A Multi-Criterion Model for Evaluating the Efficiency of Solar Energy Incentives

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Abstract

Regardless of any scientific uncertainty about climate change, unequivocal evidence illustrates the emergence of various renewable energies in the international economy. One promising and prevailing technology is solar energy. Given the heightened demand for renewable energy, the current debate centers on how to foster an environment conducive to investment and efficiency in order to increase total welfare. This article provides a survey of the major incentives that exist in the international community to promote the adoption of solar power, introduces a unique working model that compiles and modifies core conclusions in the literature, and provides a methodology to assess the effectiveness of these incentives. This article's underlying objective is to create a reasonable theoretical model and qualitative list of criteria that can be applied to various incentives, like feed-in-tariffs, in order to determine optimal incentives for use in United States energy policy.

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I. Introduction

Economists have spent a significant amount of time analyzing the potential economic ramifications of climate change and the effects of various policy proposals to mitigate those costs. However, uncertain climactic models have not precluded rapid renewable energy development. Trends towards sustainability have stimulated renewable energy development and growing public support. Moreover, if fossil fuel prices rise in the coming decades and concerns over greenhouse gasses (GHG) continue to mount, there will be further pressure on renewable energies to serve as the world's power source. Because current renewable energy technology (RET) is not yet cost-competitive with fossil fuels, there is an opportunity for the implementation of policies that incentivize renewable energy development and increase economic growth. While the goal for policymakers is to optimize social welfare by creating a climate conducive to supply and demand forces, interest groups will inevitably clamor for subsidies to artificially boost their profits and international competitiveness.

Even though solar power, a prevailing renewable energy, is currently not cost competitive with fossil fuels because of storage challenges, higher research and development costs, and energy intermittency[2], there is still significant opportunity for gains in profitability. One of the prevailing renewable energies is solar power. Yet, while governmental agencies are clamoring to provide the industry with various types of incentives, there must be a critical discussion of incentive efficiency and cost-effectiveness. The article has three connected purposes: (1) compile the major incentives used for solar power in the United States and abroad; (2) create a model for evaluating the effectiveness, or value added, of an incentive; (3) develop central questions and answers regarding the attributes of a successful incentive package for the solar industry.

The research concludes with an application of the developed general quantitative model and qualitative criteria for incentive valuation. Using growth in the share of capital, contributions to welfare, and measured technological innovation, in addition to other criteria such as analyses of forecasted business confidence, efficiency, and unintended consequences, feed-in-tariffs are shown to be an ineffective incentive instrument employed by many national governments. Building on existing research, the article shows that an optimal incentive must enhance the long-term profit maximizing points in the market. Without a sustained commitment to innovation and cost-reduction, incentives merely induce short-term production without real economic gains.

2 This list is not meant to be a comprehensive explanation of why solar is not as expansive as fossil fuels.

Therefore, to promote long-term progress, agencies must implement incentives that are structured on the basis of value-enhancing criteria for renewable energy development.

II. A Brief Background on Solar Market Information

The renewable energy market as a whole is projected to achieve a net worth of $349.2 billion by 2020. Specifically, solar power, one of the most lucrative sectors positioned for profitability, is expected to achieve $113.6 billion in net worth by 2020, and was estimated to be worth $71.2 billion in 2010 (Pernick et al; 2011). Despite the recent economic contraction, in 2008 to 2009, the solar photovoltaic market value grew by 15% and 45% in GW capacity (EPIA; 2010). Market forecasts by the European Photovoltaic Industry Association (EPIA) estimate that solar energy could satisfy roughly 12% of total European Union energy demand by 2020, absent any further external price support mechanisms.

While developing predictions for market expansion, it is important to differentiate between the two major forecasting models: (1) the business-as-usual scenario where there are no additional external incentives provided, and (2) the policy-driven scenario where additional support mechanisms, such as feed-in-tariffs (FiT) are used more extensively. The EPIA estimates that under scenario (1) solar power will provide approximately 15,000 MW by 2014, whereas under scenario (2), solar power is estimated to provide 30,000 MW by 2014, in the European market. While the discrepancy between the policy-driven and business-as-usual scenarios is large, it should not justify the implementation of inefficient and ineffective mechanisms that create perverse incentives for energy development.

These realities demonstrate the importance of providing optimal incentives for the solar industry; there is a unique opportunity to increase economic growth, but it requires strategic implementation of sound public policies. However, potential for growth within the market does not alone serve as a justification for providing subsidies for the industry for two reasons. First, incentives that are directed to the solar industry could potentially be more efficiently allocated elsewhere; policymakers will need to persuasively illustrate that incentives for a given industry and/or companies will be spent comparatively better than allocation in other areas. Second, there is a real risk for protectionist behavior in a scenario where each country operates under a policy-driven scenario, namely because countries will perceive gains as zero-sum activities. Policymakers must make a conscious effort to avoid the perception of artificially inflating the domestic industry at the expense of foreign competition. However, the two aforementioned concerns need not prevent meaningful implementation of sound economic incentives in the solar sector. If policymakers develop a valid rationale for slowly phasing strategic and cost beneficial incentives for the solar industry, the two concerns can be managed, if not completely obviated.

III. Review of the Literature and Analytic Compilations

This section will survey current market research on the solar industry, probe pressing questions facing its future growth, and lay a foundation for analyzing the role of incentives in the alternative energy market.

A. Existing Market Based Incentives in the United States and Abroad

The international community has implemented a wide array of federal and local incentives over the past decades. In order to accurately assess the costs and benefits of incentives, it is necessary to be aware of those that exist. This allows for empirical testing and more precise forecasting of the effects of various incentives. The subsequent section summarizes the most important incentives that have been cited in the literature, laying a foundation for the model and qualitative analysis that will be developed (Price, et al; 2010):

