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Effectiveness of feed-in tariff and renewable portfolio standard under strategic pricing in network access

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Abstract

Although some policy schemes are intended to promote production from renewable energy sources (RES), strategic pricing in network access possibly offsets the effectiveness of these policies. This study compares the effectiveness of fixed-price and premium-price feed-in tariffs (FIT) and renewable portfolio standards (RPS) for promoting production from RES, explicitly considering strategic pricing in network access. The effects of vertical structure, i.e., vertical integration and separation, are also investigated. An analytical model consists of a monopolist and a competitive fringe, where the fringe firm produces from RES-E. The vertically integrated monopolist is able to set the access price incurred by the fringe and its own output. Under vertical separation, in contrast, the access price is set by an independent operator in the network sector. It is shown that under vertical integration, the effectiveness of both FIT policies are fully offset by strategic pricing in network access, whereas RPS does not create an incentive for the manipulation. This is because a higher access price induces a higher cost for the vertically integrated monopolist to meet the purchase obligation under RPS. Consequently, RPS is potentially more effective than FIT policies under vertical integration. It is also shown that vertical separation improves the effectiveness of both FIT policies but adversely reduces that of RPS.

Key words : Fixed-price FIT · Premium-price FIT · RPS · Access price · Vertical integration · Vertical separation

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1 Introduction

Feed-in tariffs (FIT) and renewable portfolio standards (RPS) are mainstream policy schemes for promoting generation from renewable energy sources (RES). FIT is a price regulation that includes broadly divided fixed-price FIT and premium-price FIT. The former type fixes the price of renewable electricity, whereas the latter adds a premium set by a policymaker to the market equilibrium price. RPS mandates an electric utility to procure a certain percentage of the electricity that it sells from renewable energy sources.

Most theoretical studies on FIT and RPS focus on the performance of each scheme (e.g., Siddiqui, Tanaka and Chen, 2016; Tanaka and Chen, 2013; Amundsen and Bergman, 2012; Fischer, 2010; Zhou and Tamás, 2010; Amundsen and Mortensen, 2001; Jensen and Skytte, 2002). Only a few studies, such as Tamás, Shrestha and Zhou (2010) and Hibiki , Kurakawa (2013), compare the effectiveness and efficiency of these policies. Tamás et al. (2010) compare the market equilibria of premium-price FIT and RPS policy schemes by using a model that does not explicitly consider strategic pricing in network access.

Although some policy schemes are intended to promote production from renewable energy sources (RES-E), strategic pricing in network access possibly offsets the effectiveness of these policies. Ropenus and Jensen (2009) theoretically show that the strategic manipulation of access charges by the monopolist partially offsets the effectiveness of fixed-price feed-in tariffs for promoting renewable power production, and unbundling with perfect regulation on access charges eliminates the possibility of manipulation. Consequently, it is possible for the fixed-price feed-in tariff to work entirely.

The purpose of this study is to compare the effectiveness of fixed-price and premium price feed-in tariffs (FIT) and renewable portfolio standards (RPS) for promoting production from RES, explicitly considering strategic pricing in network access. We also investigate the effects of vertical structure, i.e., vertical integration and separation.

Our study is most closely related to the work of Ropenus and Jensen (2009), who investigate how the effectiveness of fixed-price feed-in tariffs depends on industry structure, i.e., vertical integration and separation. They assume a market structure with a monopolist and a competitive fringe, where the fringe produces from renewable energy sources. They show that under vertical integration, a rise in the feed-in tariff induces the monopolist to raise access charges for the fringe, and effective unbundling with an externally set access charge does not create the possibility for the monopolist to extract part of the fringe's profit. Consequently, unbundling increases the effectiveness of the fixed-price feed-in tariff. Our study expands their analysis by considering RPS and premium-price FIT and showing comparative effectiveness between these policies under vertical integration and separation.

We analyze a model with a monopolist and a competitive fringe, where the monopolist determines the output from non-renewable energy sources and the competitive fringe determines the output from renewable energy sources. Both firms need to access a transmission network sector to sell the electricity that they produce. Under vertical integration, a vertically integrated monopolist is able to set the access price incurred by the fringe in addition to its own output. Under vertical separation, the access price is set by an independent operator in a network sector to maximize its own profit.

