[company, featuretype] = \( \frac{\text{Feature AbandonmentFraction[company, featuretype]}}{3} \)

Units: Dimensionless

Fraction of features under development that are abandoned at 1st stage of product development

Feature Abandonment Fraction 2[company, featuretype] = \( \frac{\text{Feature AbandonmentFraction[company, featuretype]}}{3} \)

Units: Dimensionless

Fraction of features under development that are abandoned at 2nd stage of product development
Feature Abandonment Fraction \[3\{company,featuretype\}\]=Feature Abandonment Fraction[company,featuretype]/3
Units: Dmnl
Fraction of features under development that are abandoned at 3rd stage of product development

Feature Completion Rate[company,featuretype]=Feature Completion Rate 3[company,featuretype]
Units: Features/Month
The rate at which features are developed into the product determined by how many features were started and providing a 3rd order delay to complete them in the avg feature devl time

Feature Completion Rate 1 [company,featuretype]=Feature Devl Rate 1[company,featuretype]*(1-Feature Abandonment Fraction 1[company,featuretype])
Units: Features/Month
The rate at which features are developed into the product determined by how many features were started and providing a 3rd order delay to complete them in the avg feature devl time

Feature Completion Rate 2[company,featuretype]=Feature Devl Rate 2[company,featuretype]*(1-Feature Abandonment Fraction 2[company,featuretype])
Units: Features/Month
The rate at which features are developed into the product determined by how many features were started and providing a 3rd order delay to complete them in the avg feature devl time

Feature Completion Rate 3[company,featuretype]=Feature Devl Rate 3[company,featuretype]*(1-Feature Abandonment Fraction 3[company,featuretype])
Units: Features/Month
The rate at which features are developed into the product determined by how many features were started and providing a 3rd order delay to complete them in the avg feature devl time

Feature Devl Rate 1[company,featuretype]=\text{MIN}(Features Under Development 1[company,featuretype]/Avg \ Feature Devl Time[company,featuretype], Feasible Feature Devl Rate[company,featuretype])*3
Units: Features/Month
Develop 1/3 of features in minimum of 1/3 the avg feature development time or 1/3 the amount of time it takes given the resources we have to develop features

Feature Devl Rate 2[company,featuretype]=\text{MIN}(Features Under Development 2[company,featuretype]/Avg Feature Devl Time[company,featuretype], Feasible Feature Devl Rate[company,featuretype])*3
Units: Features/Month
Develop 1/3 of features in minimum of 1/3 the avg feature development time or 1/3 the amount of time it takes given the resources we have to develop features

Feature Devl Rate 3[company,featuretype]=\text{MIN}(Features Under Development 3[company,featuretype]/Avg Feature Devl Time[company,featuretype], Feasible Feature Devl Rate[company,featuretype])*3
Units: Features/Month
Develop 1/3 of features in minimum of 1/3 the avg feature development time or 1/3 the amount of time it takes given the resources we have to develop features

Feature Obsolescence Rate[company,featuretype]=Features[company,featuretype]/Avg Feature Lifetime[company,featuretype]
Units: Features/Month
Features that go out of date per month

Feature Shortfall[company,featuretype]=Desired Features[company,featuretype]-Features[company,featuretype]
Units: Features
How many features we're missing compared to what we desire.

Feature Start Rate[company,featuretype]=\text{MIN}(Feasible Feature Devl Rate[company,featuretype], Desired Feature Development Rate[company,featuretype])
Units: Features/Month
Start features at the rate at which we can develop them
Feature Value[company]=Features[company,nonappropriable]*Nonappropriable Feature Multiple + Features [company,appropriable]
Units: Features
Value of combined approbriable and nonapprobriable features

Features[company,featuretype]= INTEG (Feature Completion Rate[company,featuretype]-Feature Obsolescense Rate[company,featuretype],Initial Features[company,featuretype])
Units: Features
Features of the product

Features Under Development 1[company,featuretype]= INTEG (+Feature Start Rate[company,featuretype]-Abandonment Rate 1[company,featuretype]-Feature Completion Rate 1[company,featuretype],0)
Units: Features
1st stage of feature development

Features Under Development 2[company,featuretype]= INTEG (+Feature Completion Rate 1[company, featuretype]-Abandonment Rate 2[company,featuretype]-Feature Completion Rate 2[company,featuretype],0)
Units: Features
2nd stage of feature development

Features Under Development 3[company,featuretype]= INTEG (+Feature Completion Rate 2[company,featuretype]-Abandonment Rate 3[company,featuretype]-Feature Completion Rate 3[company,featuretype],0)
Units: Features
3rd stage of feature development

FINAL TIME = 720
Units: Month
The final time for the simulation.

Firm Cash for Cost Share Agreement=IF THEN ELSE(Technology Development Switch for Cost Share =0,0,Cost Share Amount*(1-Public Cost Share Fraction))
Units: Dollars/Month
Fraction of total cost share funding that is paid by the firm

Fraction effort for adoption=IF THEN ELSE(Weighted total prospects>0, ((1-Fraction effort for knowledge)*(Purchasers Emphasis Multiplier*Purchasers)/Weighted total prospects), 0)
Units: Dmnl
Fraction of sales effort to make sure purchasers start using product

Fraction effort for decision=IF THEN ELSE(Weighted total prospects>0, ((1-Fraction effort for knowledge)*(Hot Prospect Emphasis Multiplier*Hot Prospects)/Weighted total prospects), 0)
Units: Dmnl [0,1]
Percent of effort of sales people applied to persuading prospects to seriously consider purchasing

Fraction effort for knowledge=0.25
Units: Dmnl
Percent of sales effort devoted to converting potential prospects to prospects

Fraction effort for persuasion=IF THEN ELSE(Weighted total prospects>0,((1-Fraction effort for knowledge)*(Prospect Emphasis Multiplier*Prospects)/Weighted total prospects), 0)
Units: Dmnl [0,1]
Percent of effort of sales people applied to persuading prospects to trial
Fraction Of Firms Capable Of Adopting=(Effect Of Features On Fraction of Firms Capable of Adopting*(Effect Of Price On Fraction of Firms Capable of Adopting)*(Effect Of Technology On Fraction of Firms Capable of Adopting))
Units: Dimnl
Initial capability of firms to adopt is affected by features and technology relative to the initial features and initial technology development

Fractional Eng Attrition Rate = 0.02
Units: 1/Month
Percent of engineers that leave per month

Frequency of Private Funding=36
Units: Months
The frequency with which VCs evaluate and invest in the firm

FUD Adjustment Time[company,featuretype]=2
Units: Months [0,10,0.1]
How long to take to adjust FUD to desired level

Function for Effect of Approaching Theoretical Maximum Technology Development Eng Hrs Required per Technology([(0,0),(1,1e+008)],(0,2000),(0,1,3000),(0,2,4000),(0,3,5000),(0,4,6000),(0,5,7000),(0,6,100 00),(0,7,100000),(0,8,1e+006),(0,9,1e+007),(1,1e+008))
Units: Person*Hours/Feature
As the theoretical maximum of a technology is approached the number of hours necessary to develop a technology increases

