臺灣能源期刊　第六卷　第四期　第353-367頁　中華民國108年12月
Journal of Taiwan Energy
Volume 6, No. 4, December 2019, pp. 353-367

The Effects of the Feed-In-Tariff System and the Renewable Energy Development Fund on Taiwan's Power Market

Ming-Chung Chang[1*]

ABSTRACT

Green power development is a global trend, and the goal of Taiwan's own green power is to be nuclear-free nationwide as regulated by Article 23 of the Basic Environment Act. The feed-in-tariff (FIT) price system and renewable power development fund are two policy tools designed to assist in this green power development. This study therefore investigates the effects of these two policies on Taiwan's power market and concludes that a research and development (R&D) investment subsidy is a better method to help the country's renewable energy development compared to the FIT price system over the long term, which would decrease Taiwan's long-term power price. Overall, consumer surplus and social welfare will improve in the long term, and the power industry's profit will remain stable, thus maintaining this industry's liberalization.

Keywords: Renewable energy development fund, Feed-in-tariff price, Power market.

1. Introduction

A new energy system such as a micro-grid aims to reduce greenhouse gas (GHG) emissions and dependence on fossil fuels. It is a small-scale power grid that operates independently and also connects with the super-grid. When the quantity of electricity supplied by the super-grid is insufficient, the electricity generated by the micro-grid can supplement the shortfall from the super-grid. The feed-in-tariff (FIT) price system also operates smoothly between the super-grid and the micro-grid when the surplus electricity generated by the micro-grid is sold back to the traditional power company after being transmitted to the super-grid.

The black energy generated by the super-grid and the renewable energy generated by the micro-grid are considered as substitutes for each other. A traditional power generator is a producer of black energy due to its use of fossil fuels, but a renewable power generator always uses clean energy such as solar, wind, and water to generate green power. Taiwan's renewable energy development fund pushes for clean energy as a substitute for the consumption of black energy. The country's power market is now implementing the FIT price system and the regime of the renewable energy development fund in order to achieve the goal of being nuclear-free as regulated by Article 23 of the Basic Environment Act.

This paper therefore investigates the effects of the FIT price system and the regime of the

[1] Professor, Department of Finance, Chihlee University of Technology.
* Corresponding Author, Phone: +886-2-22576167#1780,
E-mail: changmc@mail.chihlee.edu.tw

Received Date: August 8, 2019
Revised Date: October 5, 2019
Accepted Date: October 25, 2019

renewable energy development fund on Taiwan's power market. These two energy policies are based on Taiwan's Renewable Energy Development Act, which was promulgated in 2009 and amended on May 1, 2019 to encourage power suppliers over the long run to produce and use green power instead of black power. The amended Act emphasizes all citizens' participation. The FIT price system and the renewable energy development fund help achieve this goal of full participation by attracting more private green power generators to join the market.

Articles 7 and 9 of the Renewable Energy Development Act individually talk about: (i) a research and development (R&D) subsidy on power generation and the storage of renewable energy and (ii) the calculation of the wholesale purchase rate to purchase the renewable energy power. The former is an indirect price subsidy via cost reduction of generating green power, while the latter provides a direct price subsidy incentive to green power suppliers to produce a lot of green power. The former is a long-term policy, and the latter is a short-term policy for Taiwan's green energy development. In the long-term respective, the latter may be substituted by the former.

In order to present a solid perspective on these two regimes, a proper analytical tool is necessary before the new power regime can be executed in order to mitigate the risks of market failure. As such, game theory is one available approach to analyze the competitive strategies and behaviors of black energy makers versus green energy makers. The literature has utilized several game theory methods to model and analyze power industry competition. Hobbs and Pang (2007), Yao *et al*. (2007), and Han and Liu (2013) used the Cournot approach to set up non-cooperative games in energy markets, thus challenging the smooth-type setting of the electricity demand function, and investigated the results of an electricity market with price caps. Chang *et al*. (2013), Hawthorne and Panchal (2014), and Taha *et al*. (2014) incorporated the electricity market policy of the FIT price system into the model framework. The first paper took the Stackelberg game which is a game of leader-follower relationship to describe a competition among power firms in the electricity market, while the latter two obtained the Nash equilibrium by means of expected value formulation and algorithms, respectively.

Meng and Zeng (2013) and Chang (2014) are two other studies that applied the leader-follower game in their analysis of the power market. The former emphasized power pricing for a smart grid, and the latter included the issue of reducing emissions in the FIT price system. Wang and Watanabe (2016) and Andoni *et al*. (2017) also applied the Stackelberg game theory on the renewable energy market to discuss issues related to the biomass supply chain and renewable power generators paying a transmission fee to transmission line investors. The past literature has typically used the Stackelberg game theory to analyze the power market, implying that this market in many countries exhibits a leader-follower framework. Hence, our paper analyzes government policy in the power market by using the Stackelberg game theory.

The FIT price system based on the market-based mechanism is one tool that can assist in renewable energy development. Another common tool is renewable portfolio standards (RPS) based on a command-and-control mechanism. The FIT price system promises a premium price for renewable energy generation, while the RPS regime sets a minimum quota or proportion for renewable energy generation. The first successful

FIT price system was in Germany in 1990, but it was not until 1998 that four major electricity industries in the United States introduced the RPS regime. Lauber (2004) discussed the merits of co-existence between the FIT and RPS regimes and concluded that the two systems cannot be compared under a common standard since they serve different proposes. He also indicated that the RPS regime restricts geographical distribution, limits technological diversity, and relies on foreign equipment producers; the FIT regime, by contrast, serves as a bridge to a broad technological and geographical spectrum. Hence, the FIT regime contributed more than the RPS regime in the early phases of renewable energy development.