We show that under vertical integration, the market equilibria of the fixed-price and premium price feed-in tariff policy schemes are same as that of the benchmark case. This result indicates that the effectiveness of both FIT policy schemes is fully offset by strategic pricing in the network access under vertical integration. It also indicates that under these policy schemes, the monopolist practically faces the same decision making as the benchmark case; it is able to set a price for renewable electricity as a monopsony through manipulating the access price. In contrast to the FIT policy schemes, RPS does not create an incentive for the manipulation. This is because a higher access price shifts the inverse supply function upward, which in turn induces a higher cost for the vertically integrated monopolist to meet purchase obligations. Consequently, RPS is potentially more effective than FIT policy schemes under vertical integration.

We also show that vertical separation improves the effectiveness of both FIT policies but adversely reduces that of RPS. RPS under vertical separation gives the independent network operator room to increase its profit by raising the access price, whereas RPS under vertical integration does not create an incentive for access price manipulation. In the case of fixed-price and premium-price feed-in tariff policies, the unbundling increases renewable electricity production because it makes it impossible for the monopolist to set a renewable electricity price as a monopsony. The effect of vertical separation under RPS is a contrast to the cases of fixed-price and premium-price FIT policies, in which unbundling enables the policymaker to increase the output of the fringe.

The remainder of this paper is organized as follows: Section 2 sets out the model and derives conditions for market equilibria in the cases of the policies investigated. Section 3 investigates the effects of vertical separation comparing the outcomes between vertical integration and separation. Section 4 summarizes the analysis and concludes.

2 The model

2.1 Outline

Consider a market structure with a monopolist and a competitive fringe, where the monopolist determines the output from non-renewable energy sources q_M, whereas the competitive fringe determines the output from renewable energy sources q_F. The fringe firm sells its output to the monopolist at price P_R in the renewable electricity market. The monopolist sells total electricity $Q = q_M + q_F$ to a final representative consumer in a retail market, where inverse demand is $P(Q)$. Both firms need to access a transmission network sector to sell the electricity they produce.

Throughout the analysis, the fringe firm determines its output q_F to maximize its profit π_F, taking the prices for renewable electricity and network access as given,

$$\max_{q_F} \pi_F = P_R q_F - C_F(q_F) - a q_F, \tag{1}$$

where $C_F(\cdot)$ is the production-cost function with $C'_F > 0$ and $C''_F > 0$. The first-order condition of profit maximization $P_R - a = C'_F(q_F)$ yields renewable electricity inverse supply function $P_R(q_F, a) = a + C'_F(q_F)$ and supply function $q_F(P_R, a)$ with $\partial q_F(P_R, a)/\partial P_R = 1/C''_F > 0$ and $\partial q_F(P_R, a)/\partial a = -1/C''_F$.

Under vertical integration, a vertically integrated monopolist is able to set the access price a incurred by the fringe in addition to its own output. Under vertical separation, the access price is set by an independent operator in network sector to maximize its own profit.

The monopolist is obliged to purchase renewable electricity from the fringe firm under a policy scheme set by a policymaker in advance. We investigate three mainstream policy schemes: a) the fixed-price feed-in tariff (FIT), b) the premium-tariff feed-in tariff, and c) renewable portfolio standard (RPS). Under the fixed-price FIT, the price for renewable electricity is fixed at $P_R = \overline{P}_R$, which is set by the policymaker in advance. Under the premium-price FIT, the price for renewable electricity is set at $P_R = P + t$, where P is an equilibrium price in the retail market, and t is a premium set by the policymaker. RPS policy requires the monopolist to purchase a certain proportion of renewable electricity to its own output. Let β denote the proportion of the purchase obligation set by the policymaker. The monopolist is obliged to purchase at least $q_F = \beta q_M$ of electricity from renewable energy sources (RES).

We also consider a benchmark case in which no policy for promoting production from renewable energy sources is implemented. Under the benchmark case, the monopolist is able to set a price for renewable electricity as a monopsony.

2.2 Vertical integration

Under vertical integration, the vertically integrated monopolist is able to set the access price incurred by the fringe in addition to its own output.