Incentive Name	*Description*
Carbon Pricing Scheme	Government legislation indirectly shifts the cost-structure of energy, which is achieved most notably through means of a cap-and-trade or carbon tax. The central challenge in these policies is developing an accurate price that reflects the true cost imposed by the externality.
Investment Tax Credit	Sections 48 (for businesses) and 25D (for residences) of the Internal Revenue Code describe the credit for specific energy projects, most notably those that include "equipment which uses solar energy to generate electricity." This incentive provides consistent financial support for growth by reducing the relative cost for energy development, thus increasing solar producers' profit maximizing point.
Renewable Energy Grants	Section 1603 of the American Recovery and Reinvestment Act authorizes the Department of the Treasury to provide renewable energy project developers cash grants in light of the Investment Tax Credit. This grant program was created due to an inadequate supply of financial capital for investment.
Manufacturing Tax Credit	Similar to the Investment Tax Credit, this credit decreases the relative cost of investment for advanced energy manufacturing. Eligible technologies include: renewable energy, energy conservation, electric grids supporting intermittent sources of renewable energy, carbon capture and storage, biofuel refining or blending, and hybrid-electric vehicles and components
MACRS and Bonus Depreciation	The Modified Accelerated Cost Recovery System allows investors to depreciate certain investments in solar power using a 5-year accelerated depreciation schedule, having the terminal impact of reducing tax expense. There is also a bonus depreciation schedule for all solar projects installed in 2008, which provided up to 50% depreciation in the first year, and the remaining 50% in the second to fifth years.

Renewable Energy Loan Guarantee Program	The Department of Energy (DOE) loan guarantee program was established by Title XVII of the Energy Policy Act of 2005 to provide loan guarantees for projects that "avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ new or significantly improved technologies as compared to commercial technologies," including energy efficiency, renewable energy, and advanced transmission and distribution as well as advanced nuclear power, advanced coal-based power, and carbon capture and sequestration technologies.
Clean Energy Bonds	Clean renewable energy bonds were established by EPACT 2005 to provide renewable project financing for non-taxable entities that cannot directly use the ITC for solar facilities. These are equivalent to a zero-interest loan.
Solar on Federal Property	$5.5 billion was appropriated for the Federal Buildings Fund for green building improvements, including energy efficiency measures and the use of renewable energy sources.
State Energy Program	Funding from the DOE for this program goes to all state energy offices for the financing of energy audits, building retrofits, education/training, and new financing mechanisms for renewable energy investments.
Energy Efficiency and Conservation Block Grant Program	Funding provides competitive grants to develop, implement, and manage energy efficiency and conservation projects and programs.
Renewable Energy Production Incentive	This incentive was implemented to expand eligible facilities and authorize federal appropriations through 2026.
Tradable Green Certificates	Known also as Renewable Energy Certificates (RECs) in the United States, Tradable Green Certificates (TGCs) have been used primarily throughout Europe. RECs and TGCs have many parallels with carbon pricing schemes, namely tradable permits. Green certificates represent the environmental value of generated renewable energy. Their main purpose is to promote the efficient transition to renewable energy by enabling firms to sell, purchase, or barter certificates under free market forces.
Feed-in-Tariffs	Feed-in-tariffs (FiTs) are used predominantly in Europe to encourage renewable energy production. They typically determine a long-term premium price for individuals to receive for generating renewable energy. Contracts last approximately 15-25 years.

The European and United States markets have excelled in the production and distribution of solar photovoltaics. Understanding the basic accomplishments achieved by major renewable energy producers provides empirical support that renewable energy can result in profitable investments. This provides a foundation for further analysis to determine the most effective method to increase profitability, since not all incentives are created equal when it comes to increasing total welfare. The following provides an overview of the various accomplishments of key players in the solar industry (EPIA; 2010):

Country	*Description*
Belgium	Belgium exhibited strong growth in 2009 with a capacity of 292 installed megawatts (MW). Belgium has primarily used feed-in-tariffs and tax rebates to stimulate adoption of solar technology. The country has also implemented a Green Certificate Trading scheme, which uses an exchange market with minimum and maximum prices as a market allocation mechanism.
Czech Republic	The Czech Republic had a booming solar economy in 2009 with 411 installed MW. With a combination of strides in bureaucratic efficiency and feed-in-tariff operations, the Czechs are in a position to tout a relatively strong solar economy. That said, evidence indicates that the 2010 market collapse has greatly hindered their efforts.
France	France began employing a unique version of feed-in-tariffs, specifically for Building Integrated Photovoltaics (BPIV), which led to 2009 growth with 285 installed MW. Losses in efficiency have prevented 100 MW from grid connection.
Germany	Germany is known as the largest producer of photovoltaics world-wide in 2009, adding 3.806 gigawatts (GW). Germany's use of feed-in-tariffs has resulted in notable advancements in the solar industry.
Spain	Following Germany, Spain is the second largest player in the market for solar energy, with cumulative installed photovoltaic (PV) capacity of 3.4 GW. Spain's growth is significant, amounting to a 410% increase over its 2007 cumulative installed capacity of 0.66 GW. As in Germany, much of this adoption is a result of the country's feed-in-tariff scheme.
United States	In 2009, the United States had 477 installed MW, and will have an estimated 3 GW installed by 2014. While the U.S. has been less active at promoting solar energy use, its market mechanisms have been allocating a material share of investment towards solar energy production.

In addition to the advancements seen in the European and United States PV markets, other countries such as China and India have also exhibited intense economic growth in their solar energy sectors. Alternative energy subsidies, particularly for solar power, tend to be higher in China and India. However, this is likely due to the structure of their governments, which allow leaders more authoritative decision making power (Ritger and Vidican; 2010; Markets and Markets; 2010). Nonetheless, it is clear that many countries are implementing incentives for catalyzing greater adoption of solar energy.

B. Regulatory and Market Approaches

While market based approaches have proven to successfully encourage alternative energy adoption and reduce supplier production costs, it is important to acknowledge that there are many companies that still do not transition to cleaner fuels because of the high cost of clean energy, even when there are incentives. This is a public policy dilemma, since it has already been established that fossil fuels create negative externalities, such as carbon dioxide and sulfur oxide emission, which are detrimental to human health and ecosystems (Rivers and Jaccard; 2006). As such, the social costs are not currently reflected in the market. Therefore, the regulatory approach claims that policy intervention must be taken to return social welfare to its optimal level. Moreover, proponents of such an approach claim that costs for alternative energy will decrease because firms will gain experience with producing a technology.

A thorough body of empirical evidence indicates that a firm's costs will decrease and productivity will increase as experience is gained (Arrow; 1962). For example, the cost of solar energy will decrease for a company that has learned to scale effectively and build and distribute its product efficiently by using absorbent photovoltaics and cost-effective inputs. While learning-by-doing may increase productivity, firms typically do not have incentives to quantify the social benefits that accrue, skewing their perceived estimation of return on investment. Therefore, many firms choose to invest less in renewable energies than what is optimal from a social perspective (Rivers and Jaccard; 2006).