Baur and Uriona (2018) found that the FIT scheme has given rise to skyrocketing costs in Germany's photovoltaic market. Choi *et al*. (2018) took South Korea as an example to compare FIT and RPS schemes in the renewable electricity market, concluding that the latter is effective for photovoltaic energy and the former is good for non-photovoltaic energy, such as wind power, bio-energy, and fuel cells from the social planner's respective; however, the performance in the mind of a social planner runs opposite to that for the energy generator. Zhang *et al*. (2017b) concluded that the RPS scheme is more effective in terms of the development of China's photovoltaic power industry than the FIT scheme. Other studies have compared the FIT scheme with the RPS scheme in the wind power industry and waste incineration power industry, such as Zhang *et al*. (2017a) and Zhao *et al*. (2017), respectively.

In addition to studies on different scheme comparisons, the literature regarding the effect of the FIT price system on the power market presents works by Tamás *et al*. (2010), Kim and Lee (2012), and Sun and Nie (2015). While the literature has rarely examined the effect of the renewable energy development fund on Taiwan's power market, and the previous study did indicate that R&D expenditure has a positive effect on renewable energy technology innovation in China (Lin and Chen, 2019). Yu *et al*. (2016) recommended that the government should subsidize enterprise R&D investment within a certain range in order to avoid a crowding-out effect. They also stated that the government's long-term price subsidy to help the development of renewable energy technology is not an effective measure and that the price subsidy policy will be eventually canceled. Grafström and Lindman (2017) found that the price of fossil fuel is also the main component of electricity prices and can influence the diffusion and innovation of renewable energy technologies.

Taiwan's FIT price system will have a short-term effect on electricity prices in the country, and the R&D subsidy from its renewable energy fund will have a long-term effect on the diffusion and innovation of domestic renewable energy technologies. Hence, this study investigates the effects of the FIT price system and the renewable energy development fund on the power market at the same time, taking Taiwan's power market as an example since these two policies have been simultaneously enacted in the country. Aside from theoretical analysis, we also conduct empirical analysis. Specifically, we forecast a long-term result based upon the goal of a nuclear-free homeland as regulated by the Basic Environment Act.

The rest of this paper proceeds as follows. Section 2 sets up the model. Section 3 presents the analytical results. Section 4 provides the empirical analysis. We conclude with some findings in the final section.

2. The Model Set-up

For the objective of electricity liberalization, a micro-grid firm and a super-grid firm not only co-exist in a competitive market, but also consolidate electricity supply. This paper assumes two electricity suppliers are in the power market: one is a black power supplier, which generates power through use of fossil fuels, and the other is a green power supplier, which generates power by using renewable resources. The power market demand function is:

$$P = a - b(q + g). \tag{1}$$

Here, P is the power market's price, q is the quantity of black power demanded, and g is the quantity of green power supplied; otherwise, $g \in [0, \bar{g}]$, where $\bar{g}$ represents the quantity of green power supplied in the long run, and $\bar{g} = q + g$ means that green power fully substitutes for black power in the long run.

The green power supplier in Taiwan's FIT price system has priority in terms of supplying power to the market, and the black power supplier has a duty not only to supplement any shortage of power, but can also buy back all the green power at a guaranteed price. In terms of game theory, the green power supplier decides the quantity of green power, and then the black power supplier decides the quantity of green power to supplement the shortage of green power after the green power supplier's decision. Hence, this study denotes the green power supplier as the Stackelberg leader in the game and the black power supplier as the Stackelberg follower. The same idea appears in Chang *et al*. (2013). Parameter a represents the power's maximized price, and b refers to the price elasticity of demand.

The scale of a black power supplier is generally larger than that of a green power supplier, and thus the former owns economies of scale on electricity production relatives to the latter. Hence, it is reasonable to set the unit production cost of black power as 0 and the unit production cost of green power as c, where $c > 0$. The profit function for the black power firm before paying tax to the government is:

$$\pi = P(q + g) - rg\,, \tag{2}$$

where parameter r is the green power buy-back price.

The Renewable Energy Development Act in Taiwan requires that the black power supplier, i.e., government-run Taiwan Power Company (TPC), contribute a percentage s of its profit to the Renewable Energy Development Fund in order to help green power development, where $s \in [0, 1]$. Hence, the profit function for the black power firm after paying tax to the government is $\pi' = (1 - s)\pi$, where $s\pi$ is R&D investment. This study applies the idea of Cabon-Dhersin and Ramani (2004) whereby R&D investment helps lower unit production cost, and so we have $c - (s\pi)^{1/2}$ herein. Hence, the profit function for the green power firm is:

$$\pi^g = rg - (c - (s\pi)^{1/2})g. \tag{3}$$

Based on a factual situation, we may express the relationship among the parameters by $0 < P < c < r$ and $0 < g < q$. The former means that the buy-back price of green power must be higher than its generation cost, and the black power's market selling price is the lowest; otherwise, the quantity of green power supplied must be less than of black power.