Function for Effect of Features on Investor Win Fraction([(0,0)-(4,4)],(0,0),(0,1),(1,1),(2,2),(3,3),(4,4))
Units: Dimensionless
The multiple of funding an investors is willing to invest because of the superiority of functionality of the product

Function for Effect of Market Size on Private Investment Win Fraction([(0,0)-(1000,600)],(0,0),(0,1),(0,10,0),(0,100,300),(0,1000,500))
Units: Dimensionless
No funding will be provided if the market size is below the threshold. Once the minimum market size is reached then the higher the multiple the higher the funding multiple.s

Function for Effect of Technology Development on Cost Share Fraction([(0,0)-(1,1)],(0,3.0),(0,3.0,67),(0,4,0.67),(0,4,0.5),(0,5,0.33),(0,6,0.33),(0,6,0))
Units: Dimnl
Cost Share Fraction depends on the development of the firms technology, relative to a reference value representing the physical limit to technology development. The higher the value of the technology development relative to the reference, the lower the cost share fraction because governments only pay for risky, long-term technology development

Function for Effect of Technology Development on Public RD Funding([(0,0)-(1,1)],(0,1),(0,5,0),(1,0))
Units: Dimnl
Cost Share Fraction depends on the development of the firms technology, relative to a reference value representing the physical limit to technology development. The higher the value of the technology development relative to the reference, the lower the cost share fraction because governments only pay for risky, long-term technology development

Function for Effect of Technology on Investor Win Fraction([(0,0)-(4,4)],(0,0),(0,1),(1,1),(2,2),(3,3),(4,4))
Units: Dimensionless
The multiple of funding an investor is willing to invest because of the superiority of functionality of the product
Function for Effect of Unit Cost on Investor Win Fraction:
\[ ((-0.1,0)-(4,2),(0,0),(0,1),(1,1),(1,1),(1.25,1.35),(1.6,1.65),(2,1.85),(2.5,1.95),(3,2)) \]
Units: Dimensionless
The multiple of funding a investor is willing to invest because of the cost difference compared to the competition.

Functionality Threshold as a Multiple of Incumbent Functionality = 2
Units: Dimensionless
The factor of superiority the product functionality must be over competitors.

Funding Frequency = 36
Units: Months
The frequency with which a single public funding pulse occurs.

Funds Raised From Private Investors = (1 - Investor Exit Switch) * (Indicated Funds from Private Investors / TIME STEP) * PULSE TRAIN(0,0, Frequency of Private Funding, FINAL TIME)
Units: Dollars/Month
Funds raised from private investors at the investor decision date.

Government Market Stimulation = INTEG (Market Stimulation Payouts, 0)
Units: Dollars
The amount of public spending to promote market stimulation.

Gross Profit = Revenue - COGS
Units: Dollars/Month
The amount of money a firm makes from sales less the cost of the goods sold.

Hot Prospect Emphasis Multiplier = 4
Units: Dmnl
Emphasis sales force places on hot prospects.

Hot prospect loss rate = MAX(0, Norm Decision Rate - Purchase Rate)
Units: Prospects/Month
If rate of persuasion is not great enough to keep prospects from remaining the maximum prospect lifetime, then this is the rate they will be lost at.

Hot Prospects = INTEG (Persuasion Rate - Hot prospect loss rate - Purchase Rate, Initial Hot Prospects)
Units: Prospects
Prospects who have been qualified to be more likely to purchase and/or are trialing the product.

Increase Adopters Switch = 0
Units: Dimensionless [0,1,1]
Whether's there's a policy that will effect firms capab to adopt.

Increase Adoption Capab Switch = 0
Units: Dimensionless [0,1,1]
Whether's there's a policy that will effect firms capab to adopt.

Increase In Addressable Market = Effect of Marketing Effort on Market Size Fn(Normalized Marketing)
Units: 1/Month
Increase in market (potential prospects) based on the effectiveness of marketing efforts.

Increase in Adopters Due To Policy = Increase Adopters Switch * RAMP(Increase of Adopters/Adopter Increase Ramp Time, Adopter Increase Start Time, (Adopter Increase Start Time + Adopter Increase Ramp Time))
Units: Dimensionless
Ramp up effect of policy to increase capab of adoption.
Increase In Eng Experience = Engineers * Eng Work Month + Adoption Rate * Exp Gain Per Adoption
Units: Persons * Hours/Month
Engineers learn from time spent working and from experience with adopters

Increase In Potential Prospects = Total Population * Increase In Addressable Market * Fraction Of Firms Capable Of Adopting * (1 + Increase in Adopters Due To Policy)
Units: Prospects/Month
Tracks increase in size of potential market by fraction of total firms that we are able to address that are capable of adopting product per time period

Increase In Sales Experience = Sales Force * Sales Work Month + Adoption Rate * Exp Gain Per Purchase
Units: Persons * Hours/Month
Sales people learn from time spent working and from experience making sales (purchases)

Increase of Adopters = 0.05
Units: Dimensionless [0, 1, 0.01]
What additional fraction of firms will be capable of adopting per month

Increase of Adoption Capab = 0.05
Units: Dimensionless [0, 1, 0.01]
What additional fraction of firms will be capable of adopting per month

Increase Of Capab Of Firms To Adopt Due To Policy = Increase Adoption Capab Switch * RAMP (Increase of Adoption Capab/Adoption Capab Increase Ramp Time, Adoption Capab Increase Start Time, (Adoption Capab Increase Start Time + Adoption Capab Increase Ramp Time))
Units: Dimensionless
Ramp up effect of policy to increase capab of adoption

Indicated Cost Share Amount = Technology Development Switch for Cost Share * Cost Share Switch * (IF THEN ELSE (Funds Raised From Private Investors >= 0, MIN (Funds Raised From Private Investors * TIME STEP / (1 - Public Cost Share Fraction), Maximum Cost Share Investment), 0))
Units: Dollars
Cost Share amount is determined by the technology development and the available working capital

Indicated Desired Engineers = MIN (Desired Engineers, Maximum Employees from Current Size)
Units: People
The number of engineers the firm wishes to have in total

Indicated Desired Sales Force = MIN (Desired Sales Force, Maximum Sales Force from Current Size)
Units: People
The total number of sales personnel desired

Indicated Funds from Private Investors = Available Private Investor Financing
Units: Dollars
The magnitude of the VC funding pulse is the minimum of what was desired and what was granted IF THEN ELSE (VC Financing Asking Amount <= Available VC Financing, VC Financing Asking Amount, Available VC Financing)

Indicated Private Investment Win Fraction = MAX (Effect of Functionality on Private Investment Win Fraction, Effect of Unit Cost on Private Investment Win Fraction) * Effect of Market Size on Private Investment Win Fraction
Units: Dimensionless
The fraction of funding a VC is willing to invest because of the combined effect of market size, technology cost and technology functionality.