2.2.1 The benchmark

In the case of the benchmark, the vertically integrated monopolist is able to set a price for renewable electricity P_R as a monopsony. The vertically integrated monopolist determines the prices for network access and renewable electricity, in addition to its own output,

$$\max_{a, P_R, q_M} \pi_M = PQ - C_M(q_M) - (P_R + \theta - a)q_F - \theta q_M - F_T, \qquad (2)$$

where F_T is a fixed cost at the network sector and θ is the constant marginal cost of transmission. Let $\Delta P_R := P_R - a$, and note that the first-order condition of profit maximization for the fringe can be written as $C'_F(q_F(\Delta P_R)) = \Delta P_R$. Then, we can rearrange (2) as the following expression:

$$\max_{\Delta P_R, q_M} \pi_M = PQ - C_M(q_M) - (C'_F + \theta)q_F - \theta q_M \qquad (3)$$

Differentiating with respect to ΔP_R and q_M, we obtain the first-order conditions of profit maximization for the monopolist:

$$\frac{\partial \pi_M}{\partial(\Delta P_R)} = [(P + P'Q) - (C''_F q_F + C'_F + \theta)]\frac{dq_F}{d(\Delta P_R)} = 0, \quad (4)$$

$$\frac{\partial \pi_M}{\partial q_M} = P + P'Q - C'_M - \theta = 0. \quad (5)$$

(4) and (5) determines the equilibrium outputs of the monopolist and the fringe (q_M^0, q_F^0), where the superscript 0 denotes the case of the benchmark.

2.2.2 Fixed-price FIT

Under FIT, the policymaker sets a fixed price of renewable electricity, $\overline{P}_R$. The vertically integrated monopolist determines a price for network access incurred by the fringe and its own output, taking the price of renewable electricity as given,

$$\max_{q_M, a} PQ - C_M(q_M) - (\overline{P}_R + \theta - a)q_F(a, \overline{P}_R) - \theta q_M. \quad (6)$$

Substituting the first-order condition for profit maximization of the fringe $\overline{P}_R - a = C'_F$, we can rearrange the above expression as the following:

$$\max_{q_M, a} PQ - C_M(q_M) - (C'_F + \theta)q_F(a, \overline{P}_R) - \theta q_M. \quad (7)$$

Differentiating with respect to a and q_M, we obtain the first-order conditions of the profit maximization of the monopolist,

$$\frac{\partial \pi_M}{\partial a} = [(P + P'Q) - (C''_F q_F + C'_F + \theta)]\frac{\partial q_F}{\partial a} = 0, \quad (8)$$

$$\frac{\partial \pi_M}{\partial q_M} = P + P'Q - C'_M - \theta = 0. \quad (9)$$

(8) and (9) determine the equilibrium outputs of the fringe and the monopolist.

We can see that (8) and (9) are practically the same as (4) and (5), respectively. This result indicates that the equilibrium outputs of the monopolist and the fringe under fixed-price FIT equal those under benchmark (q_M^0, q_F^0). That is, the policy implementation does not have the effect of increasing output from renewable energy sources. This is because the vertically integrated monopolist is practically able to behave as a monopsony, as (8) indicates, which in turn eliminates the effectiveness of the policy. From the first-order condition of the profit maximization of the fringe, and noting that the fringe output is q_F^0, we obtain the access price set by the monopolist as $a(\overline{P}_R) = \overline{P}_R - C_F'(q_F^0)$. From $a'(P_R) = 1$, we can see that an increase in the price of renewable electricity is fully offset by an increase in the access price set by the vertically integrated monopolist. The following proposition summarizes the above discussion.

Proposition 1
Under vertical integration, the market equilibrium realized in the fixed-price FIT is identical to that in the benchmark case, in which the monopolist is able to set a price of renewable electricity as a monopsony. That is, the implementation of the FIT policy fails to increase production from renewable energy sources.

2.2.3 Premium-price FIT

The policymaker sets a premium, t, added to the market price in the retail market. The fringe determines its output taking the price of renewable electricity, $P_R = P + t$, as given,

$$\max_{q_F} (P+t)q_F - C_F(q_F) - aq_F. \tag{10}$$

The first-order condition for profit maximization $P + t - a = C_F'(q_F)$ yields an output from renewable energy sources as $q_F = q_F(a, q_M, t)$. Note that under the premium-price FIT policy, the output of the monopolist affects the fringe output via the retail market price, in contrast to fixed-price FIT.