However, the reality that there is a socially optimal level that has not yet been reached does not necessitate regulatory approaches. Rather, it should accentuate the value of conservatively targeting effective incentives in the marketplace. In this sense, learning-by-doing is best achieved by creating incentives to develop efficiencies that are recognized by the market. Rivers and Jaccard provide a base analysis that is used in the article's assumption that a market based approach is socially optimal.

In order to avoid unnecessary complications, we accept the results acquired by Rivers and Jaccard, which are elaborated on in part A of the Appendix, pertaining to their specific model on heterogeneous firms with imperfect foresight regarding the socially optimal level and benefits of clean energy technology. The existence of heterogeneity in firms provides further credence to the argument that market based approaches, rather than regulatory, are the most efficient and cost-productive policies. Market based instruments allow firms to allocate emissions reductions between technologies in the most efficient method, as opposed to a one-size-fits-all approach in a command and control policy. Rivers and Jaccard find that a market based approach is almost always more cost-effective than a regulatory instrument. The presence of heterogeneity only further decreases the benefits of a command and control policy by increasing the average cost for firms. Thus, Rivers and Jaccard provide an excellent introductory analysis, concluding that cost savings increase through the use of market mechanisms.

C. Relevant Qualitative Literature

The National Renewable Energy Laboratory created a seminal study, led by Gouchoe (2002), which provides a broad qualitative analysis of the effectiveness of alternative energy incentives. Although there are numerous ways to define effective renewable energy incentives, including, but not limited to, a reduction in the cost of technology over a given time period, installed capacity, and the amount of electricity produced, the policymaking community needs more precise criterions for evaluation. While Gouchoe does not provide quantitative guidelines for evaluation, seven notable suggestions are offered from the literature regarding criteria that renewable energy incentives must take into account in order to create economic value:

a) Funding stability and duration: Incentives should create certainty for recipients and be operational for optimal duration. Timeframes that are too short will be ineffective, while those that are too long will be inefficient.
b) Incentive amount: The magnitude of the incentive must be large enough to catalyze investment and result in an eventual correction of the negative externality.
c) Quality assurance: Incentive programs must be designed to monitor performance and provide incentives for the company to use financial stimuli effectively.
d) Application process: Incentives should be easy to apply for and in clude relevant assistance from program administrators.
e) Consumer education and awareness: Marketing is necessary to edu cate the public about renewable energy technologies and existing in centives.
f) Institutional barriers: Foundational issues must not inhibit the effec tiveness of incentive programs by creating unnecessary inefficiency.
g) Complementary financial incentives: Incentives will be most effective when combined; packages of incentives are the most effective way to stimulate wide-reaching demand[3].

While some of the aforementioned criteria that characterize an incentive may appear to be intuitive, it is important to acknowledge core contributions to the literature and consensuses that have been achieved. These overriding criteria for policy evaluation of incentive packages are integrated throughout the model and policy discussion in the paper.

D. Introduction of the Basic Cobb-Douglas Function

Barro, Sala-i-Martin, and Mankiw (1995) created a model that can be applied to analyze endogenous growth in capital, as it pertains to enhancing firm productivity. They use a Cobb-Douglas production function that uses

3 This does not imply that every recipient must receive a variety of incentives. However, on the aggregate, a mix of incentives should be used.

the physical stock of capital, the quantity of raw labor, and a fixed technology parameter as inputs. Their model is constructed to analyze capital formation across countries and the direction that it flows. It is clear that the concern here is not with capital formation and its direction, but rather the emphasis is on developing a model for predicting growth in capital, as it pertains to contributions to the multiplier effect for energy incentives. As such, the Barro, Sala-i-Martin, and Mankiw model is modified (illustrated in 2.11) so that it may be applied to the discussion of energy economics for incentive valuation.

E. A Base Model for Welfare Analysis

Li and Lofgren (2008) develop a sound model for welfare analysis. It is well known that policymakers aim to effectively optimize social welfare. However, measuring the effectiveness of public policies can be challenging because the effects of specific policies must be isolated amidst a dynamic and multi-dimensional international economy. A problem with many earlier welfare models is that they apply unjustifiable and inaccurate discount rates for future social profits. In this sense, if there is a low risk of environmental harm resulting from climate change and/or pollution, many historical models ascribe an unrealistically low economic value and therefore a high discount rate. Li and Lofgren change the emphasis from 'second-best' constraints to environmental concerns and the effects of projects' lifetime consequences. Their approach to welfare analysis is an essential element in the model because of the interaction that welfare contributions have to the multiplier effect for incentives.

F. The Implications of Technological Change

Clarke, Weyant, and Edmonds (2008) have made a significant contribution to the literature on the sources of technological change[4], namely the role that incentives play in fostering innovation and greater efficiency measures. Technological change is one of the most efficient methods for driving economic growth, originally concluded by Solow, but specifically analyzed by Clarke et al (2006). Technological innovation in the solar industry can help correct the negative externalities regarding atmospheric carbon dioxide, pollution, and the potential for climate change. This accentuates the opportunity for policies to positively influence the growth of industries and lead to improvements in technology and long-run efficiency. For example, when coupled with effective conditions, grants for research and development (R&D) can induce technological change. For policymakers, an important result is the spillover

4 Technological change refers to a given knowledge base, intangible or tangible (physical stock or intellectual capital). Induced technological change refers to a change in the rate or direction of technological change in response to a particular set of policies, for example, targeted incentives.

that occurs. Extensive studies illustrate that the social rates of return for R&D spillovers are comparatively higher than those for private rates (Griliches; 1992). Therefore, the challenge becomes optimizing incentive packages to create the highest rate of return possible, by providing private firms with necessary resources for research and development, product development, or any other relevant project associated with launching renewable energy technology into the market.

This model is developed purposely by Clarke, Weyant, and Edmonds (2006) to remain abstract in order to accentuate the value of influences on technological change, namely indirect spillovers through intra-industry efforts and innovation driven by external incentives. External incentives serve as catalysts for intra-industry innovation. In this sense, fostering conditions for knowledge spillovers drives technological change. The explanation of the Clarke et al (2006) model is explained in more detail in part B of the appendix.