Indicated Public RD Funding = Maximum Public RD Funding * Public RD Funding Fraction
Units: Dollars
Actual amount of public R&D funding each pulse
Inflow of Technology Development Funding = (1 - Switch for Relaxing Public Funding Restrictions) * Inflows of Public Capital
Units: Dollars/Month
Infow of cash to fund technology development

Inflows Of Capital = Switch for Relaxing Public Funding Restrictions * (Inflows of Public Capital) + Cash Received From Customers + Funds Raised From Private Investors + Cost Share Amount
Units: Dollars/Month
Cash coming in per month

Inflows of Public Capital = Public RD Investment
Units: Dollars/Month
The sum of total funding from the government.

Initial Adopters = 0
Units: Prospects
Start with no adopters

Initial Avg Engineering Experience = 10000
Units: Hours [0, 60000, 50]
How much relevant experience initial engineers have on average

Initial Avg Sales Experience = 1500
Units: Hours
How much experience initial sales people have on average

Initial Capab of Firms to Adopt = 0.05
Units: Dmnl [0, 1, 0.01]
Fraction of firms initially that are capable of adopting product

Initial Competitor Cost Per Unit = 100000
Units: Dollars/Unit
How much it costs competitor to produce the competing unit. Assume this is a mature technology and that learning does not reduce their costs

Initial Cost Per Unit = 2e+006
Units: Dollars/Unit
Cost of the technology when the technology is first invented

Initial Engineers = 2
Units: Persons [0, 40, 0.1]
Number of engineers company initially has

Initial Features[company, featuretype] = 0, 0; 100, 2;
Units: Features [0, 300, 0.1]
Amount of features product has when firm starts compared to competitors

Initial Hot Prospects = 0
Units: Prospects [0, 1000, 1]
Initial number of prospects actively evaluating the firm’s technology

Initial Payment = Price * Initial Payment Fraction
Units: Dollars/Unit
Amount that customer pays up front

Initial Payment Fraction = 1
Units: Dmnl [0, 1, 0.01]
Fraction of price that is paid by customer up front
Initial Potential Prospects=0
Units: Prospects
Initial potential prospects are firms initially capable of adopting the RET that could presumably be evaluating the entire field of RET options to replace their current fossil-fuel technologies.

Initial Prospects=0
Units: Prospects [0,1000,1]
Initial prospects are all the firms initially capable of adopting that are aware of their options and have not ruled out purchasing the RET venture’s technology.

Initial Public Investment=-3e+006
Units: Dollars [0,1e+007,10000]
The initial public investment in R&D.

Initial Purchasers=0
Units: Prospects [0,1000,1]
Start with no purchasers.

Initial Sales Force=0
Units: Persons [0,20,0.1]
Number of sales people company initially has.

Initial Technology Development[company]=1,40
Units: Features [0,300,0.1]
Amount of technology development when firm starts compared to competitors.

INITIAL TIME =0
Units: Month
The initial time for the simulation.

Initial Total Population=1e+006
Units: Prospects
Max possible number of adopters.

Investor Exit Switch=IF THEN ELSE ((ZIDZ(Cumulative Profit,Total Private Investments))>Private Investor Required Rate of Return,1,0)
Units: Dimensionless
If VC return is met, VC funding stops.

Units: Prospects/(Person*Hour)
The persuasion rate of sales effort as affected by price and features.

Knowledge Rate=Norm Knowledge Rate*Prospect Conversion Fn(ZIDZ(Potential Knowledge From Sales Effort,Norm Knowledge Rate))
Units: Prospects/Month
The rate of persuading prospects to become hot prospects is determined by the persuasion from sales effort until it asymptotically approaches the normal conversion rate (prospects are not persuaded faster than that).

Knowledge Sales Effort=Fraction effort for knowledge*Sales Effort
Units: Persons*Hours/Month
Total number of hours spent by the sales force on persuasion per month.
Log of Working Capital=log(IF THEN ELSE (Working Capital<=0, 1,Working Capital), 10)
    Units: Dimensionless
    Semi log plot for depicting the "valley of death"

Loss Of Eng Experience=(Engineer Lay Offs+Eng Attrition Rate)*Avg Engineer Experience
    Units: Persons*Hours/Month
    Experience lost when engineers leave

Loss Of Sales Experience=(Sales Layoffs+Sales Attrition Rate)*Avg Sales Experience)
    Units: Persons*Hours/Month
    Experience lost when sales people leave

Lost Prospect Lifetime=12
    Units: Months
    Amount of time before a lost prospect will reconsider becoming a prospect

Lost Prospects= INTEG (Adopter loss rate+Hot prospect loss rate+Potential Prospect Loss Rate+Prospect Loss Rate+Purchaser Loss Rate-Prospect Regain Rate,0)
    Units: Prospects
    Former prospects who currently are not considering adopting the product

Maintenance Billing=Adopters*Quantity Per Purchase*Price*Maintenance Fraction*Maintenance Period
    Units: Dollars/Month
    Amount being charged to adopters per month for maintenance

Maintenance COGS=Maintenance Billing*(1-Maintenance Margin)
    Units: Dollars/Month
    The costs for maintenance

Maintenance Fraction=0.2
    Units: Dmnl
    The fraction of the price that is charged per period

Maintenance Margin=0.8
    Units: Dmnl
    The fraction of the maintenance charge which is profit

Maintenance Period=1/12
    Units: 1/Month
    The period over which the maintenance charge is made (i.e. 1/12 of a yearly fee is charged monthly)

Market Stimulation Payouts=Total Obligation Spent on Firm+Total Subsidy spent on Firm
    Units: Dollars/Month
    Amount of public funding used to stimualte the market

Marketing Effort=MIN(Desired Marketing Effort, 0.5*SalesMktg Effort)
    Units: Persons*Hours/Month
    Spend no more than 50% of total sales effort on marketing, up to the desired marketing effort

Max Adoption Productivity From Sales=1
    Units: Prospects/(Person*Hour) [0,?]
    Maximum number of purchasers that will able to start using product per hour of sales effort

Max Competitor Margin=0.3
    Units: Dmnl
    Maximum margin competitor will extract

Max Decision Productivity From Sales=1/16
    Units: Prospects/(Person*Hour) [0,?] 
    Maximum number of prospects that can be persuaded per person-hour of sales effort
Max Eng Vacancy Cancellation Rate = Eng Vacancies / Eng Vacancy Cancellation Time
Units: Persons / Month
The maximum engineering vacancy cancellation rate is determined by the number of vacancies outstanding and the minimum cancellation time.

Max Hires Per Month = MIN(Change in Workforce Required / Months for Runway Adjustment, Total Labor * Maximum Workforce Growth Rate)
Units: People / Month
Maximum number of people to be added (or if negative, subtracted) from work force. Constrained to be less than the maximum fractional assimilation/growth rate for the labor force.