The vertically integrated monopolist determines its output and the network access price incurred by the fringe,

$$\max_{a, q_M} PQ - C_M(q_M) - (P + t + \theta - a)q_F - \theta q_M. \tag{11}$$

Substituting the first-order condition of the fringe yields

$$\max_{a, q_M} PQ - C_M(q_M) - (C_F' + \theta)q_F(a, q_M; t) - \theta q_M. \tag{12}$$

Differentiating with respect to a and q_M, we obtain the first-order conditions as follows:

$$\begin{aligned}\frac{\partial \pi_M}{\partial a} &= [(P+P'Q)-(C''_F q_F + C'_F+\theta)]\frac{\partial q_F(a,q_M)}{\partial a}=0, \quad (13)\\ \frac{\partial \pi_M}{\partial q_M} &= P+P'Q-C'_M-\theta \\ &\quad +[(P+P'Q)-(C''_F q_F + C'_F+\theta)]\frac{\partial q_F(a,q_M)}{\partial q_M}=0. \quad (14)\end{aligned}$$

Because $\partial q_F/\partial a = -1/C''_F < 0$ from the first-order condition of the fringe, (13) is equivalent to the following expression:

$$(P+P'Q)-(C''_F q_F + C'_F+\theta)=0. \quad (15)$$

Substituting (15) into (14), we obtain

$$P+P'Q-C'_M(q_M)-\theta=0. \quad (16)$$

(15) and (16) are, respectively, equivalent to (4) and (5), which are conditions for market equilibrium under the benchmark. That is, the premium-tariff FIT under vertical integration yields market equilibrium (q^0_M, q^0_F), which is same as that of the benchmark, irrespective of the level of premium tariff t set by the policymaker. From the first-order condition of the fringe, and noting that equilibrium output of the fringe is q^0_F, the access price set by the monopolist is represented as $a = t + P^0 - C'_F(q^0_F)$, where P^0 denotes the equilibrium price in the retail market under the benchmark. This expression indicates that an increase in the premium tariff is entirely offset by an increase in the access price set by the vertically integrated monopolist. The following proposition summarizes the above.

Proposition 2
The market equilibrium realized in the premium-price FIT under vertical integration is the same as that of the benchmark (in which the monopolist in the retail market is able to set a price for renewable electricity); this result indicates that the policy does not have the effect of increasing production from renewable energy sources.

2.2.4 RPS

RPS policy requires the monopolist to provide a certain proportion of electricity to its own production from renewable sources. The policymaker sets a mandatory proportion, β. The monopolist is required to satisfy $q_F \geq \beta q_M$, purchasing electricity from the fringe.[1]

The monopolist determines its own output and a price for network access:

$$\max_{a,q_M} \pi_M := PQ - C_M(q_M) - [P_R(q_F, a) + \theta - a]q_F - \theta q_M. \quad (17)$$

Recall that $P_R(q_F, a) = a + C_F'(q_F)$ is the inverse supply function of renewable electricity, which is derived from the first-order condition of profit maximization by the fringe. Differentiating (17) with respect to a yields

$$\frac{\partial \pi_M}{\partial a} = -\left(\frac{\partial P_R(q_F, a)}{\partial a} - 1\right) q_F. \quad (18)$$

Because $\partial P_R(q_F, a)/\partial a = 1$, the effect of the access price on the monopolist's profit is $\partial \pi_M/\partial a = 0$ for all $a \geq 0$. That is, RPS does not create any incentive for manipulation in access prices. This is because a higher access price shifts the inverse supply function upward, which in turn induces higher cost for the vertically integrated monopolist to meet the purchase obligation, and vice versa. Then we obtain the following proposition.

Proposition 3
RPS policy under vertical integration does not motivate the vertically integrated monopolist to manipulate the network access price incurred by the fringe.

The equilibrium output of the monopolist is determined by the following first-order condition with respect to q_M:

$$\begin{aligned} \frac{\partial \pi_M}{\partial q_M} &= (P + P'Q - C_M' - \theta) \\ &\quad + \left[P + P'Q - \left(\frac{\partial P_R}{\partial q_F} q_F + P_R + \theta - a\right)\right] \frac{dq_F}{dq_M} = 0. \end{aligned} \quad (19)$$

[1] For simplicity, we do not consider tradable certificates here.

