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Feed-in tariffs combined with capital subsidies for promoting the adoption of residential photovoltaic systems

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ABSTRACT

Both feed-in tariffs (FITs) and capital subsidies have been widely employed to promote the adoption of renewable energy technologies. This study sheds light on the combined use of FITs and capital subsidies. The purpose of the study is to clarify their optimal combinations in order to encourage households to adopt photovoltaic (PV) systems. The study develops a microeconomic model embodying the idea of two-part tariffs. The most important findings concern the combination that maximizes social welfare: if FITs are applied to the total PV electricity generated, they should be set at the avoided cost per unit of PV electricity, and capital subsidies should be used to control the number of adopters; whereas, if FITs are applied to only surplus PV electricity, the previous principle is distorted. However, a numerical example suggests that the distortion has little effect on the maximized social welfare and, thus, it makes little difference whether FITs are applied to all PV electricity or just the surplus PV electricity. The findings may also be applied to the adoption of wind-power generation systems and to adoption by businesses.

1. Introduction

A wide variety of support measures have been employed to promote renewable energy technologies (RETs), including, among others, renewable portfolio standards, tax credits, and the subjects of the present study: feed-in tariffs (FITs) and investment or capital subsidies. A typical FIT system allows the electricity generated from renewable energy sources (RES-E) to be sold to electric utilities at a set price for a set period of years (Mir-Artigues and del Río, 2016, Chapter 8); both the price and period are determined by a regulatory authority, and the cost of purchasing the RES-E is passed on to all ratepayers through increased electricity rates. In contrast, capital subsidies are granted to households or businesses as a lump sum payment when they adopt RETs; the funds for capital subsidies are raised through taxation. These serve as incentives for adopting RETs and generating RES-E to promote diffusion of the technologies.

FITs and capital subsidies are often used in combination (Dusonchet and Telaretti, 2010; Hsu, 2011; Zhao et al., 2013; del Río and Mir-Artigues, 2014; Mir-Artigues and del Río, 2014). A possible reason for this is that each offers distinct advantages (del Río and Mir-Artigues, 2014; Mir-Artigues and del Río, 2014; Hirvonen et al., 2015). FITs ensure relatively stable revenue flows to investors over a predetermined period of years; moreover, they enable a government to spread its expenditure more evenly over the period, which may enhance public acceptance, resulting in the political feasibility of this approach. In contrast, capital subsidies can lower an investor's cost of financing, which is the main barrier to investment.

However, the combination of FITs and capital subsidies may involve either inefficiency, redundancy, or overlap (del Río and Mir-Artigues, 2014; Mir-Artigues and del Río, 2014). If FITs and capital subsidies are not coordinated properly, the combination may either overcompensate adopters, thereby burdening ratepayers and taxpayers, or undercompensate, thereby potentially failing to achieve the targeted degree of RET diffusion (Lesser and Su, 2008; Mayr et al., 2014).

In Japan, for example, the number of households that have adopted photovoltaic (PV) systems has increased enormously since 2009, when both FITs and capital subsidies came to be widely available (METI, 2013). Besides the national government, many prefectural and municipal governments have offered households capital subsidies. In 2013, the Japanese government provided a capital subsidy of either ¥15,000/kW or ¥20,000/kW[1] per installed PV-panel capacity (¥100.00 was approximately equivalent to $1.00 at the time). In addition, the Gunma prefectural government and the city of Takasaki, Gunma, for instance, offered capital subsidies of ¥15,000/kW and ¥30,000/kW, respectively. Furthermore, households could sell PV electricity at much higher FITs than was the case with retail electricity rates: PV electricity was priced

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[1] Those adopters were granted ¥15,000/kW whose cost of a PV system was ≤¥500,000/kW, and ¥20,000/kW whose cost was ≤¥410,000 kW. The subsidy was larger for those whose cost was lower to encourage cost reductions.

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at ¥38.0/kWh, while retail electricity rates were either ¥18.89/kWh, ¥25.19/kWh, or ¥29.10/kWh,[2] depending on the amount of monthly consumption (Tokyo Electric Power Company, June 2013). It seems that these compensations were so generous that PV systems were adopted even if physical conditions, e.g., solar radiation, were unsuitable, placing an excessive financial burden on society.

Nevertheless, only a limited number of studies (reviewed in Section 2.1) have considered FITs and capital subsidies in combination, relative to the voluminous literature investigating such support measures in isolation. The purpose of the present study is to address this gap in the existing research, in particular by developing a theoretical model.

The study focuses on FITs and capital subsidies for the residential sector, where households considering adoption of RETs, typically PV systems, are interested in such remunerations, but, at the same time, must pay for FITs and capital subsidies indirectly through increased electricity rates and taxes. Taking into account that these support measures are aimed at diffusing PV systems further, the study focuses on the earlier stage of diffusion by assuming that the amount of PV generation is much smaller than the electricity consumption of the population.