Max Knowledge Productivity From Sales = 1 / 4
Units: Prospects / (Person * Hour) [0, ?]
Maximum number of prospects that can be created per person-hour of sales effort

Max Persuasion Productivity From Sales = 1 / 8
Units: Prospects / (Person * Hour) [0, ?]
Maximum number of prospects that can be persuaded per person-hour of sales effort

Max Sales Productivity Multiplier = 10
Units: Dimensionless
Max amount of productivity multiple that experience can bring

Max Sales Vacancy Cancellation Rate = Sales Vacancies / Sales Vacancy Cancellation Time
Units: Persons / Month
The maximum sales vacancy cancellation rate is determined by the number of vacancies outstanding and the minimum cancellation time.

Maximum Cost Share Investment = 2.5e+008
Units: Dollars
The highest amount of funding that can offered for a cost-shared public-private partnership

Maximum Employees from Current Size = MAX(Minimum Headcount for Expansion, Engineers * Maximum Expansion Ratio)
Units: People
The maximum number of engineers that can be supported

Maximum Expansion Ratio = 1.01
Units: Dimensionless [0, 6]
The largest incremental increase in the number of engineers

Maximum Layoff Rate = Engineers / Average Layoff Time
Units: People / Month
Maximum layoff rate is determined by the number of engineers and the layoff time.

Maximum Private Investor Financing = 5e+007
Units: $
The highest amount of funding an investor is willing to offer

Maximum Public RD Funding = 1.655e+007
Units: Dollars
The maximum amount of a single public funding investment for R&D

Maximum Sales Force Expansion Ratio = 1.05
Units: Dimensionless
The largest multiple by which the sales force can increase
Maximum Sales Force from Current Size = \( \max(\text{Minimum Headcount for Sales Force Expansion}, \text{Sales Force} \times \text{Maximum Sales Force Expansion Ratio}) \)
Units: People
The size of the sales force that can be supported

Maximum Workforce Growth Rate = IF THEN ELSE(Switch for Product Development = 0, 0.01, 0.25)
Units: 1/Months
The maximum fractional rate of expansion for the labor force the firm can achieve/tolerate/assimilate.

Min Competitor Margin = 0.3
Units: Dimensionless [0, 0.3, 0.01]
Minimum margin competitor needs to charge

Min Development Fraction = 0.5
Units: Dmnl
Min percent of engineering effort to devote to development

Min Gross Margin = 0
Units: Dmnl
Minimum margin company will charge (can be negative if wish to sell at below cost to gain initial sales)

Min Marketing Effort = 350
Units: Person*Hours/Month
Min effort we want to devote to marketing

Min Price = Cost Per Unit / (1 - Min Gross Margin)
Units: Dollars/Unit
Min price will sell at

Min Runway = 3
Units: Months
The min months of runway we need overall, so if less than this will need layoffs

Min Runway In Order To Hire = 12
Units: Months
Minimum number of months of burn we can have in order to hire new employees

Minimum Headcount for Expansion = 5
Units: People [0, 40]
The fewest number of people required before expansion limitations are realized

Minimum Headcount for Sales Force Expansion = 2
Units: People [0, 10]
The number of people required before limitations to expansion are imposed

Minimum Market Size for Private Investment = 3e+008
Units: $
The minimum market size that would be worth private sector investment

Minimum Private Investor Financing = 100000
Units: $
The smallest amount of funding that an investor is willing to offer

Units: Features
The minimum amount of technology development necessary for the technology to begin to be marketed
Minimum Technology Development as a Fraction of the Theoretical Maximum[company]=0.25
Units: Dimensionless [-1,1]
The fraction of of the theoretical maximum technology development required before a technology can
be marketable

Months for Runway Adjustment=2
Units: Months [0,6,6e-006]
How long to take to adjust hiring/firing based on runway

Months of Runway=Working Capital/Burn Rate
Units: Months
If we're burning cash, then months of cash we have left. If positive cash flow, then this will be a very
large number

Net Income=Operating Income-Defaults on AR
Units: Dollars/Month
The amount of money a firm has after defaults on accounts receivable have been removed

Nominal Subsidy=(Price*-Subsidy Policy Effect on Price)*Subsidy Policy
Units: Dollars/Unit
Amount of money subsidized to the customer when making a purchase

Nonappropriable Feature Development Fraction=0.5
Units: Dimensionless
Fraction of development effort applied to non-appropriable features (as opposed to approbriable
features)

Nonappropriable Feature Multiple=100
Units: Dimensionless
Avg multiple of value of approbriable features that nonapprobriable features have

Norm Adoption Rate=Purchasers/Avg Purchaser Lifetime
Units: Prospects/Month
Rate at which purchasers could start using the product

Norm Decision Rate=Hot Prospects/Avg Hot Prospect Lifetime
Units: Prospects/Month
Rate at which prospects can be persuaded to trial the product

Norm Knowledge Rate=Potential Prospects/Avg Potential Prospect Lifetime
Units: Prospects/Month
Rate at which prospects can be persuaded to trial the product

Norm Persuasion Rate=Prospects/Avg Prospect Lifetime
Units: Prospects/Month
Rate at which prospects can be persuaded to trial the product

Normal Adopter Loss Fraction=0.01
Units: 1/Months
What fraction of adopters we lose every month normally

Normal Default Fraction=0.002
Units: 1/Month
The 'normal' fraction of customers that default on what they owe per month

Normal Hazard Rate=0.05
Units: 1/Month
Given normal values for hazard rate components, the normal hazard rate of failure
Normalized Cust Fincl Condition=1
Units: Dimensionless
How able customers are able to pay their bills compared to normal (1 is normal, 0 means they are bankrupt, and >1 means they have cash to spare)

Normalized Cust Support=xIDZ(Engineering Effort for Cust Support,Cust Support Needed,1)
Units: Dmnl
Fraction of max cust support effectiveness (If we don’t need any cust support, then we’re supplying all that is needed). Also amount of cust support determines how soon product is “delivered”.

Normalized Features=Feature Value[self]/Feature Value[competitor]
Units: Dmnl
Features of our company compared to competition (0 is no features, 1 is equiv features to competition)

Normalized Marketing=ZIDZ(Marketing Effort,Desired Marketing Effort)
Units: Dmnl
Normalized marketing determined by proportion of sales/marketing resources we have compared to desired

Normalized Price=Price* Price Adjustment Fraction Due To Policy/Competitor Price
Units: Dmnl [0,50]
Normalized price (actual price divided by competitor/reference price)

Normalized Technology=Technology Value[self]/Technology Value[competitor]
Units: Dmnl
Technologies of our company compared to competition (0 is no technology, 1 is equiv technology to competition)

Normalized Word of Mouth=ZIDZ((Contact Rate*Potential Prospects*ZIDZ(Adopters,Total Population)),Word of Mouth Reference)
Units: Dmnl
Adoption by word of mouth is driven by the contact rate between potential adopters and active adopters. The word of mouth effect is small if the number of active adopters relative to the total population size is small.