Substituting $P_R = a + C'_F(q_F)$ and $q_F = \beta q_M$ and rearranging terms, we obtain the following expression:

$$(P + P'Q)(1 + \beta) = C'_M + (C'_F + C''_F \beta q_M)\beta + (1 + \beta)\theta. \tag{20}$$

The left-hand side of (20) is the marginal revenue of increasing production. The first term of the right-hand side is the marginal production cost, the second term is the marginal procurement cost of renewable electricity, and the third term is the marginal transmission cost.

2.3 Vertical separation

In the case of vertical separation, the network sector is separated from the monopolist. An independent operator in the network sector sets a price for network access incurred by the monopolist and the fringe to maximize its profit, π_T,

$$\max_a \pi_T := (a - \theta)Q - F_T. \tag{21}$$

From the first derivative with respect to a: $Q + (a - \theta)dQ/da$, we obtain

$$\left.\frac{d\pi_T}{da}\right|_{a=\theta} = Q > 0. \tag{22}$$

This indicates that the independent network operator sets the access price higher than the marginal transmission cost irrespective of the policy implemented.[2]

2.3.1 The benchmark

In the case of the benchmark, the monopolist is able to set a price for renewable electricity as a monopsony. In contrast to the case of vertical integration, the monopolist must absorb the network access price set by the independent operator. The maximization problem of the monopolist is represented as follows:

$$\max_{q_M, P_R} \pi_M := PQ - C_M(q_M) - aq_M - P_R q_F. \tag{23}$$

[2]Recall that in the case of RPS under vertical integration, an increase in access price does not have a positive/negative effect on the profit of the vertically integrated monopolist.

Differentiating with respect to q_M and P_R yields first-order conditions of profit maximization,

$$\frac{\partial \pi_M}{\partial q_M} = P + P'Q - C'_M - a = 0, \tag{24}$$

$$\frac{\partial \pi_M}{\partial P_R} = (P + P'Q)\frac{dq_F}{dP_R} - \left(q_F + P_R\frac{dq_F}{dP_R}\right) = 0. \tag{25}$$

(24) and (25) determines the equilibrium outputs of the monopolist and the fringe as a function of a, and the total output can be represented as $Q(a) = q_M(a) + q_F(a)$. The independent operator in the network sector sets a price for network access a^*:

$$a^* = \arg\max_a (a - \theta)Q(a) - F_T. \tag{26}$$

2.3.2 Fixed-price FIT

The policymaker sets a fixed price for renewable electricity, $\overline{P}_R$. As in the case of benchmark, the first-order condition of profit maximization for the fringe can be represented as

$$\overline{P}_R - a = C'_F(q_F). \tag{27}$$

The monopolist determines its output taking the prices for renewable electricity $\overline{P}_R$ and network access a as given,

$$\max_{q_M} \pi_M := PQ - C_M(q_M) - aq_M - \overline{P}_R q_F. \tag{28}$$

The first-order condition of profit maximization for the monopolist is

$$\frac{d\pi_M}{dq_M} = P + P'Q - C'_M - a = 0. \tag{29}$$

(27) and (29) determines the equilibrium output of the fringe and the monopolist as functions of a and $\overline{P}_R$. Then, the total output can be represented as $q_M(a, \overline{P}_R) + q_F(a, \overline{P}_R) = Q(a, \overline{P}_R)$. The independent operator in the network sector sets a price for access $a^*(\overline{P}_R)$:

$$a^*(\overline{P}_R) = \arg\max_a \pi_T := (a - \theta)Q(a, \overline{P}_R) - F_T. \tag{30}$$

The first-order condition of profit maximization for the independent operator is

$$\frac{d\pi_T}{da} = (a - \theta)\frac{dQ}{da} + Q(a, \overline{P}_R) = 0. \tag{31}$$