The social welfare function consists of consumer surplus (CS) and producer surplus (PS). Based on the power demand function with its rigid price of black power in Eq. (1), consumer surplus is $(a-P)(q+g)/2$, and producer surplus is the power industry's aggregate profit, i.e., $\pi+\pi^g$. Hence, the social welfare function is:

$$W=(a-P)(q+g)/2+(\pi+\pi^g). \quad (4)$$

The first term on the right-hand side in Eq. (4) shows that making up for the shortfall in the quantity of power supplied and a low power price will push up consumer surplus; the second term denotes that an appropriate government policy in relation to the power industry's profit also benefits social welfare.

This paper uses a three-stage game to conduct the model analysis. In stage 1, the social planner adopts two energy policies: the optimal ratio of R&D investment (s) and the optimal buy-back price of green power (r) to maximize social welfare. In stage 2, the green power firm as both a Stackelberg leader and green power maker chooses the quantity of green power (g) to be supplied to maximize its profit. In stage 3, the black power firm as a Stackelberg follower or green power taker chooses the quantity of black power (q) supplied to supplement the shortage of power in the market. All players' payoff functions and their strategies are in Table 1 as follows.

3. Analytical Results

This section adopts backward induction to obtain the solution to the sub-game perfect Nash equilibrium (SPNE).

3.1 SPNE Solutions

Since the production quantity of green power in the short run is less than $\bar{g}$ and the quantity of long-term green power production should achieve $\bar{g}$, this section divides the *SPNE* solutions into short-term and long-term ones.

3.1.1 Short-term SPNE

In stage 3, the black power supplier chooses the quantity of black power supplied to make up for the shortage in the quantity of green power supplied by $q=(a-P)/b-g$. The result has two meanings: (i) the black power supplier does not seek to maximize profit, but instead supplements the shortage of green power; and (ii) black power and green power are substitute goods in which one is more and the other is less, and a low power price causes high power demand.

In stage 2, the green power supplier chooses the quantity supplied of green power to maximize its profit. The quantity of green power supplied is $g_L=2[3sP(a-P)-(r+c)^2b-(r-c)b^2\sqrt{3sP(a-P)+(r-c)^2b}\,]/(9srb)$ or $g_H=2[3sP(a-P)-(r+c)^2b+(r-c)b^2\sqrt{3sP(a-P)+(r-c)^2b}\,]/(9srb)$,[1] in which the former involves a strategy of low production quantity (LPQ), while the latter involves a strategy of high

Table 1. Players' payoff functions and strategies in the three-stage game (by author)

Stage # - Player	Payoff function	Strategy
Stage 1 - Social planner	$W=(a-P)(q+g)/2+(\pi+\pi^g)$	s and r
Stage 2 - Green power firm	$\pi^g=rg-(c-(s\pi)^{1/2})g$	g
Stage 3 - Black power firm	$\pi=P(q+g)-rg$	q

[1] The computation processes of g_L and g_H are as follows. Take the solution in stage 3, i.e., $q=(a-P)/b-g$, into the profit function of the green power supplier as $\pi^g=rg-(c-(s\pi)^{1/2})g$, where $\pi=P(q+g)-rg$ and $P=a-b(q+g)$. By setting $d\pi^g/dg=0$ and computing a solution, we get the two solutions of low production quantity (g_L) and high production quantity (g_H) in stage 2.

production quantity (HPQ). In other words, the green power supplier has room to adopt a strategic policy.

In stage 1, the social planner chooses the buy-back price of green power and the R&D investment ratio to maximize social welfare. The social planner's decision in the short term is:

$$r_L^* = (10/9)c \text{ and } s_L^* = (5/81)b^2c/(P(a-P)), \text{ or} \quad (5\text{-}1)$$

$$r_H^* = 2c \text{ and } s_H^* = b^2c/(P(a-P)). \quad (5\text{-}2)$$

The policy in Eq. (5-1) is a low interference (LI) one and the policy in Eq. (5-2) is a high interference (HI) one,[2] since the former's buy-back price and ratio of R&D investment are lower than the latter's buy-back price and ratio. Table 2 lists the strategy and policy combination for the green power firm and the social planner.

Table 2. The combination of a firm's strategy and government policy in the short term (by author)

Social planner / Firm	LPQ	HPQ
LI	Scenario 1	Scenario 2
HI	Scenario 3	Scenario 4

3.1.2 Long-term SPNE

In stage 3, the black power supplier in the long term does not produce black power anymore, i.e., $q = 0$, which also implies that the green power supplier in stage 2 supplies the green power quantity $g = \bar{g}$. The setting $q = 0$ fits the fashion of the RE100 initiative, which is a global corporate leadership initiative to commit to 100% green electricity. The RE100 initiative is not only an industrial trend, but also the final target of sustainable development. By substituting the long-term results $q = 0$ and $g = \bar{g}$ into Eq. (4), we have the comparative static results of $dW/dr = -s\bar{g}^2/(2(s\bar{g}(P-r))^{1/2}) < 0$ and $dW/ds = (P-r)\bar{g}^2/(2(s\bar{g}(P-r))^{1/2}) > 0$ given $r < P$, which not only guarantee that the number in the root symbol is a positive real number, but also ensure that $dW/ds > 0$.