IV. Model

Although definitions of incentives vary, the general consensus in economic literature is that incentives are discrete offers that elicit an expected response. Incentives are created for the purposes of motivating an individual / entity (or, individuals / entities) to choose an alternative to the status quo (Sweeney; 2004, Grant; 2002). For the purposes of the article, incentives can be defined as financial transfers that promote a change in behavior.

While the definition of an incentive is established, it is more challenging to develop criteria for evaluating its success or failure. There are multiple ways in which to interpret the outcome of an incentive for solar power. These interpretations include, but are not limited to: the number of jobs that are created, the economic growth that ensues, and the amount of energy that is generated.

While the above interpretations of success are valid, they lack consolidation and precision. To formulate a generalized principle for evaluating the effectiveness of incentive mechanisms for solar power, I develop an equation that recognizes the necessary parameters and variables. The following are the variables that will be used and their corresponding meaning:

Variable	*Description*
V	V represents the total value added as a result of the incentive.
I = I(t) where 0 < t < 1	I represents infrastructure within a given community and is a function of t, which stands for the community's tax rate. Taxes are between (0,1). This model also presupposes previous neoclassical models that illustrate the negative effects of taxes on capital investment, competition, and incentives for reproducible (human) capital innovation.
M = M(C, H) $M^1(C, H) >$ if M(C + H) > 0 $M^1(C, H) >$ if M(C + H) = 0 $M^1(C, H) >$ if M(C + H) < 0	M represents mindset and is a function of C and H, which stand for cultural traditions and historical context. Although C and H are qualitative variables, they are to be estimated based on a community's propensity to invest in environmental preservation. Additionally, the magnitude of these attitudes is characterized in terms of a positive (+), indifferent (0), or negative (-) view towards the environment[5].
T	T represents total incentive expenditures in real dollars.
K = K(G, W, Q) where $K^1(G, W, Q) > 0$ results in positive growth	K represents the multiplier for the incentive mechanism and is a function of G, real growth in capital and international positioning and changes in human capital, W, contributions to welfare, and Q, production that is directly correlated with technological change that results from the given incentives.
D	D represents the depreciation and/or cost towards the environment.

Infrastructure, mindset, and depreciation are held constant as exogenous variables, whereas the multiplier and total expenditures are endogenous variables. The terms are treated as such to capture changes in value when total expenditures and the multiplier are varied. Using comparative statics to measure changes in relevant endogenous variables, the following model is deduced:

$$V = I(t) + M(C, H) + TK(G, W, Q) - D \tag{2.1}$$

$$\frac{\partial V}{\partial K} > 0 \tag{2.2}$$

$$\frac{\partial V}{\partial T} > 0 \text{ for } (0,\delta) \tag{2.3}$$

$$\frac{\partial V}{\partial T} < 0 \text{ for } (\delta, \propto) \tag{2.4}$$

With constraints of:

$$c_i = \frac{p_T}{(1+r)^n} \tag{2.5}$$

where p_T is the price of the incentive (quantity of dollars spent), r is the interest rate, and n is the number of years.

5 Objectively expressing these attitudes is challenging because of the subjectivity latent in the qualitative data. However, we assume that a similar approach will be taken to the explanation in West, et al (2010).

The total value added by an incentive is subject to the constraints of the total incentive expenditure in present value terms, which is the amount that a given policymaker intends to spend on a project. Converting the expenditures into present value terms is important because policymakers are often forecasting incentive mechanisms to take place at a particular date in the future – not in the current n_0 time period.

The results from (2.3) and (2.4) also illustrate an important consideration, namely that total expenditures for a given incentive will increase the value added up until point δ; following δ, diminishing marginal productivity sets in and the value added will decrease. The purpose of this article is not to ascertain the exact point δ, not only because it is path dependent on the type of incentive and its respective targeted community, but also because it would sacrifice other important findings. The cardinal argument is merely that pure expenditure, without thoughtful formulation in context of the specific energy, will fail to result in the adoption, production, and profitable implementation of solar energy.

One can also use comparative statics to derive an optimization problem and its corresponding first order conditions:

$$V = I(t) + M(C, H) + TK(G, W, Q) - D \tag{2.6}$$

$$T, K$$

$$L = I(t) + M(C, H) + TK(G, W, Q) - D + \mu\left(C_i - \frac{p_T}{(1+r)^n}\right) \tag{2.7}$$

First Order Conditions: (2.8)

1. $\frac{\partial L}{\partial \mu} = \left(C_i - \frac{p_T}{(1+r)^n}\right) = 0$

2. $\frac{\partial L}{\partial T} = K^*(G^*, W^*, Q^*) - p_T = 0$

3. $\frac{\partial L}{\partial K} = T^* - p_T = 0$

We set condition 2 equal to 3 and arrive at max V: $T^* = K^*(G^*, W^*, Q^*)$ (2.9)

We assume that 2 and 3 are maximized following:

Second Order Conditions:

$$\frac{\partial L^2}{\partial^2 K} < 0 \text{ and } \frac{\partial L^2}{\partial^2 T} < 0 \tag{2.10}$$

Growth

We first look to define G, which is part of K(G, W, Q) because of its significance in the model. A neoclassical Cobb-Douglas closed-economy growth model is used to simplify the argument (Barro, et al; 1995):

$$G = AP^{\alpha}K^{\eta}\left(Le^{gn}\right)^{1-\alpha-\eta} \text{ Where } \alpha > 0, \eta > 0, \alpha + \eta < 1 \tag{2.11}$$

This Cobb-Douglas function uses G, total growth with inputs, A, a fixed technology parameter[6], P, international positioning achieved through growth in output and capital, α, an exogenous growth factor for P, K, stock of physical capital, η, an exogenous growth factor for K, L, a given rate that labor and human capital, with growth g and time n, contribute to total growth.
Growth is maximized when:

$$G^* = A\left(P^*\right)^{\alpha}\left(K^*\right)^{\eta}\left(L^*e^{gn}\right)^{1-\alpha-\eta} \tag{2.11}$$

where $\alpha > 0, \eta > 0, \alpha + \eta < 1$.

