Internal Carbon Financing with Transferable Offsets from Renewable Portfolio Standard

Jongmin Yu[a] *and Hyo-Sun Kim*[b]

ABSTRACT

Power generation under the Renewable Portfolio Standard (RPS) can reduce greenhouse gas emissions below the baseline level, so entities may argue to use this attribute to meet the goal of Emission Trading Scheme (ETS). Although these two quantity-based regulation systems have different policy objectives, both mechanisms are implicitly linked by credit conversions depending on credit prices. This paper builds an analytic partial equilibrium model and derives market equilibria in a closed form to demonstrate how each mechanism influences the other by policy instruments such as a renewable requirement, a reduction target in greenhouse gas emission, levels of penalties, or marginal costs. We can compare "direct vs indirect" effectiveness of a regulatory changes across both markets with the case where converting renewable offsets are completed prohibited.

Keywords: Emission trading scheme, Renewable portfolio standard, Climate change, Market linkage

https://doi.org/10.5547/01956574.42.2.joyu

1. INTRODUCTION

At the 21th annual session of Conference of the Parties to the United Nations Framework Convention on Climate Change, countries initiated a new phase of international climate change regime for the post-2020 era called Paris Agreement by replacing the Kyoto Protocol. Many countries are running the market-based incentive mechanism such as Emission Trading Scheme (ETS) to control greenhouse gas (GHG) emissions and Renewable Portfolio Standard (RPS) to boost power generation using renewable energy sources rather than depending fossil fuels. They have different policy objectives but can reduce GHG emissions by using renewables as the primary abatement option to reduce GHG; therefore, ETS and RPS interact and influence one another. Policy makers have also operated ETS and RPS jointly: e.g. NOx budget trading program in U.S. has been operating a set-aside program to allocate quotas when generating electricity using renewable energy; California Air Resource allows to use offsets up to 8% (4% after 2021) to meet its obligation target (Latham. and Watkins, 2011); each member of EU-ETS has different offset limits although the market is integrated (about 13% in average); the Chinese-ETS has separated municipal schemes with 5% in Beijing, 8% in Chongqing, 10% in Gunagdong, 5% in Shanghai, 10% in Shenzhen, 10% in Tianjin;

a Associate Professor, Department of Economics, Hongik University, 94 Wausan-ro, Mapogu, Seoul, 121-791, Republic of Korea.

b Corresponding author. Energy Group Chair, The Presidential Committee on Northern Economic Cooperation, KT Building West, 178 Sejongdaero, Jongro-gu, Seoul, 03154, Republic of Korea. E-mail: koreacarbon@gmail.com.

Korean-ETS allows 10% of total compliances.[1] The US Clean Power Plan has a carbon-intensive target, not total emissions: power plants must meet a certain threshold requirement on the ratios between GHG emissions and electricity output (MWh). Electricity generators using renewables can sell emission reduction credits which can be used at lower rates (lbs / MWh) than those of other emission plants. The UK has allowed the conversion of renewable power generation exceeding requirements of the RPS into ETS carbon credits. The value of REC (Renewable Energy Credits: generated from the renewable energy producers can be sold and traded under the compliance system of the RPS) can be converted into carbon reduction, allowing the UK-ETS to sell it as carbon credits but this system has been suspended due to integration with EU-ETS since 2005.

Much academic research has been conducted on the links between multiple ETSs or RPSs implemented in different types or regulatory boundaries. (Rausch and Karplus, 2014; Curtis et al, 2014; Perez et al, 2016; Yu and Mallory, 2017). Amundsen and Mortensen (2001) show the price of REC the profit of renewable energy providers is affected by the targeted share of renewables, the GHG emissions cap, and uncertainty related to renewable investments. Once EU-ETS was implemented, a number of empirical studies on emissions trading and related policy instruments that discuss issues such as interaction between ETS and RPS have been published. (Fischer and Preonas, 2010; Gawel et al., 2013; Johnstone, 2003; Gonzalez, 2007; Sorrell and Sijm, 2003; Tsao et al., 2011). Tsao et al. (2011) show that economic incentives appear to be less effective in the California electricity market when the ETS and RPS are assumed to be linked highlighting the role of energy mix. Chen and Wang (2013) investigate the interactions among ETS, green pricing program, and RPS in the U.S. on how double counting and bundling affect each individual market prices or social surplus. Bird et al. (2013) illustrate simulations on dynamics of electricity prices in the presence of carbon market and REC market. Fais et al. (2014) analyse the REC market as being heavily dependent on FIT since the carbon price of EU-ETS collapsed. Thurber et al. (2015) note that markets are vulnerable to the strategic behaviour of market participants when market-based mechanisms with multiple goals interact.