We should emphasize that the term $r < P$ here is a long-term condition that fits the condition in which the Taiwan government has announced many times the hiking of electricity prices in order to improve electricity usage efficiency, because too low electricity prices in Taiwan have caused excess power usage and even power waste. In the long run, P will equal P' and P' will be higher than the FIT price. Based on the results above, $dW/dr < 0$, and $dW/ds > 0$, the social planner chooses the buy-back price of green power and its R&D investment ratio to maximize social welfare. Thus, the equilibrium solutions in stage 1 are:

$$r^* = 0 \text{ and } s^* = 1. \quad (6)$$

3.2 Short-term and Long-term Equilibrium Results

This section presents the model's short-term and long-term equilibrium solutions.

3.2.1 Short-term Equilibrium Solutions

Since the objective of the social planner is to maximize social welfare, the green power firm and the black power firm will both still implement their

[2] The computation processes of r_L^* and s_L^* in Eq. (5-1) of and r_H^* and s_H^* in Eq. (5-2) are as follows. Take the solutions in stages 2 and 3 - i.e., $q_i = (a-P)/b - g_i$ and $\pi_i^g = rg_i - (c-(s\pi_i)^{1/2})g_i$, where $\pi_i = P(q+g_i) - rg_i$, $P = a - b(q+g_i)$, and $i = L$ or H - into the social welfare function, $W_i = (a-P)(q+g_i)/2 + (\pi_i + \pi_i^g)$. Letting $dW_i/dr_i = 0$ and $dW_i/ds_i = 0$ to compute the solution in stage 1 by a simultaneous equation, we get the best solution for the social planner such as the solutions in Eqs. (5-1) and (5-2).

Table 3. The best path to develop green power (by author)

Social planner / Firm	LPQ	HPQ
LI	$(a-P)(135ac+19Pc+28P\sqrt{c})/(270bc)$	$(a-P)(225ac-91Pc+28P\sqrt{c})/(450bc)$
HI	$(a-P)(a+P)/(2b)$	$(a-P)(27a+11P)/(54b)$

strategies in accordance with this goal no matter what. Table 3 shows the optimal social welfare under the different scenarios. The ranking in terms of optimal social welfare from highest to lowest based on the strategy combination is (HI, LPQ), (HI, HPQ), (LI, LPQ), and (LI, HPQ).[3]

The highest social welfare responds to the strategy combination (HI, LPQ) in which the social planner's policy involves a high buy-back price (r_H^*) and a high ratio of R&D investment (s_H^*) as shown in Eq. (5-2), causing the green power supplier to adopt low production capacity, i.e., $g^* = 0$. This result implies that a social planner's high interference policy stalls the generation of green power. However, the social planner does not expect "Zero" green power. Hence, the social planner gives up the first-best policy to seek the second-best policy by adopting a low market interference policy with a low buy-back price (r_L^*) and low ratio of R&D investment (s_L^*), as shown in Eq. (5-1). This avoids the conundrum caused by "Zero" green power and achieves the second-best social welfare responding to strategy combination (LI, LPQ).

Proposition 1 Under the FIT price system and renewable power development fund, the second-best policy of a low buy-back price and low ratio of R&D investment will stimulate the green power firm to supply a positive quantity of electricity.

Table 4 exhibits the equilibrium solution under the second-best policy in which the quantity of green power supplied is positive; moreover, the quantity of black power supplied is also positive if the black power's price is not higher than cost c. Producer surplus and consumer surplus are both positive. In addition, the profit of the black power firm is higher than that of the green power firm even when the black power firm is a Stackelberg follower and the green power firm is a Stackelberg leader. This result is caused by the green power firm running at high cost, and it needs part of the black power firm's profit as R&D investment to reduce its own production cost.

Table 4. The short-term equilibrium solution under the second-best policy (by author)

Symbol	Equilibrium solution
g^*	$2(a-P)P/(25bc) > 0$
q^*	$(a-P)(25c-2P)/(25bc) > 0$, if $c > P$
π^*	$5(a-P)P/(9b) > 0$
π^{g*}	$16(a-P)P/(135b) > 0$
CS^*	$(a-P)^2/(2b) > 0$

3.2.2 Long-term Equilibrium Solutions

In the long run, a zero-black power situation will be realized by $q^* = 0$ and $g^* = \bar{g}$. In addition, the social planner's long-term policy requires that

[3] Substituting the best solutions in stages 1, 2, and 3 into Eq. (4)'s social welfare function, we obtain 4 likely social welfare solutions in which the social planner may adopt the strategy of (r_H^*, s_H^*) or (r_L^*, s_L^*), i.e., HI or LI, and the green power supplier may set up low production quantity (LPQ) or high production quantity (HPQ). The values of social welfare function in response to strategy combinations (LI, LPQ), (HI, LPQ), (LI, HPQ), and (HI, HPQ) are W(LI, LPQ), W(HI, LPQ), W(LI, HPQ), and W(HI, HPQ), where W(HI, LPQ) > W(HI, HPQ) > W(LI, LPQ) > W(LI, HPQ), as W(HI, LPQ) – W(HI, HPQ) = $(8(a-P)P)/(27b) > 0$, W(HI, HPQ) – W(LI, LPQ) = $(2(a-P)P(9c-7))/(135bc) > 0$, and W(LI, LPQ) – W(LI, HPQ) = $(4(a-P)P(46c+7))/(675bc) > 0$.