Operating Income=Gross Profit-Total Salary Expense
Units: Dollars/Month
The firm income after paying salaries of employees

Outflow of Technology Development Funding=Technology Development Salary Expense
Units: Dollars/Month
Cash being paid each month for technology development

Outflows Of Capital=((1-Switch for Relaxing Public Funding Restrictions)*(Salary Expense Net Technology Development Salary Expense))+COGS+Firm Cash for Cost Share Agreement+(Switch for Relaxing Public Funding Restrictions*Total Salary Expense)
Units: Dollars/Month
Cash being paid out per month

Perceived Feature Obsolescence Rate[company,featuretype]=Feature Obsolescence Rate[company,featuretype]
Units: Feature/Month
What managers believe feature obsolescence rate is based on the actual rate (assume perception meets reality)

Perceived Technology Obsolescence Rate[company]=Technology Obsolescence Rate[company]
Units: Feature/Month
What managers believe technology obsolescence rate is based on the actual rate (assume perception meets reality)
Persuasion Productivity Of Sales Effort = \min(\max(\text{Persuasion Productivity From Sales, Sales Experience Multiplier} \cdot \max(\text{Persuasion Productivity From Sales} \cdot \text{Effect Of Features On Persuasion Efficiency} \cdot \text{Effect Of Price On Persuasion Efficiency} \cdot \text{Effect Of Marketing On Persuasion Efficiency} \cdot \text{Effect Of Word Of Mouth On Persuasion Efficiency} \cdot \text{Effect Of Technology On Persuasion Efficiency}), \text{Sales Experience}))

Units: Prospects/(Person\cdot\text{Hour})

The persuasion rate of sales effort as effected by price and features

\text{Persuasion Rate} = \text{IF THEN ELSE}(\text{Norm Persuasion Rate} > 0, \text{Norm Persuasion Rate} \cdot \text{Prospect Conversion Fn}(\text{ZIDZ(\text{Potential Persuasion From Sales Effort, Norm Persuasion Rate)}), 0), 0)

Units: Prospects/Month

The rate of persuading prospects to become hot prospects is determined by the persuasion from sales effort until it asymptotically approaches the normal conversion rate (prospects are not persuaded faster than that)

\text{Persuasion Sales Effort} = \text{Fraction effort for persuasion} \cdot \text{Sales Effort}

Units: Persons\cdot\text{Hours/Month}

Total number of hours spent by the sales force on persuasion per month

\text{Portion of Min Effort for Marketing} = \text{Fn}([0,0)-(0.005,10)],(0,10),(0.001,2),(0.002,1.5),(1,1.2),(1.47401,1.1),(1.85933,1.05),(100,1])

Units: Dmnl

If 0 Prospects, then devote max time to marketing, and if equal or more prospects compared to population, devote most of time to sales, and asymptotic in between!

\text{Potential Adoption From Sales Effort} = \text{Adoption Sales Effort} \cdot \text{Adoption Productivity Of Sales Effort}

Units: Prospects/Month

The amount of effort the sales people apply to persuasion times the productivity of that effort (which is determined by attributes of the product)

\text{Potential Decision From Sales Effort} = \text{Decision sales effort} \cdot \text{Decision Productivity Of Sales Effort}

Units: Prospects/Month

The amount of effort the sales people apply to persuasion times the productivity of that effort (which is determined by attributes of the product)

\text{Potential Knowledge From Sales Effort} = \text{Knowledge Sales Effort} \cdot \text{Knowledge Productivity Of Sales Effort}

Units: Prospects/Month

The amount of effort the sales people apply to persuasion times the productivity of that effort (which is determined by attributes of the product)

\text{Potential Market Size} = \text{Total Population} \cdot \text{Fraction Of Firms Capable Of Adopting} \cdot \text{Quantity Per Purchase} \cdot \text{Target Price} + \text{Increase Adopters Switch} \cdot \text{Total Population} \cdot \text{Fraction Of Firms Capable Of Adopting} \cdot \text{Quantity Per Purchase} \cdot \text{Target Price} \cdot (1 + \text{Increase of Adopters})

Units: $

The size of the entire market

\text{Potential Persuasion From Sales Effort} = \text{Persuasion Sales Effort} \cdot \text{Persuasion Productivity Of Sales Effort}

Units: Prospects/Month

The amount of effort the sales people apply to persuasion times the productivity of that effort (which is determined by attributes of the product)

\text{Potential Prospect Loss Rate} = \max(0, \text{Norm Knowledge Rate} - \text{Knowledge Rate})

Units: Prospects/Month

If rate of persuasion is not great enough to keep prospects from remaining the maximum prospect lifetime, then this is the rate they will be lost at

\text{Potential Prospects} = \text{INTEG} (\text{Increase In Potential Prospects} + \text{Prospect Regain Rate} - \text{Knowledge Rate} - \text{Potential Prospect Loss Rate}, \text{Initial Potential Prospects})

Units: Prospects

Potential customers that have been selected to apply sales effort to persuade to trial the product.
Price = MAX(Target Price, Min Price)
    Units: Dollars/Unit
    If target price is greater than the min price we can charge, charge that. Otherwise, charge our min price.

Price Adjustment Fraction Due To Policy = \( l + (\text{Subsidy Policy} \times \text{RAMP( Subsidy Policy Effect on Price/Subsidy Policy Ramp Time, Subsidy Policy Start Time, (Subsidy Policy Start Time + Subsidy Policy Ramp Time)})\)
    Units: Dimensionless
    If there's a subsidy policy, then effect on our cost will ramp up to it's full effect starting at start time and taking the amount of time specified by ramp time.

Private Funding = Funds Raised From Private Investors
    Units: Dollars/Month
    Funds raised from private investors at the investor decision date

Private Investments = Funds Raised From Private Investors
    Units: Dollars/Month
    New investments to add to Total Investments

Private Investor Required Rate of Return = 1.3
    Units: Dimensionless
    The rate of return that VCs require on their investment

Product COGS = Cost Per Unit * Purchase Rate * Quantity Per Purchase
    Units: Dollars/Month
    Cost of goods sold for products sold

Product Development Effort\[self,approp\] = IF THEN ELSE (Cash for Firm Operations <= 0, 0, Appropriaible Feature Development Fraction * Engineering Effort Net of Customer Support * (1 - Technology and Product Development Effort Allocation\[self\]))


Product Development Effort\[competitor,featuretype\] = 8750, 8750
    Units: Persons*Hours/Month
    Assume competitor has 50 people each for approb and nonapprob feature devl

Product Features Under Development\[company,featuretype\] = INTEG (+Feature Start Rate\[company,featuretype\] - Abandonment Rate\[company,featuretype\] - Feature Completion Rate\[company,featuretype\], 0)
    Units: Features
    Features that are being worked on by the engineering staff

Productive Eng Work Month = Eng Work Month * Engineering Experience Productivity Multiplier
    Units: Hours/Month
    Productive hours worked per month by engineers (experienced engineers are more productive)

ProspectConversionFn\([((0,0),(2e+016,1),(0,0),(0.5,0.5),(0.75,0.7),(1,0.85),(1.25,0.95),(1.5,1),(100,1),(0,0),(0.5,0.5),(0.75,0.7),(1,0.85),(1.25,0.95),(1.5,1),(1e+016,1)])\)
    Units: Dimnl
    The fraction of prospects that move to the next stage

Prospect Emphasis Multiplier = 2
    Units: Dimnl
    Emphasis sales force places on prospects

Prospect Loss Rate = MAX(0, (Norm Persuasion Rate - Persuasion Rate))
    Units: Prospects/Month
    If rate of persuasion is not great enough to keep prospects from remaining the maximum prospect lifetime, then this is the rate they will be lost at
Prospect Regain Rate = Lost Prospects / Lost Prospect Lifetime
Units: Prospects/Month
Rate at which lost prospects become potential prospects again

Prospect to Population Ratio = ZIDZ(Total Prospects, Total Population)
Units: Dimn
Ratio between all current prospects and total population

Prospects = INTEG (Knowledge Rate - Persuasion Rate - Prospect Loss Rate, Initial Prospects)
Units: Prospects
Potential customers that have been selected to apply sales effort to persuade to trial the product.