In this paper departing from previous studies, we construct an analytical model stylizing the features of the ETS and RPS mechanisms reflecting institutional conditions and realities. By deriving the closed-form solution, we explicitly demonstrate indirect market linkages and show how price equilibriums respond to policy changes of their own or of the other market to answer the following research question: how do the two markets interact differently when RPS and ETS are implicitly linked through the offset program as opposed to the case where both markets are not linked at all? This question starts from the fact that not all the amount of emission reductions by the capped sector achieved cannot be claimed as offsets; whereas, power generations from renewables outside of the capped sector are allowed to be claimed as offsets. In the long run, facilities using renewables can replace fossil fuels and consequently reduce emissions by rendering them obsolete; however, huge sunken costs make it difficult for power plants to replace existing facilities. Instead, they attach only a reduction device to the chimneys or convert fuel only from coal to natural gas, which disincentives to increase using renewables in response to ETS at least in the short term. Apart from existing carbon emissions facilities, outside the capped facilities have stronger incentives to increase renewables to comply with RPS. This is because GHG reductions with renewables outside the organizational boundaries can be claimed as “offsets” as the companies’ voluntary reductions. If renewable energy is generated within the organizational boundaries, the power generation itself does not play a role in reducing the amount of existing emissions and, therefore, cannot be claimed

1. https://www.ieta.org/resources/China/Chinas_National_ETS_Implications_for_Carbon_Markets_and_Trade_ICTSD_March2016_Jeff_Swartz.pdf.

as offsets: i.e., an individual firm can earn better profits by claiming offsets after pulling factories out of the regulated capped facility. Or, companies can choose this option only when the value of the offset is higher than the value of REC. The institutional background of this limited renewable offset usage for either ETS or RPS is as follows: most offset programs including Clean Development Mechanism (CDM) need "Legal and Regulatory Additionality" as a requirement for offset certification and a project can be considered as additional only if the project is not previously implemented under any official policies or regulations. Since ETS is the working regulation to reduce emissions and the purpose of the offset project should not be a means of compliance with existing regulations, only some projects could be considered as voluntary rather than policy enforcement satisfying the legitimate additionally requirement.

We find the policy instruments have distinct effects depending on the linkage between RPS and ETS markets. First, we show relatively different policy impacts when the both markets are indirectly linked by renewable offsets and find a policy directly affects its own market with larger price changes but has an indirect effect on the other market with smaller price changes. Second, we calibrate the case when renewables are not transferrable.

Our main contribution to the existing literature by constructing analytical partial equilibrium model is that we could describe the market dynamics in renewable certificates and carbon credits when policy makers use various tools affecting demand/supply in each market. They can compare price trajectories when the renewable conduit is open or closed between the two markets, and to estimate simultaneous policy effectiveness for both markets.

The paper proceeds as follows: in section 2, a theoretical background of ETS with RPS is provided with a classic supply-demand analysis and the analytic models of representative parties in both markets are formulated; in section 3, the model is calibrated with parameters of typical ETS and RPS market systems and derives policy implications about the market linkage; and the study's conclusions are presented in the final section.