This study develops a microeconomic model, which focuses on a household's decision-making regarding the adoption of a PV system. It aggregates some engineering details with a simple parameter whenever possible (cf. Mir-Artigues and del Río, 2016, Chapter 7). The present model is as an extension of the model by Yamamoto (2012), by incorporating both FITs and capital subsidies to investigate them in combination, and may be outlined as follows. A government offers a combination of FITs and capital subsidies to households for the adoption of a PV system. Then, households make decisions on adoption based on utility maximization. The model is not dynamic, but rather static, since its aim is to examine the decision-making by heterogeneous households at present, given the availability of FITs and capital subsidies.

The model assesses the superiority of different combinations of FITs and capital subsidies against several common governmental criteria (Mir-Artigues and del Río, 2016, Chapter 5). These include maximization of PV electricity output in terms of the benefit it provides (Oliva et al., 2014), minimization of promotion cost in terms of cost-effectiveness (del Río and Cerdá, 2014; Cerdá and del Río, 2015), and maximization of social welfare (e.g., Pirnia et al., 2011). In particular, social welfare is commonly used in the economic literature to assess economic efficiency. It consists of the surplus or net benefit for market participants, typically consumers and producers, in equilibrium. A concrete definition of social welfare in this study is presented in Section 4.3.[3]

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature, including the idea of a two-part tariff, which is applicable to the combination of FITs and capital subsidies. Section 3 describes a basic model, where FITs are applied to all the PV electricity generated. Section 4 examines the model in terms of several governmental criteria. Section 5, in contrast, is concerned with FITs applied only to surplus PV electricity by adapting the model developed in Section 3 and the section revisits the social welfare maximization problem. The results are illustrated by a numerical example in Section 6. Section 7 offers a discussion of the results in terms of the previous research. Finally, Section 8 provides the policy implications of the results and concludes with suggestions for future research.

2. Literature review

This section offers a review of the relevant literature. In the first subsection, studies dealing with the combined use of FITs and capital subsidies are reviewed. Unlike those studies, the present study views the problem as a variation on a two-part tariff system. In the second subsection, literature relevant to the idea of two-part tariffs is reviewed, and several hurdles that must be overcome if the idea is to be applied to our problem are identified.

2.1. Studies on the combined use of FITs and capital subsidies

To my knowledge, only two studies have explicitly addressed the combined use of FITs and capital subsidies, although a few others deal with the issue implicitly. The first of the two explicit studies is by Mir-Artigues and del Río (2014). The investigators developed a dynamic mathematical model to account for the inter-temporality of FITs and upfront capital subsidy payments. They found that, for an investor to achieve a given level of profitability, i.e., a ratio of profit to investment, financial costs are invariable for any combination of FITs and capital subsidies. What should be investigated in the next step is the financial cost to all investors; in general, given a certain combination of FITs and capital subsidies, some potential investors invest and some do not, depending on their own profitability calculation.

The second study, by Hsu (2011), examined the combination through a system dynamics model that simulates both the adoption of PV systems in society and the policy cost. Hsu compared three combinations: high FITs and low subsidies, medium FITs and medium subsidies, and low FITs and high subsidies. It was found that there is no difference between the three in terms of adoption of PV systems, but that a lower policy cost is achieved with the lower FITs/higher capital subsidies combination. Each household's decision-making was not addressed explicitly in the study, while the causal feedback in the system dynamics model led to the results.

Two studies have dealt with the issue implicitly. Both of these sought to make use of an auction process. First, Mayr et al. (2014) investigated an auction for qualifying eligible developers and determining remuneration levels for each support scheme. Second, Lesser and Su (2008) proposed a two-part FIT scheme consisting of a capacity payment and an energy payment. The capacity payment level is determined through an auction process, whereas energy payments are tied to the spot market price of electricity. As these studies show, an auction allows policymakers to avoid having to determine FIT or capital subsidy levels administratively. However, the scheme would be somewhat complicated if an auction were applied to the combination of FITs and capital subsidies.

Finally, it deserves mentioning that Klein (2008) described a methodology to determine FIT levels in terms of two concepts of cost associated with RES-E. One is the cost of RES-E generation, including investments in production facilities, O & M costs, interest payments for loans, and so forth. The other is the cost avoided by using RES-E, including not only the expenses of conventional power generation but also external costs—costs not priced in through market mechanisms—such as those associated with climate change, health impacts of air pollution, and energy supply vulnerability. These concepts of cost clarify two distinct objectives of compensation: RES-E generation cost compensation and avoided cost compensation. However, governments set only a single FIT level, resulting in the present controversy about FIT levels. One avenue to reconciliation may be to use two types of remuneration, one for RES-E generation-cost compensation, and the other for avoided-cost compensation. In other words, it is suggested that FITs might be used for avoided-cost compensation and capital subsidies for RES-E generation-cost compensation.

In light of the above literature review, the idea of two-part tariffs may play a key role in appropriately setting the respective levels of FITs and capital subsidies. Therefore, Section 2.2 reviews the standard

[2] The monthly consumption was divided by 120kWh and 300kWh into three tiers; a higher rate was applied to the higher tier of consumption. For example, if the monthly consumption was 400kWh, the bill was the sum of ¥18.89/kWh multiplied by 120kWh, ¥25.19/kW multiplied by 180kWh, and ¥29.10/kW multiplied by 100kWh.

[3] Prima et al. (2011) provided a simple explanation for social welfare on the electricity market.