2.3.3 Premium-price FIT

The fringe determines its output taking the price for renewable electricity $P_R = P + t$ as given,

$$\max_{q_F}(P+t)q_F - C_F(q_F) - aq_F, \tag{32}$$

where t is a premium tariff set by the policymaker. The first-order condition

$$P + t - a = C_F'(q_F) \tag{33}$$

generates renewable electricity supply $q_F(a, q_M; t)$. Note that output of the monopolist q_M is included as an argument because it influences the fringe output via the retail market price. Differentiating both sides of (33) with respect to q_M and rearranging terms yields the following:

$$\frac{\partial q_F}{\partial q_M} = \frac{P'}{C_F'' - P'}. \tag{34}$$

The monopolist is obliged to purchase renewable electricity from the fringe at price $P+t$ and incurs access price a per unit of electricity it produces,

$$\max_{q_M} PQ - C_M(q_M) - (P+t)q_F - aq_M. \tag{35}$$

The first-order condition of profit maximization is

$$\frac{d\pi_M}{dq_M} = P + P'q_M\left(1 + \frac{\partial q_F}{\partial q_M}\right) - C_M' - t\frac{\partial q_F}{\partial q_M} - a = 0. \tag{36}$$

2.3.4 RPS

The monopolist is obliged to satisfy purchase obligation $q_F \geq \beta q_M$. We assume that this constraint is satisfied by $q_F = \beta q_M$.

$$\max_{q_M} \pi_M := PQ - C_M(q_M) - aq_M - P_R(q_F, a)q_F. \tag{37}$$

The first-order condition of the profit maximization is

$$\frac{d\pi_M}{dq_M} = (P + P'Q)\left(1 + \frac{dq_F}{dq_M}\right) - C_M'(q_M) - \left(P_R + \frac{dP_R}{dq_F}q_F\right)\frac{dq_F}{dq_M} - a = 0. \tag{38}$$

Substituting $q_F = \beta q_M$ and $P_R = a + C'_F(q_F)$ and rearranging the terms yields the following expression:

$$(P + P'Q)(1 + \beta) = C'_M + (C'_F + C''_F \beta q_M)\beta + (1 + \beta)a. \tag{39}$$

The left-hand side of (39) is the marginal revenue of increasing production. The first term of the right-hand side is the marginal production cost, the second term is the marginal procurement cost of renewable electricity, and the third term is the marginal price of transmission. The sum of these terms is the total marginal cost of increasing production. Recall that under vertical separation, the independent operator in the network sector sets a price for network access higher than marginal transmission cost; $a > \theta$. Comparing (20) and (39) indicates that the total marginal cost of increasing production is higher under vertical separation than vertical integration for any β. Then, we obtain the following proposition.

Proposition 4
Under RPS, vertical integration generates higher production from renewable energy sources than vertical separation for any β. Therefore, vertical integration enables the policymaker to generate higher production from renewable energy sources than vertical separation.

3 Comparison of vertical integration and separation

In this section, we compare outcomes between vertical integration and separation using quadratic cost functions and a linear inverse demand function in the retail market; $C_M(q_M) := c_M(q_M)^2/2$, $C_F(q_F) := c_F(q_F)^2/2$, $P(Q) := A - BQ$.

We can calculate the output of the fringe in the case of benchmark under vertical integration as follows:

$$q_F^0 = \frac{(A - \theta)c_M}{2Bc_M + 4Bc_F + 2c_M c_F}. \tag{40}$$

As proposition 1 states, fixed-price and premium-price FITs yield the same fringe-production level as the above.

First, we investigate the case of fixed-price FIT. From (27), (29) and (31), the access price set by the independent operator in the case of fixed-price FIT under vertical separation is calculated as

$$a = \frac{\theta}{2} + \frac{Ac_F + c_M\overline{P}_R}{2(c_M + c_F)}, \tag{41}$$

and the corresponding output of the fringe is derived as follows:

$$q_F = \frac{(c_M + 2c_F)\overline{P}_R - (c_M + c_F)\theta - Ac_F}{2c_F(c_M + c_F)}. \tag{42}$$

Differentiating the above expression with respect $\overline{P}_R$, we obtain

$$\frac{dq_F}{d\overline{P}_R} = \frac{c_M + 2c_F}{2c_F(c_M + c_F)} > 0. \tag{43}$$

This finding indicates that increasing the fixed price under vertical separation increases the production of the fringe, although the effect of a higher fixed price is partially offset by the higher access price, as we can see from (41) that $da/d\overline{P}_R = c_M/2(c_M + c_F) < 1$. Because the fringe output in the case of fixed-price FIT is constant under vertical integration (as proposition 1 states), a sufficiently higher fixed-price level under vertical separation generates higher fringe production than vertical integration. The following proposition summarizes the discussion above:

Proposition 5
In the case of fixed-price FIT, a higher fixed price for renewable electricity increases the output of the fringe only if the network sector is vertically separated. Correspondingly, vertical separation with a sufficiently high fixed price enables the policymaker to achieve higher production from renewable energy sources than vertical integration.