Welfare

Li and Lofgren's model (2008) is used because it best describes the social cost and benefit that result from a policy project; many other models that conduct welfare analysis purely focus on changes in tax rates or regulation. Instead, this model allows the policymaker to input different scenarios, such as a tax or regulation, into the model to observe the effects. There are a few adjustments to the Li and Lofgren model, namely that capital goods are not counted since they are included in (2.11). This also allows the use of a more simplified model without employing Hamiltonian dynamics.

W can be defined by amending the Li and Lofgren welfare analysis model. This describes a given incentive's contribution to welfare (Li and Lofgren; 2008):
Let $C = (C_1, C_2 ..., C_n)$ be an n-dimensional vector of consumption flow at a given time t, which includes all possible goods and services that implicate social welfare through consumer and/or producer surplus. C also includes long-term horizon goods, such as environmental services and ecosystem functions. Therefore, the prices of these services are rental prices. I use a utilitarian measure of welfare at time t = 0 with the expression:

$$W_0 = \int_0^{\infty} U(C(t))\exp(-\Theta t)\,dt \tag{2.12}$$

where U(C) is an arbitrary concave, non-decreasing, instantaneous utility

6 Technology is held constant in this portion of the model for purposes of simplicity.

function with continuous second order derivatives C ≥ 0 and Θ is the utility rate of discount.
At each point in time t, consumption C(t) is allocated within the n-dimensional possibility set S(C(t):α) where α is a collection of parameters such that it remains strictly convex.

$$W^*_0(\alpha) = \int_0^{\infty} U\left(C^*(\alpha, t)\exp(-\Theta t)\right)\mathrm{d}t \qquad (2.13)$$

Technological Change

Finally, we define Q as the production that changes as a direct result of technological change. Innovation is a driving force behind efficiency and profit-maximization. As such, it is important to consider its composition. Consider the following modification to Clarke (2008):

$$max\ Q = f(A, x) \qquad (2.14)$$

$$A$$

$$s.t.\ C = F(x) - Z(y)$$

$$Q = \left(Q_1, Q_2, (\,)\,..(\,), Q_n\right) \qquad (2.15)$$

where Q is an n-dimensional vector of technologies, like solar cells, knowledge pools, and human capital, which all exist at a given time t. Consider a time, T, that represents a time in the future. T is used to represent the technological change in time periods for vector Q. A utilitarian measure is used to quantify technological change.

$$Q(\alpha) = \int_t^T Q(A(t))\exp(-\theta)dt \qquad (2.16)$$

where Q(A) is an arbitrary convex exponential function that illustrates the relationship between gains in technology and production

$$Q^*(\alpha) = \int_t^T Q^*(A(t))\exp(-\theta)dt \qquad (2.17)$$

where Q*(A) is the optimal amount of technological change that occurs given the constraints

Q	Total production resulting from a given technologies/technologies and basket of other inputs
A	Technology which spans on infinite spectrum of inputs, ranging from human capital to physical stock; technology is defined loosely to entail the broad set of processes spanning technical expertise, experience and equipment used by individuals to produce products and services (Clarke; 2008)
x	A basket of exogenous inputs, such as capital and labor.

We use (2.17) to demonstrate a general form for maximum technological productivity. The interaction between technological change and productivity inevitably implicates the effect of the incentive multiplier; an incentive that spurs technological innovation will create knowledge pools and spillovers greater than what previously existed. There are three different activities that drive technological change: intra-industry initiatives, direct spillovers, and indirect spillovers (Clarke; 2008). Of particular importance are direct spillovers, as well as their contribution to subsequent indirect spillovers. Policies that result in technological change and spillover within an industry will offer not only immediate benefits of a new technology, but also an amplification of the rate at which existing pools of knowledge can be used. As such, the general form in (2.17) illustrates one of the objectives of policymakers designing incentive packages.

Model Remarks

The above work has clearly failed to leverage the exogenous variables. This is because focus is given to the factors that are most relevant to policymakers working on a specific project. Factors, such as I(t) and M(C, H), cannot be changed as easily, as they require top-down and bottom-up structural decisions in federal tax policy and social mindset, respectively. As such, the endogenous variables are highlighted and given context to accentuate the significance of the value-added model established above. However, a description of t, C, and H is provided to establish a working knowledge for the general factors that influence the acquisition of values for the exogenous variables, in case future analysis on them is pursued.

More importantly, G, W, and Q – which determine K – are scrutinized to develop a broader model for incentive based evaluation. Growth, welfare, and technological productivity are important criteria because they are the fundamental drivers of incentive effectiveness. To improve upon the criteria established by Gouchoe (2002), an incentive that enhances international positioning and capital growth, contributions to aggregate welfare and technological productivity will inevitably increase total energy generation, profitability, and cost-effectiveness. While there are many models that analyze the cost-effectiveness of solar energy in depth using a certain region as a case study, few have compiled holistic criteria for incentive valuation. This work serves as a synthesis of core models to develop a more comprehensive method for evaluating policy decisions, both quantitatively and qualitatively.

V. Discussion

A. Solar Energy's Competitiveness

Generating a model that attempts to evaluate the effectiveness of public policy incentives is a prerequisite to solar energy's expansion. In order to make solar power more cost competitive, the true social costs and benefits must be reflected in the market, and effective incentives must be applied to the energy industry to resolve the existence of fossil fuels' negative externalities. Although solar energy is not yet cost competitive with fossil fuels and nuclear power because of storage challenges, higher research and development costs, and energy intermittency, it is making significant strides (Borenstein; 2008). According to some estimates, primary costs for installation including parts and labor have fallen significantly in recent years. However, another primary cost, replacement of inverters, has not been falling as quickly, resulting in a lag for consumer wide adoption of solar energy as a source for electricity.

Because solar power is expensive relative to other energy production methods, the industry needs incentives to innovate if it is to quickly establish itself as a dominant energy source in the market. Incentives must reconcile with the reality that the net present cost of installing solar photovoltaic technology exceeds the net present benefits, assuming current real interest rates and current real costs for electricity (Borenstein; 2008). At its most basic level, the question concerns how to make the marginal benefits outweigh the marginal costs for solar adoption.