$r^* = 0$ and $s^* = 1$ as shown in Eq. (6). From this, we can compute the long-term equilibrium solution. In Eq. (3), $\pi^g = rg - (c - (s\pi)^{1/2})g$, where $g = \bar{g}$, $r^* = 0$, and $s^* = 1$ in the long run imply:

$$\pi^{g*} = 0 \text{ and } \pi^* = c^2. \quad (7)$$

From Eq. (2), $\pi^* = P\bar{g} - r^*\bar{g}$ in the long run, where $\pi^* = c^2$ and $P = P'$ cause the long-term power price to become:

$$P' = c^2/\bar{g}. \quad (8)$$

According to Eq. (4), the equilibrium social welfare in the long run is:

$$W^* = (a\bar{g} + c^2)/2, \quad (9)$$

where long-run social welfare depends on the quantity of green power supplied and the green power production cost. In addition, the black power firm is the only seller in the power market and only sells the green power that was purchased from the green power firm.

3.3 A Comparison between the Short-term and Long-term Equilibrium Results

Table 5 provides a comparison between the short-term and long-term equilibria. The price of power in the short term is fixed at P, and the long-term price of power is decided by the quantity of green power supplied $\bar{g}$, regarding which a large (small) $\bar{g}$ results in a low (high) price of power. In the long run, "full" green power $\bar{g}$ and "zero" black power are the targets; in the short run, a low price of black power, i.e., $P < (25/4)c$, causes its quantity demand to be higher than that of green power, i.e., $q^* > g^*$; on the contrary, a high price of black power, i.e., $P > (25/4)c$, causes its quantity demand to be higher than that of black power, i.e., $q^* > g^*$. In the short run, the green power firm's profit is positive; however, its long-term profit is zero since the policy of R&D investment at full cost substitutes for the policy of a guaranteed buy-back price, i.e., $r^* = 0$ and $s^* = 1$ in Eq. (6). Thus, we have the next proposition.

Proposition 2 The FIT price system and renewable power development fund are two price-oriented tools for green power R&D. In the long run, the renewable power development fund is a better method to aid green power development than the FIT price system. Hence, the FIT price system can be a short-term policy tool and the renewable power development fund can be a long-term policy tool.

Proposition 2 finds support in the past literature, such as Lin and Chen (2019) who claimed that R&D expenditure has a positive

Table 5. Comparison of the short-run and long-run situations (by author)

Symbol	Equilibrium solution	
	Short-run	Long-run
P	$P < a$	$c'^2/\bar{g}$
g^*	$2(a-P)P/(25bc)$	$\bar{g}$
q^*	$(a-P)(25c-2P)/(25bc)$	0
π^*	$5(a-P)P/(9b)$	c'^2
πg^*	$16(a-P)P/(135b)$	0
CS*	$(a-P)^2/(2b)$	$[a-(c'^2/\bar{g})]^2/(2b)$
W^*	$(a-P)(135ac+19Pc+28P\sqrt{c})/(270bc)$	$(a\bar{g}+c'^2)/2$

impact on renewable energy technology innovation in the long run. Nicolli and Vona (2016) and Schleich *et al*. (2017) indicated that R&D funding has an important role at stimulation innovation in renewable energy technology. Zhang *et al*. (2017) concluded that governments in China should promote renewable energy technological progress and reduce any subsidy on electricity prices.

This paper now compares the difference between the short-term marginal cost and the long-term marginal cost of the green power firm. We obtain the former by means of Eq. (5-1), using $c = (9/10)r_L^*$ as its calculation, and determine the latter by Eq. (7), i.e., $\pi^* = c^2$. We hereafter define the long-term cost as $c^{'}$, where $c^{'} = \sqrt{\pi^*}$ based on Eq. (7). The FIT price determines the short-term marginal cost of the green power firm, while the black power firm's profit decides the long-term marginal cost. In addition, the price of black power (P) fixes the short-term consumer surplus and social welfare, while in the long term the quantity of green power supplied ($\bar{g}$) and the green power production cost ($c^{'}$) determine consumer surplus and social welfare.

3.4 Policy Implications

Table 5 shows that the critical variable impacting the short-term result is P, and the long-term critical variable is $\bar{g}$. Specifically, a low price of black power (P) results in a large quantity of black power being supplied, large consumer surplus, and high social welfare in the short run. In the long run, a large quantity of green power ($\bar{g}$) supplied results in a low price of power, large consumer surplus, and high social welfare. This result indicates that the social planner should switch the critical policy from one that is short-term "price" oriented to one that is long-term "quantity" oriented. In the long run, as suggested in Proposition 2 of this study, a renewable energy development fund should be used to subsidize green power R&D in order to reduce the production cost. For this, the FIT price system is defined as a short-term policy tool, and the social planner does not adopt it in the long term.

The main mechanisms used to develop renewable energy are the FIT price system and the renewable portfolio standard (RPS). Evidence from the history of Taiwan's RPS policy indicates that its implementation is ineffective. For instance, the suggested renewable energy ratio ranges from 10% to 14% based on forecasted electricity capacity by 2020, but this target was revised to 10% by 2010 at the 2005 National Energy Conference. The Sustainable Energy Policy Framework issued in 2008 further revised the RPS target to 8% by 2025. Cost-down R&D investment in renewable energy by the renewable energy development fund can be an effective incentive to stably realize the RPS target. Our research presents the long-term effect of the renewable energy development fund, which is rarely seen in the past literature.