Public Cost Share Fraction = Function for Effect of Technology Development on Cost Share Fraction
(Cumulative Technology Development / Theoretical Maximum Technology Development[Self])
Units: Dimn
The fraction of a cost shared project that will be funded by the public sector

Public Development Investments = (Public RD Investment + Cost Share Amount * Public Cost Share Fraction) * EXP(-Effective Discount Rate * Time)
Units: Dollars/Month
Discounted public funding for development

Public Investments = (Public RD Investment + Cost Share Amount * Public Cost Share Fraction + Market Stimulation Payouts) * EXP(-Effective Discount Rate * Time)
Units: Dollars/Month
New investments to add to Total Investments

Public RD Funding Fraction = Function for Effect of Technology Development on Public RD Funding
(Cumulative Technology Development / Theoretical Maximum Technology Development[Self])
Units: Dimn
The percentage of the total public R&D funding. As technology development increases, the government sponsors less R&D money

Public RD Investment = Indicated Public RD Funding / TIME STEP * PULSE TRAIN(0,0,Funding Frequency,FINAL TIME)
Units: Dollars/Month
An instantaneous pulse of public R&D funding each period

Purchase Rate = IF THEN ELSE(Norm Decision Rate > 0, Norm Decision Rate * Prospect Conversion Fn(ZIDZ(Potential Decision From Sales Effort, Norm Decision Rate)), 0)
Units: Prospects/Month
The rate of persuading hot prospects to purchase the product

Purchaser Loss Rate = MAX(0, Norm Adoption Rate - Adoption Rate)
Units: Prospects/Month
Rate at which purchasers choose not to use the product

Purchasers = INTEG (Purchase Rate - Adoption Rate - Purchaser Loss Rate, Initial Purchasers)
Units: Prospects
Prospects who have purchased but aren't using

Purchasers Emphasis Multiplier = 1
Units: Dimn
Emphasis sales force places on purchasers (since they already purchased, relatively less emphasis)

Quantity Per Purchase = 1
Units: Units/Prospect [0, 20, 2e-005]
Average number of units each adopter purchases/uses at a time
Reference Production for Initial Cost = 1
Units: Prospects
Initial Cost is assuming already produced this many of product

Reference Technology Development for Initial Cost = 1
Units: Features
Initial Cost is assuming already produced this many of product

Reset Annual Cash Flow from Private Investment = IF THEN ELSE (Reset Switch = 1, Annual Cash Flow from Private Investment Stock / TIME STEP, 0)
Units: Dollars/Month
Reset annual Private Investment to zero at the beginning of next year in order to restart the accumulation of annual revenue for next year.

Reset Annual Cash Flow from RD Funding = IF THEN ELSE (Reset Switch = 1, Annual Cash Flow from Public RD Funding / TIME STEP, 0)
Units: Dollars/Month
Reset annual revenue to zero at the beginning of next year in order to restart the accumulation of annual revenue for next year.

Reset Annual Total Cash Flow from Public Funding = IF THEN ELSE (Reset Switch = 1, Annual Total Cash Flow from Public Funding Stock / TIME STEP, 0)
Units: Dollars/Month
Reset annual public funding to zero at the beginning of next year in order to restart the accumulation of annual revenue for next year.

Reset Interval = 0.5
Units: Month
Length of reset time step for plotting

Reset Switch = IF THEN ELSE (Cumulative Ticks >= Reset Interval, 1, 0)
Units: Dimensionless
To keep reset log of of time step for plotting

Reset ticks = IF THEN ELSE (Reset Switch = 1, Cumulative Ticks / TIME STEP, 0)
Units: Dimensionless
To keep track of time step for plotting

Revenue = Price * Purchase Rate * Quantity Per Purchase + Maintenance Billing
Units: Dollars/Month
The amount of money the firm makes from sales

Salary Expense Net Technology Development Salary Expense = Total Salary Expense - Technology Development Salary Expense
Units: Dollars/Month
The amount of salary paid for effort other than technology development effort

Sales Attrition Rate = Sales Force * Sales Fractional Attrition Rate
Units: Persons/Month
Rate at which sales people leave (quit)

Sales Average Layoff Time = 2
Units: Months
The average time required to lay off a sales person

Sales Effort = SalesMktg Effort - Marketing Effort
Units: (Person * Hours) / Month
Effort devoted to direct sales
Sales Experience = \text{INTEG (Increase In Sales Experience + Sales Experience From Hiring - Loss Of Sales Experience, Initial Sales Force * Initial Avg Sales Experience)}

Units: Persons * Hours

Cumulative sales experience of organization

Sales Experience From Hiring = Sales Hiring Rate * Avg Experience Of New Sales Hires

Units: Persons * Hours / Month

Experience gain from hiring

Sales Experience Productivity Multiplier = \text{MIN((Avg Sales Experience / Sales experience reference) } ^ \left(\frac{1 + Sales Productivity Change Per Double Experience}{LN(2)}\right), \text{ Max Sales Productivity Multiplier)}

Units: Dim

Learning curve for productivity from experience (from Sterman pg 507, from Zangwill and Kantor (1998))

Sales experience reference = 2000

Units: Hours

Amount of sales experience which will produce normal productivity

Sales Force = \text{INTEG (+Sales Hiring Rate - Sales Attrition Rate - Sales Layoffs, Initial Sales Force)}

Units: Persons

Number of sales and marketing employees

Sales Force Adjustment Time = 6

Units: Months [0, 90, 1]

The time period over which the firm seeks to bring the sales force in line with the desired level.

Sales Fractional Attrition Rate = 0.02

Units: 1 / Month

Percent of sales people that leave per month

Sales Hiring Rate = \text{(Sales Vacancies / Avg Time to Fill Sales Vacancies) * (1 - Bankrupt Switch)}

Units: Persons / Month

Hire sales people based on how many vacancies have been created and the avg time to fill them

Sales Layoffs = \text{MAX(Bankrupt Switch * ((Sales Force / TIME STEP) - Sales Attrition Rate), MIN(Desired Sales Lay Off Rate, Sales Maximum Layoff Rate))}

Units: Persons / Month

Sales people being layed off per month

Sales Maximum Layoff Rate = Sales Force / Sales Average Layoff Time

Units: People / Month

Maximum layoff rate is determined by the number of sales people and the layoff time.