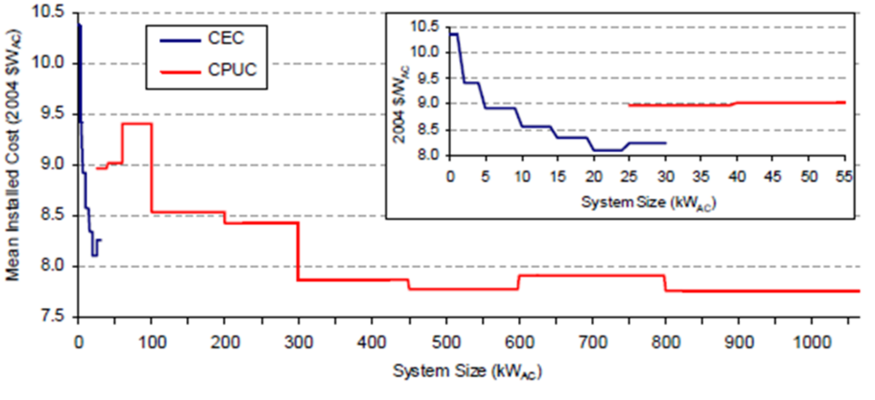
In the past, the majority of U.S. solar development has been almost entirely focused on generating electricity from rooftops or ground-mounted photovoltaics on residential and commercial communities. However, there has been a recent spike in interest for utility scale plants, implementing newer technologies and efficiency standards (Nimmons; 2008).

Technological advancements have impacted the levelized cost of energy (LCOE[7]) for photovoltaic panels and are fostering increasing adoption of utility scale solar power. For the past decade, the cost of PV has declined by 2-4% per year on average, with the current price under $4/watt (DeJongh; 2010). Moreover, as more utility scale projects materialize, the investment costs will continue to decline due to cost reductions in equipment components. In this sense, the two effects – reductions in the cost of producing solar photovoltaics

7 The LCOE is accepted as the net present value of the total life cycle costs of the anticipated solar energy project divided by the quantity of energy produced over the system life.

and the cost of equipment in utility scale plants – will interactively enhance each other. Utility companies realize that they will not be able to meet demand solely through the use of residential scale projects because of their inherent limitations, namely that the magnitude of energy remains limited unless adopted on a widespread scenario. Without significant incentives for consumer adoption of residential solar power, it remains unlikely that it would expand enough to make a significant impact (DeJongh; 2010).

While studies support the use of both residential and distribution based solar energy, a vast majority of economic literature indicates that, all else equal, scaling and utility based solar power will result in the very substantial cost savings. Even though the cost of producing photovoltaics has been decreasing steadily per year, it has not decreased enough to make residential solar power a cost-effective option for a large portion of consumers. Without a technological breakthrough, studies indicate that one of the best options that utilities have to reduce their cost per kilowatt hour is to purchase plots of land and place vast quantities of solar panels to produce electricity. Supporting evidence comes from a Berkeley case study on California's solar economy. Findings, based on the analysis of two systems (CPUC, California Public Utilities Commission, and CEC, California Energy Commission), illustrate that the average system cost falls substantially for larger systems. The largest systems in the CEC dataset are roughly \$2.5/WAC cheaper than 1 kW installations; the largest CPUC-funded systems are roughly \$1.5/WAC less expensive than the smaller systems funded by that program (Wiser, et al; 2006).



While utility scale solar power offers concrete benefits and efficiency improvements for an expanding solar market, the emphasis is not purely on comparative residential and utility scale solar projects. Instead, utility and residential scale solar power is used to accentuate the complexity latent in the solar industry, namely that each renewable energy technology has many subgroups that warrant thoughtful policy and economic analysis. This is an important conclusion because it necessitates that incentives for the solar industry be specific and targeted. Because, for example, solar and residential scale projects are unique in their financing and power generational abilities, they require distinct incentives for economic growth. As such, the value of having a predictive model that gauges the expected success of incentives will be pivotal in order to distinguish between profitable investments in various renewable energy technologies.

B. Surveying Feed-in-Tariffs and their Ramifications

The above discussion has been useful in describing incentives from the perspective of utility recipients. On the other side is the provider of incentives – local, state, and federal governments. The question of value maximization and cost minimization necessitates a conclusion regarding effective incentive outcomes. One incentive that has received significant attention by the economic and reporting community alike, touted to resemble the aforementioned characteristics the most, is the feed-in-tariff (FiT) (Couture and Gagnon; 2010). The majority of feed-in-tariffs guarantee a minimum price per kilowatt hour that an electrical utility has to pay to a private, independent, producer of renewable power. While FiTs have succeeded in promoting greater use of solar energy in many European countries, they have been criticized because of high costs, inefficiencies, and distortions between regional electrical utilities (Sijm; 2002).

Although the reviewed models provide an effective way for quantifying gains from various incentives, it is important to also qualitatively assess the implications of policy action in application of the already employed quantitative techniques. Therefore, a few criteria can be developed to represent central features of an incentive. These criteria include, but are not limited to: business confidence & certainty, effectiveness at achieving the desired goal, efficiency, and extent to which significant unintended consequences result. This section will begin to reconcile core issues developed in studies from the literature.

Business Confidence & Certainty

Feed-in-tariffs were created to catalyze renewable energy production, with a salient feature of instilling certainty within the market. However, FiTs can be interpreted as being tantamount to regulation because an electrical utility is forced to pay an independent producer a set fee for electrical generation. Therefore, often times, feed-in-tariffs can work at odds with a given community's economic structure by distorting true supply and demand.

While some proponents of feed-in-tariffs characterize FiTs as stable and predictable incentives for renewable energy generation, an economic consensus on the comparative superiority of FiTs has yet to be reached (Ragwitz; 2007, Sijm; 2002). In this sense, accepting the premise that incentives and incentive packages must vary based on the region and/or targeted energy, other incentive mechanisms, such as tax credits and rebates, may provide a more effective catalyst for value creation in the energy sector.

One issue, however, that has not been covered as extensively in the literature is the ability of local and federal governments to implement long-term growth objectives through feed-in-tariffs. Because FiTs only set a price between a buyer and a seller, competition does not constantly monitor the extent to which the price is overvalued or undervalued. Although this can be remedied to a degree with price adjustments by regulatory officials, the long-term total costs can still be unsustainable. Therefore, even though FiTs unequivocally promote short-term energy generation, it is questionable whether long-term welfare can increase enough to justify the costs. Under a Ricardian approach, individuals will perceive feed-in-tariffs as short-term stimuli. However, in the long term, feed-in-tariffs and their regulatory counterparts do not induce companies to pursue new and more efficient profit maximizing points. This is empirically illustrated; feed-in-tariffs have been ineffective at lowering the levelized cost of electricity for renewable energy, specifically wind and solar energies, because they offer little long-term incentives to innovate given that they guarantee a long-run price (del Rio and Gaul; 2006). Nonetheless, there is room for FiTs to be more effective if their pricing schemes can be modified, not only to fit the economic environment, but also to attach decisive and optimal timeframes for prices to avoid long-term market distortion.