The setting up of a renewable energy development fund not only indirectly promotes the achievement of the RPS target, but also directly completes the liberalization of the power market. In the past, Taiwan's power market was a monopoly in which the government-run Taiwan Power Company (TPC) provided generation, transmission, and distribution, selling electricity in an all-in-one package. In January 2017, the legislature's revision of the Electricity Act broke the power market's monopoly structure and allowed independent power producers (IPPs) to freely enter the domestic power market and compete with the monopolist (TPC). We also see that the other function of the renewable energy development fund is to lower the IPPs' entry barrier by means of an R&D investment subsidy to lower production costs. The final goal of the Electricity Act is to separate generation, transmission, and distribution, with electricity sold independently, thus enabling the country's power market to become fully liberalized.

Lipp (2007) pointed out that Denmark and Germany are world leaders in the field of renewable energy development with their experience of the FIT price system. Lauber (2004) investigated the two main schemes of a FIT price system and RPS with tradable green certificates and concluded that these two systems cannot be measured by putting them together on the same scale since they serve different purposes. The former is a price policy tool, and the latter is a quantity policy tool. Our study also distinguishes the FIT price system as a short-term policy tool. In the long term, the FIT price system can be replaced by the policy of a renewable energy development fund in relation to an R&D investment subsidy. Hence, the co-existence of the two schemes in the short term is more helpful for renewable energy development.

4. Numerical Analysis

This paper uses the results of our model to perform numerical analysis. Table 6 exhibits the original data, including the average FIT price (r), the quantity of green power supplied (g), the quantity of black power supplied (q), the market price of power (P), and the estimated parameters, including the maximized price of power (a), the slope of the power demand curve (b), the marginal cost of the green power firm (c), the long-term quantity of power ($\bar{g}$), and the long-term price of power ($P^{'}$). We obtain parameters a and b by estimating the regression function in which the variables are the market price of power (P) and the total quantity of power supplied ($q+g$) and obtain parameter c via the short-term equilibrium FIT price (r_L^*) in Eq. (5-1). For long-term numerical analysis, it is necessary to obtain the parameter $\bar{g}$, which we get by forecasting the long-term quantity of power supplied. The long-term price of power ($P^{'}$) comes from the formula ($c^{'2}/\bar{g}$) in Table 5. The data period covers 2013 to 2017, and we forecast the long-term results. Because of the goal of a nuclear-free homeland as regulated by Article 23 in Taiwan's Basic Environment Act and due to limited data, this study sets the forecasted year at 2025.

Figure 1 shows the bar charts for consumer surplus, producer surplus (which is the sum of both power firms' profits), and social welfare for the years 2013 to 2017 as well as year 2025 for long-term forecasting.

Figure 1 illustrates that consumer surplus and social welfare are increasing and producer surplus is decreasing year by year, except for 2013. In the forecasted year of 2025, consumer surplus and social welfare reach their respective peaks, and producer surplus also achieves small growth versus the other observation years. This result implies that the current power policies in Taiwan, i.e., the FIT price and the mechanism of the renewable power development fund, are helpful for improving consumer surplus and social welfare, for maintaining the liberalization of the power market, and for sustaining stable excess profit in the power industry.

5. Conclusion

This study employs the Stackelberg game to analyze the effects of the FIT price system and the renewable power development fund on Taiwan's power market. In addition to short-term analysis,

Table 6. The data and estimation of parameters in Taiwan's power market (by author)

	Original data				Estimated parameter					
	Average FIT price (NT$ per kWh)	Average quantity supplied of green power (kWh)	Average quantity supplied of black power (kWh)	Power market average price (NT$ per kWh)	Maximized power price (NT$)	Slope of power demand curve	Short-term marginal cost of green power firm (NT$ per kWh)	Long-term marginal cost of green power firm (NT$ per kWh)	Long-term quantity supplied of power (kWh) in year 2025	Long-term power market price (NT$ per kWh) in year 2025
Parameter symbol	r	g	q	P	a	b	c	$c^{'}$	$\bar{g}$	$P^{'}$
Estimation value	3.358	50,357,064,702	171,368,893,127	2.812	8.701	0.000000000027	3.022	659,956.389	260,271,869,614	1.673