Sales Productivity Change Per Double Experience = 0.4

Units: Dim

Fractional change in productivity of sales people per doubling of their effective experience

Sales Proportion = ZIDZ(Sales Force, Total Labor)

Units: Dimensionless

Proportion of workforce made up of sales people

Sales Vacancies = \text{INTEG (Sales Vacancy Creation Rate - Sales Vacancy Closure Rate - Sales Vacancy Cancellation Rate, Desired Sales Vacancies)}

Units: People

The number of open sales positions the firm seeks to fill.

Sales Vacancy Adjustment Time = 1

Units: Months

The average time over which to adjust the actual number of sales vacancies to the desired level.
Sales Vacancy Cancellation Rate = \text{MIN}(\text{Desired Sales Vacancy Cancellation Rate, Max Sales Vacancy Cancellation Rate})

- Units: Persons/Month
- The rate at which to cancel existing sales vacancies prior to filling them.

Sales Vacancy Cancellation Time = 1

- Units: Months
- The average time required to cancel a sales vacancy.

Sales Vacancy Closure Rate = Sales Hiring Rate

- Units: Persons/Month
- Vacancies are closed when the employee is hired.

Sales Vacancy Creation Rate = \text{MAX}(0, \text{Desired Sales Vacancy Creation Rate})

- Units: Persons/Month
- The rate at which to create new sales positions and begins to recruit for them.

Sales Work Month = 175

- Units: Hours/Month
- How many hours worked per month by sales people

Sales Mktg Effort = \text{IF THEN ELSE} (\text{Cash for Firm Operations} \leq 0, 0, \text{Sales Force} \times \text{Sales Work Month} \times \text{Sales Experience Productivity Multiplier})

- Units: Person*Hours/Month
- Total effort for sales and marketing

SAVEPER = \text{TIME STEP}

- Units: Month [0,?] 
- The frequency with which output is stored.

Subsidy Policy = \text{IF THEN ELSE} ((\text{Cost Per Unit/Competitor Price}) < 1, 0, \text{Subsidy Policy Switch})

- Units: Dimensionless [0,1,1]
- Whether's there's a subsidy policy or not that will effect our costs

Subsidy Policy Effect on Price = -0.2

- Units: Dimensionless [-1,0,0.01]
- What fraction our price will change based on subsidy policy (-0.1 = 10% decrease, 1 = double, -1 means it goes to 0)

Subsidy Policy Ramp Time = 10

- Units: Months
- Time it takes for subsidy policy to take full effect

Subsidy Policy Start Time = 0

- Units: Months
- Time at which subsidy policy starts having an effect

Subsidy Policy Switch = 0

- Units: Dimensionless
- A policy decision whether to offer a subsidy

Switch for Product Development = \text{IF THEN ELSE} (\text{Technology Development}[\text{self}] < \text{Minimum Technology Development}[\text{self}], 0, 1)

- Units: Dimensionless
- Product development may begin when technology development is advanced enough (at the minimum technology development threshold)

Switch for Relaxing Public Funding Restrictions = 0

- Units: Dimensionless [0,1,1]
- If on then cash flows down
Switch for Technology Development = 1
Units: Dimensionless [0,1,1]
To simplify the firm not to include technology development, technology development can be turned off

Target Norm Price = 0.75
Units: Dimnl [0,1,4e-006]
How much venture would like price to be compared to competitor's price

Target Price = Target Norm Price * Competitor Price
Units: Dollars/Unit
Price the venture desires to sell the product for, based on price of competition

Technology Abandonment Fraction [company] = 0.099
Units: Dimensionless
Fraction of technology under development that are abandoned

Technology Abandonment Fraction 1 [company] = Technology Abandonment Fraction [company] / 3
Units: Dimnl
Fraction of technology under development that are abandoned at 1st stage of technology development

Technology Abandonment Fraction 2 [company] = Technology Abandonment Fraction [company] / 3
Units: Dimnl
Fraction of technologies under development that are abandoned at 2nd stage of technology development

Technology Abandonment Fraction 3 [company] = Technology Abandonment Fraction [company] / 3
Units: Dimnl
Fraction of technology under development that are abandoned at 3rd stage of technology development

Technology Abandonment Rate [company] = 0
Units: Features/Month
Rate at which technology development ideas are abandoned

Technology Abandonment Rate 1 [company] = Technology Devl Rate 1 [company] * Technology Abandonment Fraction 1 [company]
Units: Features/Month
Rate at which technology ideas are abandoned in 1st stage of technology development

Technology Abandonment Rate 2 [company] = Technology Devl Rate 2 [company] * Technology Abandonment Fraction 2 [company]
Units: Features/Month
Rate at which technology ideas are abandoned in 2nd stage of technology development

Technology Abandonment Rate 3 [company] = Technology Devl Rate 3 [company] * Technology Abandonment Fraction 3 [company]
Units: Features/Month
Rate at which technology ideas are abandoned in 3rd stage of technology development

Technology and Product Development Effort Allocation [self] = Switch for Technology Development * IF
THEN ELSE (Technology Development [self] < Minimum Technology Development [self], 1, Technology and Product Effort Allocation after Minimum Technology Development [self]) + (1 - Switch for Technology Development) * 0
Units: Dimensionless
The actual fraction of engineering effort that is directed to technology development

Technology and Product Effort Allocation after Minimum Technology Development [self] = 0.5
Units: Dimensionless [0,1]
The fraction of engineering effort that is directed to technology development before the minimum technology development is achieved
Technology Completion Rate[company]=Technology Completion Rate 3[company]
Units: Features/Month
The rate at which technologies are developed is determined by how many innovations were started and providing a 3rd order delay to complete them in the avg technology devl time

Technology Completion Rate 1[company]=Technology Devl Rate 1[company]*(1-Technology Abandonment Fraction 1[company])
Units: Features/Month
The rate at which technology is developed into the technology determined by how many technology were started and providing a 3rd order delay to complete them in the avg technology devl time

Technology Completion Rate 2[company]=Technology Devl Rate 2[company]*(1-Technology Abandonment Fraction 2[company])
Units: Features/Month
The rate at which technology is developed into the technology determined by how many innovations were started and providing a 3rd order delay to complete them in the avg technology devl time

Technology Completion Rate 3[company]=Technology Devl Rate 3[company]*(1-Technology Abandonment Fraction 3[company])
Units: Features/Month
The rate at which technology is developed into the technology determined by how many innovations were started and providing a 3rd order delay to complete them in the avg technology devl time

Technology Development[company]= INTEG (Technology Completion Rate[company]-Technology Obsolescense Rate[company],Initial Technology Development[company])
Units: Features
The capabilities and development of the technology

Units: Persons*Hours/Month
The amount of engineering effort directed towards technology development