Effectiveness & Efficiency

Feed-in-tariffs have effectively created greater renewable energy production. However, this is no surprise because of the majority of FiTs' regulatory nature, which involves a set price below the market level for independent producers. As such, the question shifts to quantifying the costs of renewable energy production and whether the benefits of increased RET development outweigh the costs of subsidizing RET.

Analyzed by the Energy Research Center between 1994 and 1998, the minimum bid prices for contracts between Britain's auction model and Germany & Spain's feed-in-tariffs fell 40% and 1%, respectively. While FiTs resulted in stable electrical rates, Britain's auction market exhibited significant relative success at lowering energy prices. This small endeavor in turn helped create a sustainable system for long-term investment in RET.

Feed-in-tariffs are commended for their simplistic administrative nature because they typically require little supervision due to an upfront establishment of a long-term price scheme (Del Rio and Gaul; 2006). While this is true in certain respects, a regulatory approach creates indirect inefficiencies in the market. For example, by stifling innovation and charging a price that operates externally from the market[8], inefficiency arises. There are methods for circumventing this type of inefficiency, for example, phasing feed-in-tariffs out of a given economy over time (Sijm; 2002). However, it is important to recognize that many studies do not evaluate how realistic these remedies are, namely that once regulatory and/or full subsidies are instituted they are rarely eliminated.

Another flaw in the feed-in-tariff model is that they do not permit utility-scale solar power. Because regulatory agencies create pricing schemes that induce solar power usage primarily in residential communities, there are no incentives for scaling. Residents are unable to act as uniform bodies that pool resources to invest in larger solar production locations. In this sense, residents typically produce small amounts of energy by placing solar panels on rooftops. For these reasons, FiTs have generally been ineffective at achieving the ultimate goal: catalyzing innovation for the purposes of lower energy costs and gains in efficiency.

Unintended Consequences

Feed-in-tariffs have resulted in many material unintended consequences. Because FiTs are, by definition, at odds with competitive electrical pricing, they inevitably heighten the costs of electricity production by artificially creating a demand that would otherwise not exist. In addition, the incentive to produce at lower cost and innovate is not as strong because a set fee is determined by an external regulatory authority. Although there are methods to mitigate moral hazard and enhance the drive for innovation, FiTs are generally at a comparative disadvantage when paired against other market based incentive mechanisms.

Analyzing the effect that feed-in-tariffs had on Germany is particularly useful in understanding whether models predicting FiT success accurately represent reality. Many German utilities and consumers now oppose feed-in-tariffs because of the high costs that resulted to support renewable energy producers. For example, in 2000, a new wind turbine project would be paid 11 cents per kilowatt hour for the first five years with a falling rate thereafter. The Renewable Energy Law (EEG) that was instituted created a buyback tariff rate

8 Although every incentive alters the market, positively or negatively, certain incentives allow for more market-based interaction, such as tradable permit schemes and tax reductions for minimum purchase.

that increased 5% annually. Increased costs reached a point that resulted in net disutility and consumer dissatisfaction (Lesser and Su; 2007). This demonstrates that constant modification on FiTs is not always a feasible option, even if it is theoretically possible.

Denmark is another example of a country that has relied heavily on feed-in-tariffs, since their initial use in 1992. Utilities were obligated to purchase renewable energy from private producers at a fixed price between 70 and 85 percent of the market price for the given electricity (non-fossil fuels). Although there was a sharp increase in renewable energy production – which was expected – Denmark abandoned its guaranteed pricing in 2000, due to similar concerns about the high cost of supporting renewable energy producers. Departing from FiTs, Denmark began to institute tradable green certificates (TGC) to create a market for renewable energy (Lesser and Su; 2007). While there is inconclusive evidence as to whether TGCs create maximum incentives for market based competition, Denmark realized that feed-in-tariffs had saturated their market and failed to generate as much success for their renewable energy industry as they initially anticipated. It must be noted that the challenge for Denmark was not electrical production, but the lack of both reduced kilowatt/hour costs and long-term efficiency gains.

In addition to imposing hidden costs onto utilities and the general population, national feed-in-tariffs are eligible only to domestic generators (Sijm; 2002). Unless FiTs are structured to be received by all relevant entities – both domestic and foreign – within a given location, the incentive heightens trade protectionism. The National Foreign Trade Council has set guidelines that environmental trade legislation must follow to be compatible with international law; targeting FiTs to specific domestic producers would violate trade law (Syunkova; 2007). Although the purpose of this article is not to quantify the impact that such a violation would have, it is important to note the various unintended consequences that could possible result, such as disruptions to international trade. The negative ramifications of undermining free trade would reverberate throughout the international economy.

Conclusions on Feed-in-Tariffs

The mathematical model and qualitative analysis demonstrates that incentives must encourage the maximum utilization of the free market, rather than implementing an inherently inefficient regulatory framework. Couture and Gagnon (2010) provide an explanation detailing the distinction between market- independent and dependent tariff policies. While market independent FiTs establish a fixed payment rate for a set duration, market dependent FiTs have more flexible price structures capable of adapting to demand and reflecting environmental and social attributes. This versatile approach offers significant benefits over market independent feed-in-tariffs, primarily the gains in efficiency for utilities. Under a fixed price scheme, utilities are forced to price energy demand throughout the day at a fixed rate, which has resulted in lower marginal cost generators being scaled back (Langniss, et al; 2009, Couture Gagnon; 2010). Tamas, Shrestha, and Zhou (2010) also provide substantial evidence for this argument. Fixed price feed-in-tariff schemes are tantamount to government subsidies because they create an artificially low price to induce renewable energy development. Social welfare under this type of policy is lower than it is for tradable green certificates because the latter creates a market that compensates electrical producers for transitioning to renewable energy technologies. These findings are aligned with the argument espoused in the literature and model reviews, namely that approaches to engage markets are comparatively more efficient than regulatory schemes.