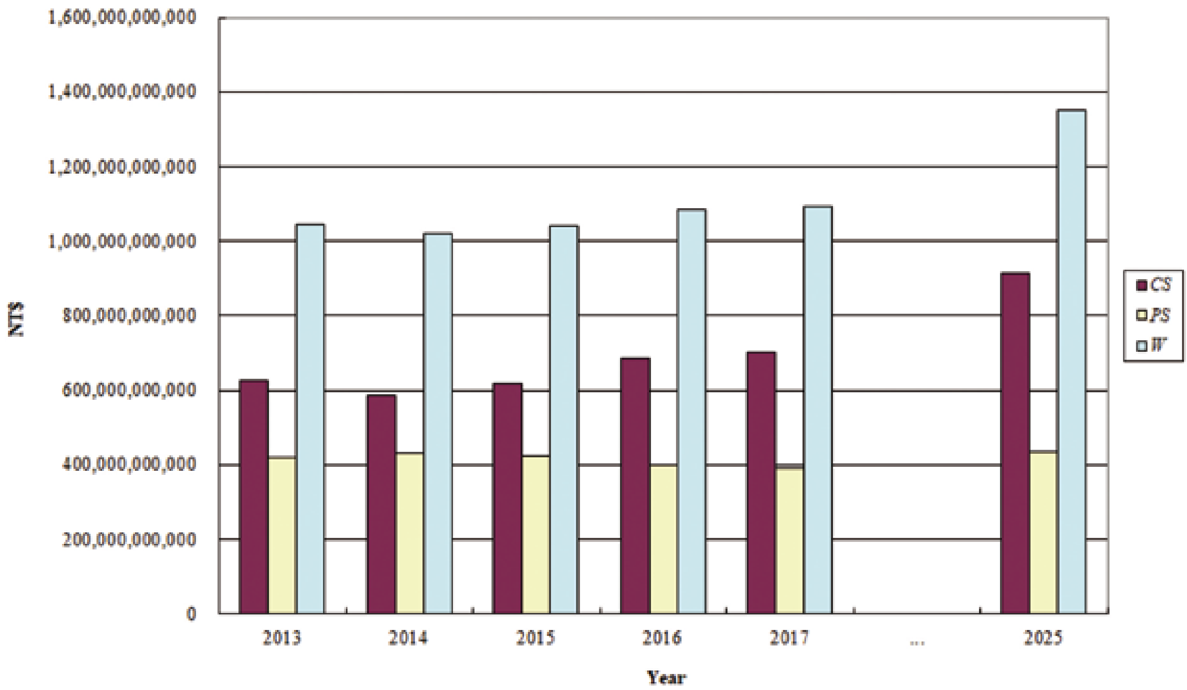

Fig. 1. The trends in consumer surplus, producer surplus, and social welfare (by author)

this paper also engages in long-term forecasting to the year 2025 based on the goal of a nuclear-free homeland as regulated by Article 23 in Taiwan's Basic Environment Act. The findings obtained herein are as follows. (i) In the forecasted year of 2025, consumer surplus and social welfare will be high due to the current policies in relation to the FIT price system and renewable power development fund. Moreover, the current power policy also benefits liberalization of the power market since the power firms will still generate excess profits. (ii) The FIT price system and a renewable power development fund are two price-oriented policy tools. In the short run, the social planner can adopt both them, but in the long run, the renewable power development fund for R&D investment is a better way to aid renewable energy development than the FIT price system. (iii) In the short run, the social planner will be in favor of adopting a low interference policy with a low FIT price and low R&D investment subsidy in order to spur the quantity of green power supplied. (iv) The theoretical model cannot confirm whether the long-term price of power will rise or fall, but the solution in the empirical analysis shows that the price of power in Taiwan will go down in the long run.

The model setting in this paper fully fits the status quo of Taiwan's power market. Based on this line of reasoning, the analytical results obtained provide timely advice not only to the Taiwan government, but also to any country that adopts the FIT price system and a renewable power development fund. The sources of renewable power include solar, wind, biomass, and geo-thermal and point toward a future study direction. In this current study, we do not classify the types of green power, but future studies can go into greater detail. Each kind of green power faces a different FIT price, R&D investment subsidy, and production cost. Future studies can broaden the range of renewable power firms to various other types. In addition, this study focuses on demand-side analysis of green power. Future research can switch to supply-side analysis or consider simultaneous analysis on the demand and supply sides.

Reference

Andoni, M., V. Robu, W. G. Früh and D. Flynn, 2017. "Game-theoretic Modeling of Curtailment Rules and Network Investments with Distributed Generation," *Applied Energy*, 201: 174-187.

Baur, L. and M. Uriona, 2018. "Diffusion of Photovoltaic Technology in Germany: A Sustainable Success or an Illusion Driven by Guaranteed Feed-in Tariffs?" *Energy*, 150: 289-298.

Cabon-Dhersin, M. L. and S. V. Ramani, 2004. "Does Trust Matter for R&D Cooperation? A Game Theoretic Examination," *Theory and Decision*, 57: 143-180.

Chang, M. C., J. L. Hu and T. F. Han, 2013. "An Analysis of a Feed-in Tariff in Taiwan's Electricity Market," *International Journal of Electrical Power & Energy Systems*, 44: 916-920.

Chang, M. C., 2014. "Electricity Tax Subsidizing the R&D of Emission-reducing Technology: The Double Dividend Effect under FIT Regime," *International Journal of Electrical Power & Energy Systems*, 62: 284-288.

Choi, G., S. Y. Huh, E. Heo and C. Y. Lee, 2018. "Prices versus Quantities: Comparing Economic Efficiency of Feed-in Tariff and Renewable Portfolio Standard in Promoting Renewable Electricity Generation," *Energy Policy*, 113: 239-248.

Grafström, J. and A. Lindman, 2017. "Invention, Innovation and Diffusion in the European Wind Power Sector," *Technological Forecasting and Social Change*, 114: 179-191.

Han, L. and A. L. Liu, 2013. "On Nash-Cournot Games with Price Caps," *Operations Research Letters*, 41: 92-97.