Technology Development Salary Expense=(1-Switch for Relaxing Public Funding Restrictions)*Avg Salary/EngWork Month*Technology Development Effort[Self]
Units: Dollars/Month
Salary paid to engineers carrying out technology development

Technology Development Switch for Cost Share=IF THEN ELSE(Public Cost Share Fraction>0,1,0)
Units: Dimensionless
Switch to initiate and terminate cost share investment

Technology Devl Rate 1[company]=MIN(Technology Under Development 1[company]/Avg Technology Devl Time[company], Feasible Technology Devl Rate[company]) * 3
Units: Features/Month
Develop 1/3 of technology in minimum of 1/3 the avg technology development time or 1/3 the amount of time it takes given the resources we have to develop technology

Technology Devl Rate 2[company]=MIN(Technology Under Development 2[company]/Avg Technology Devl Time[company], Feasible Technology Devl Rate[company]) * 3
Units: Features/Month
Develop 1/3 of technology in minimum of 1/3 the avg technology development time or 1/3 the amount of time it takes given the resources we have to develop technology

Technology Devl Rate 3[company]=MIN(Technology Under Development 3[company]/Avg Technology Devl Time[company], Feasible Technology Devl Rate[company]) * 3
Units: Features/Month
Develop 1/3 of technology in minimum of 1/3 the avg technology development time or 1/3 the amount of time it takes given the resources we have to develop technology
Technology Features Under Development = INTEG (+Technology Start Rate - Technology Abandonment Rate - Technology Completion Rate, 0)
Units: Features
Technologies that are being worked on by the engineering staff

Technology Obsolescence Rate = Technology Development / Avg Technology Lifetime
Units: Features/Month
Technologies that go out of date per month

Technology Shortfall = Theoretical Maximum Technology Development - Technology Development
Units: Features
How much technology development we're missing compared to what we desire.

Technology Start Rate = MIN(Feasible Technology Devl Rate, Desired Technology Development Rate)
Units: Features/Month
Start technology at the rate at which we can develop them

Technology Under Development 1 = INTEG (+Technology Start Rate - Technology Abandonment Rate 1 - Technology Completion Rate 1, 0)
Units: Features
1st stage of technology development

Technology Under Development 2 = INTEG (+Technology Completion Rate 1 - Technology Abandonment Rate 2 - Technology Completion Rate 2, 0)
Units: Features
2nd stage of technology development

Technology Under Development 3 = INTEG (+Technology Completion Rate 2 - Technology Abandonment Rate 3 - Technology Completion Rate 3, 0)
Units: Features
3rd stage of technology development

Technology Under Development Adjustment Time = 2
Units: Months [0,10,0.1]
How long to take to adjust TFUD to desired level

Technology Value = Technology Development
Units: Features
Value of combined approbriable and nonapprobriable technology

Theoretical Maximum Technology Development = 200,50
Units: Features [0,4000]
The physical limit to technology development

Tick = 1
Units: Dimensionless
To keep track of timesteps for plotting

Ticks = Tick
Units: Dimensionless
To keep track of timesteps for plotting

TIME STEP = 0.125
Units: Month [0,?
The time step for the simulation.
Time to Apply Effort = 1
Units: Month
Time period over which to apply desired sales hours of effort

Time to Max Prob of Failure = 1
Units: Month
When Hazard rate of failure is very high, how long for cum prob of failure to reach 100%

Total Cash Flow from Public Funding = Cost Share Amount * Public Cost Share Fraction + Market Stimulation Payouts + Public RD Investment
Units: Dollars/Month
Public funding as inflow to annual revenue accumulator.

Total Labor = Engineers + Sales Force
Units: People
The number of employees working for the firm

Total Layoffs = INTEG (Engineer Lay Offs + Sales Layoffs, 0)
Units: Persons
How many people have been layed off in total

Total Obligation Spent on Firm = Additonal Increment of Adopters * Quantity Per Purchase * Price
Units: Dollars/Month
Amount of public funding through direct market stimulation policy that benefits the firm

Total Population = INTEG (-Increase In Potential Prospects, Initial Total Population)
Units: Prospects
Total population of firms that can conceivably become a prospect

Total Private Investment = INTEG (Private Investments, Initial Public Investment)
Units: Dollars
Total amount invested in venture

Total Private Investments = INTEG (Private Funding, 0)
Units: $
The amount of money VC invests in the firm

Total Prospects = Hot Prospects + Potential Prospects + Prospects + Purchasers
Units: Prospects
All current prospects

Total Public Development Funding = INTEG (Public Development Investments, 0)
Units: Dollars
Cumulative public funding for technology development

Total Public Funding = INTEG (Public Investments, Initial Public Investment)
Units: Dollars
Total amount invested in venture by the public sector

Total Salary Expense = Avg Salary * Total Labor
Units: Dollars/Month
Total Loaded Salary for entire company

Total Subsidy spent on Firm = Nominal Subsidy * Purchase Rate * Quantity Per Purchase
Units: Dollars/Month
Total amount of subsidy paid that benefits a single firm
Unit Cost Threshold as a Fraction of Incumbent Unit Cost = 1 / Functionality Threshold as a Multiple of Incumbent Functionality
Units: Dimensionless
The factor of superiority the technology cost must be over competitors

Weighted total prospects = Prospects * Prospect Emphasis Multiplier + Hot Prospects * Hot Prospect Emphasis Multiplier + Purchasers * Purchasers Emphasis Multiplier
Units: Prospects
Number of prospects weighted by relative importance of prospects vs. hot prospects vs. purchasers for the purpose of applying sales effort

Word of Mouth Reference = 0.1
Units: Prospects/Month
Reference value for word of mouth (at which it maximizes sales effectiveness)

Working Capital = Cash Restricted for Technology Development + Cash for Firm Operations
Units: Dollars
Total amount of the firm's cash
Implementation of Policy Cases

In order to duplicate the results of each case discussed in this thesis within the model the following parameters should be changed from the default values.

Base Case
Maximum Public RD Funding: 16.55 million
Annual discount rate: 0.01, 0.02, 0.03

Policy Case 1
Maximum Public RD Funding: 12.75 million
Subsidy Policy Switch: 1
Subsidy Policy Effect on Price: -0.2
Annual discount rate: 0.01, 0.02, 0.03

Policy Case 2
Maximum Public RD Funding: 9.5 million
Subsidy Policy Switch: 1
Subsidy Policy Effect on Price: -0.2
Cost Share Switch: 1
Maximum Cost Share Investment: 250 million
Annual discount rate: 0.01, 0.02, 0.03

Carbon 10%
Carbon Policy Switch: 1
Carbon Policy Effect on Comp Cost: 0.1
Maximum Public RD Funding: 13.6 million

Carbon 30%
Carbon Policy Switch: 1
Carbon Policy Effect on Comp Cost: 0.3
Maximum Public RD Funding: 10.9 million

Carbon 50%
Carbon Policy Switch: 1
Carbon Policy Effect on Comp Cost: 0.5
Maximum Public RD Funding: 9.35 million
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