Although this analysis simplifies the issue at hand to some extent, it is meant to compile a breadth of information and accentuate the value of assessing incentives based on total benefits versus total costs – not using a single criterion for evaluation. While the discussed arguments are not intended to be fully comprehensive, they demonstrate some of the shortcomings that inhibit market independent feed-in-tariff approaches in comparison to other incentive mechanisms.

VI. Conclusion

Solar power is being subsidized in most developed countries. However, in order to grow and avoid becoming dependent on subsidies, the solar industry needs to proactively search for ways to use its received incentives more efficiently. Ultimately, solar power should become a cost-competitive technology that will displace conventional energies.

Economic incentive policy is equally as important; policymakers that provide poorly constructed incentives will heighten the tendency for solar firms to misallocate cash flow and invest in inefficient projects. Therefore, it is essential to develop criteria for evaluating the effectiveness of a given incentive, incorporating central aspects of various incentive valuation interpretations. Without objective and uniform valuation methods, policymakers will merely perpetuate perverse incentives in the renewable energy sector.

The mathematical model and qualitative criteria that have been discussed thus far introduce useful mechanisms for valuing incentives and their expected success. Seminal literature in the field of environmental economics has been surveyed and digested in this article to probe key questions and develop introductory conclusions. One such conclusion is that market based approaches are most likely encourage optimal and sustainable success in the renewable energy market. While regulatory and short-term incentive mechanisms, like feed-in-tariffs, offer compelling short-term benefits for renewable energy adoption, policymakers must acknowledge that the criteria for success encompasses more than just electrical production. Other vital objectives for renewable energy must also include converging upon and eventually surpassing the competitiveness of conventional energies in terms of cost-effectiveness, efficiency, and equity. Only by becoming profitable in the long-term will renewable energy technologies, especially solar power, become popular among consumers and utilities alike.

Additional analysis that acquires data for the model's endogenous variables will enable critical insights to be reached. In particular, estimates concerning incentives' contribution to the physical stock of capital, contributions to welfare, and technological change ought to be acquired. While developing accurate estimates of these values may prove challenging, I suggest that the wind energy production tax credit be analyzed as a base case for comparison, given that it serves as a strong model for an incentive's relative success at expanding renewable energy development. Based on existing economic theory and models, I contend that tax credits and a version of tradable permits should first be evaluated because they are the incentives that empirically capitalize upon market mechanisms the most. Upon confirmation of their effectiveness, additional research ought to be conducted to determine the most efficient method of implementation, namely whether the federal government or state and local governments are expected to achieve the most efficient outcome. While subsequent data must be subject to quantitative econometric techniques, it is also important to develop conclusions in context of the qualitative analysis established in this article, including Gouchoe (2002).

The solar energy sector has unprecedented potential for growth and innovation. However, this sector's ability to enhance total welfare is a function of both policymaker incentive construction and recipient incentive use. Determining and implementing optimal incentives for the solar industry is a challenge that can be overcome with careful analysis.

Appendix

A. Rivers and Jaccard on Firm Heterogeneity

The model has three periods: past (period 0), present (period 1), and future (period 2). No discounting takes place within periods, but costs are discounted from period 2 to period 1 by discount rate δ. Firms are also assumed to be electricity generators with three available technologies:

- A standard technology: a relatively cheap technology that emits a high amount of pollution. This is referred to, in the Rivers and Jac card model, as subscript b.
- An alternative technology: this technology is relatively more expensive, but emits less pollution than baseline technology b. Natural gas generation is an example. This technology is referred to as subscript f.
- A clean energy technology: this technology is much more expensive than the baseline technology, but emits very little pollution. This technology is referred to as subscript r.

The alternative and clean energy technologies experience decreasing costs, explained via the learning-by-doing assumption (Arrow; 1962):

$$c_{j,t} = c_{j,t=0}\left(\frac{N_{j,t}}{N_{j,t=0}}\right)^{b_j} \tag{A1}$$

Where $c_{j,t}$ is the cost of producing energy from the first unit of technology j installed in period t, $N_{j,t}$ is the total cumulative production of energy from technology j up to but not including period t, and b_j is a parameter defining how fast the cost of producing energy from technology j falls as cumulative production increases.

Without policy action that increases the relative costs of producing or forces a regulatory action, firms will use the cheapest technology, the baseline option. The marginal cost of pollution abatement, a, is measured in dollars per ton of pollution abated, calculated for clean energy and alternative technologies:

$$a_{j,t} = \frac{c_{j,t} - c_b}{e_b - e_j} \tag{A2}$$

Where $c_{j,t}$ is the marginal cost of technology j in period t in \$/kWh and e_j and c_r are increasing and concave values. The supply curve for technology j in period t is:

$$c_{j,t} = c_{j,t} + k_j (N_{j,t})^2 \tag{A3}$$

Where $c_{j,t}$ is the cost in \$/kWh for the first unit of energy produced by technology j in period t, k_j is a constant that reflects the steepness of the supply curve for technology j, denoting how fast per unit costs increase in a given period. If (A3) and (A2) are substituted for each other, one will find the marginal emissions abatement cost curve for each technology in time period t.

B. Clarke et al and Technological Change

Of particular importance in the Clarke model are the factors underlying technological change. They create a given production function for industry i as follows:

$$q_i = f(A_i, x_i) \tag{B1}$$

$$\frac{\partial A}{\partial t} = f(z) \tag{B2}$$

$$\frac{\partial A}{\partial Z_{-i}} > 0 \tag{B3}$$

$$\left(\frac{\partial}{\partial Z_{-i}}\right)\left(\frac{\partial q_i}{\partial A_i}\right) > 0 \tag{B4}$$

Where q_i is output in industry I, A_i is the sum total of technology parameters for industry i, and x_i is the sum total of inputs for industry i, including, but not limited to capital and labor; *f(z)* represents an activity, or set of activities, taken by actors within the model to help induce technological change (intra-industry efforts). Yet, technological change can also arise from external inducement, or incentives, through direct spillover. This is manifested in (B3) where technological change occurs from potential policy interventionists. This is represented with –i to refer to outside industry activities. The preceding equations are used to speculate the existence of (B4) which refers to the interaction of outside industry activities and their impact on technology parameters driven by intra-industry activities (Clarke, et al; 2006).

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