Hawthorne, B. and J. H. Panchal, 2014. "Bilevel Formulation of a Policy Design Problem Considering Multiple Objectives and Incomplete Preferences," *Engineering Optimization*, 46: 964-986.

Hobbs, B. F. and J. S. Pang, 2007. "Nash-Cournot Equilibria in Electric Power Markets with Piecewise Linear Demand Functions and Joint Constraints," *Operations Research*, 55: 113-127.

Kim, K. K. and C. G. Lee, 2012. "Evaluation and Optimization of Feed-in Tariffs," *Energy Policy*, 49: 192-203.

Lauber, V, 2004. "REFIT and RPS: Options for a Harmonised Community Framework," Energy Policy, 32: 1405-1414.

Lin, B. and Y. Chen, 2019. "Does Electricity Price Matter for Innovation in Renewable Energy Technologies in China?" *Energy Economics*, 78: 259-266.

Lipp, J., 2007. "Lessons for Effective Renewable Electricity Policy from Denmark, Germany and the United Kingdom," *Energy Policy*, 35: 5481-5495.

Meng, F. L. and X. J. Zeng, 2013. "A Stackelberg Game-theoretic Approach to Optimal Real-time Pricing for the Smart Grid," *Soft Computing*, 17: 2365-2380.

Nicolli, F. and F. Vona, 2016. "Heterogeneous Policies, Heterogeneous Technologies: The Case of Renewable Energy," *Energy Economics*, 56: 190-204.

Schleich, J., R. Walz and M. Ragwitz, 2017. "Effects of Policies on Patenting in Wind-power Technologies," *Energy Policy*, 108:

684-695.

Sun, P. and P. Y. Nie, 2015. "A Comparative Study of Feed-in Tariff and Renewable Portfolio Standard Policy in Renewable Energy Industry," *Renewable Energy*, 74: 255-262.

Taha, A. F., N. A. Hachem and J. H. Panchal, 2014. "A Quasi-Feed-In-Tariff Policy Formulation in Micro-grids: A Bi-level Multi-period Approach." *Energy Policy*, 71: 63-75.

Tamás, M. M., S. B. Shrestha and H. Zhou, 2010. "Feed-in Tariff and Tradable Green Certificate in Oligopoly," *Energy Policy*, 38: 4040-4047.

Wang, L. and T. Watanabe, 2016. "A Stackelberg Game Theoretic Analysis of Incentive Effects under Perceived Risk for China's Straw-based Power Plant Supply Chain," *Energies*, 9: 455.

Yao, J., S. S. Oren and I. Adler, 2007. "Two-settlement Electricity Markets with Price Caps and Cournot Generation Firms," *European Journal of Operational Research*, 181: 1279-1296.

Yu, F., Y. Guo, K. Le-Nguyen, S. J. Barnes and W. Zhang, 2016. "The Impact of Government Subsidies and Enterprises' R&D Investment: A Panel Data Study from Renewable Energy in China," *Energy Policy*, 89: 106-113.

Zhang, M. M., D. Q. Zhou, P. Zhou and H. T. Chen, 2017. "Optimal Design of Subsidy to Stimulate Renewable Energy Investments: The Case of China," *Renewable and Sustainable Energy Reviews*, 71: 873-883.

Zhang, Y., X. Zhao, L. Ren and Y. Zuo, 2017a. "The Development of the Renewable Energy Power Industry under Feed-in Tariff and Renewable Portfolio Standard: A Case Study of China's Wind Power Industry," *Journal of Cleaner Production*, 168: 1262-1276.

Zhang, Y., X. Zhao, Y. Zuo, L. Ren and L. Wang, 2017b. "The Development of the Renewable Energy Power Industry under Feed-in Tariff and Renewable Portfolio Standard: A Case Study of China's Photovoltaic Power Industry," *Sustainability*, 9: 532.

Zhao, X., Y. Zhang, L. Ren, Y. Zuo and Z. Wu, 2017. "The Policy Effects of Feed-in Tariff and Renewable Portfolio Standard: A Case Study of China's Waste Incineration Power Industry," *Waste Manage*, 68: 711-723.

電力收購制度以及再生能源發展基金對我國電力市場發展的影響

張民忠[1*]

摘　要

綠能發展(green power development)是全球趨勢。就我國而言，綠能發展目標是實現非核家園(nuclear-free hometown)，此目標被規範於我國的環境基本法(Basic Environment Act)第23條。電力收購制度(feed-in-tariff, FIT)以及再生能源發展基金(renewable power development fund)是我國兩項綠能發展的重要政策，本文研究上述兩項綠能政策對我國電力發展的影響。研究結果發現，就長期而言，利用再生能源發展基金進行研發與投資補貼，對於我國的再生能源發展優於電力收購制度，因為研發投資與投資補貼長期可促使電力價格下降，此外長期的消費者剩餘(consumer surplus)以及社會福利(social welfare)獲得改善，然而生產者剩餘(producer surplus)維持穩定，有利電力產業的自由化(liberalization)。

關鍵詞：再生能源發展基金，電力收購制度，能源市場

[1] 致理科技大學財務金融學系 教授
*通訊作者電話: 02-22576167#1780, E-mail: changmc@mail.chihlee.edu.tw

收到日期: 2019年08月08日
修正日期: 2019年10月05日
接受日期: 2019年10月25日