Next, we turn to the case of premium-price FIT. In the case of premium-price FIT, the price for network access set by the independent operator under vertical separation is given by

$$a = \frac{A + \theta}{2} + \left[\frac{2Bc_F + Bc_M + c_Mc_F}{2Bc_F + Bc_M + c_Mc_F + (c_F)^2}\right] t, \tag{44}$$

and the corresponding output of the fringe can be derived as

$$q_F = \frac{1}{B + c_F}\left[\left(\frac{N - Bc_F}{2N}\right)(A - \theta) + \left(\frac{(c_F)^2 + Bc_F}{N + (c_F)^2}\right) t\right], \tag{45}$$

where $N \equiv 2Bc_F + Bc_M + c_M c_F$. From (45), the effect of increasing the premium price on the fringe output is

$$\frac{dq_F}{dt} = \left(\frac{1}{B + c_F}\right) \frac{(c_F)^2 + Bc_F}{N + (c_F)^2} > 0. \tag{46}$$

This finding indicates that a higher premium has a positive effect on the fringe output with a constant magnitude.[3] Because the fringe output in the case of premium-price FIT is constant under vertical integration (as proposition 1 states), a sufficiently higher premium under vertical separation generates a higher production of the fringe than vertical integration. The following proposition summarizes the discussion above:

Proposition 6
In the case of premium-tariff FIT, a higher premium tariff increases the output of the fringe only if the network sector is vertically separated. Correspondingly, vertical separation with a sufficiently high premium tariff enables the policymaker to achieve higher production from renewable energy sources than vertical integration.

Recall that proposition 4 indicates that in the case of RPS, vertical integration generates higher fringe production than vertical separation does. The effect of vertical separation under RPS contrasts the cases of fixed-price and premium-price FIT policies, in which vertical separation enables the policymaker to increase the output of the fringe.

Finally, we compare the effectiveness of increasing the fringe production between policies under vertical integration. The output of the fringe in the case of RPS under vertical integration is calculated as

$$q_F = \frac{(\beta + \beta^2)(A - \theta)}{2B(1 + \beta)^2 + c_M + 2c_F\beta^2}. \tag{47}$$

Taking the limit of (47) with respect to β, we obtain

$$\lim_{\beta \to \infty} q_F = \frac{(A - \theta)}{2(B + c_F)}. \tag{48}$$

Note that the fringe outputs realized in the cases of fixed-price and premium-price FIT policies are same as those in the case of the benchmark, which is represented by (40). Comparing (40) and (48) derives the following proposition:

[3] Note that the constant magnitude of the premium depends on the specified functional forms assumed here.

Proposition 7
Under vertical integration, RPS is potentially more effective for promoting generation from renewable energy sources than fixed-price and premium-tariff FIT policies. In other words, RPS enables the policy-maker to generate higher fringe production than fixed-price and premium-tariff FIT policies by setting the level of proportional obligation properly.

4 Results and conclusions

It is shown that under vertical integration, the market equilibria of the fixed-price and premium-price feed-in tariff policy schemes are same as those of the benchmark case. This finding indicates that the effectiveness of both FIT policy schemes is fully offset by strategic pricing in network access under vertical integration. It also indicates that under these policy schemes, the monopolist practically faces the same decision making as the benchmark case; it is able to set a price for renewable electricity as a monopsony through manipulating the access price. In contrast to the FIT policy schemes, RPS does not create an incentive for manipulation. This is because a higher access price shifts the inverse supply function upward, which in turn induces a higher cost for the vertically integrated monopolist to meet purchase obligations. Consequently, RPS is potentially more effective than FIT policy schemes under vertical integration.

It is also shown that vertical separation improves the effectiveness of both FIT policies but adversely reduces that of RPS. RPS under vertical separation gives the independent network operator room to increase its profit by raising the access price, whereas RPS under vertical integration does not create an incentive for access-price manipulation. In the case of fixed-price and premium-price feed-in tariff policies, the unbundling increases renewable electricity production because it makes it impossible for the monopolist to set a renewable electricity price as a monopsony.

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