2. PARTIAL EQUILIBRIUM MODELING

2.1 Theoretical Background

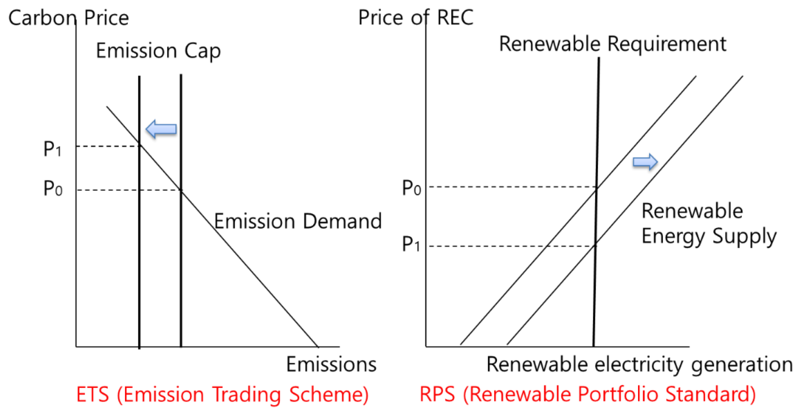
Previous empirical studies indicate that an enforcement of either RPS or ETS would lower the price of the other market. For instance, strong regulation of RPS accelerates penetration of renewables in electricity generation and ultimately lowers carbon price. Likewise, the impact of a strong emissions reduction target sends a strong price signal to the power market encouraging private investments in renewable energy; hence the increased supply of RECs results in falling prices. This general result is described using a classic supply-demand analysis in this section.

Figure 1 illustrates prices adjustment between the ETS and the REC market. In Panel A, when the price of carbon increases from P0 to P1 caused by a shrinking cap in the ETS market, regulated firms should consider additional abatement instruments, including renewable projects, to reduce GHGs. This step shifts the supply in REC market such that the price of REC decreases from P0 to P1. Panel B explains the effect of RPS enforcement on the price movement in the ETS market. When the price of the REC moves from P0 to P1 according to the rule changes in mandatory renewable energy obligations under RPS, carbon prices fall from P0 to P1 due to supply surplus of offset credits in the emissions trading scheme. The theoretical results from Figure 1 coincide with the implications of the empirical analysis of Tsao et al. (2011).

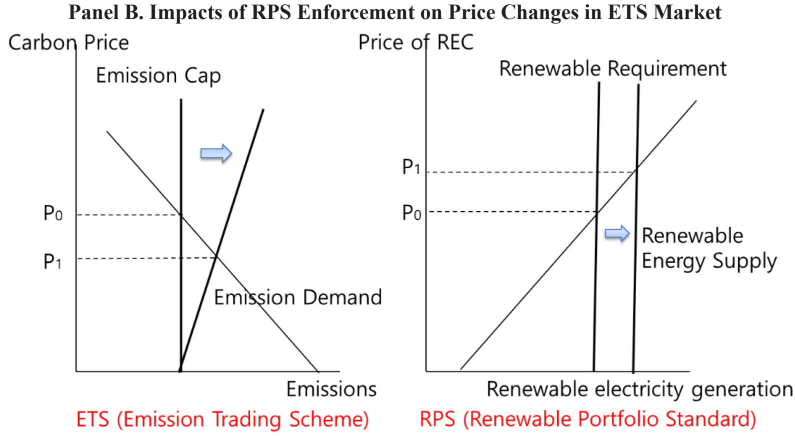
However, even if entities generate REC by achieving zero-GHG emissions, most of countries with ETS do not allow to use RECs to claim carbon credit because of a mismatch between

Figure 1: Theoretical Relation between ETS and RPS markets

Panel A. The Impacts of ETS Enforcement on Price Changes in REC Market



Panel B. Impacts of RPS Enforcement on Price Changes in ETS Market



policy objectives and the additionality issue. Therefore, carbon offsets originating from renewable projects can either be claimed as REC or as an offset credit to be used for compliance of ETS. This implies that double counting of renewable offsets for the compliance of both ETS and RPS is not allowed. Therefore, if renewables are used for one regulatory scheme, the other has fewer renewable outcomes available for compliance. Hence, it is intuitive that the strong regulatory enforcement of RPS (ETS) leads to higher REC prices (carbon), which would result in the rising price of carbon credits (RECs) due to a supply shortage thereof.

2.2 Model

Under the RPS scheme, power companies classified as liable entities must purchase and surrender RECs in order to meet their annual RPS targets. Therefore, these companies choose to optimize their strategies (such as purchasing RECs, increasing renewables, or simply paying a penalty for non-compliance) based on cost-minimization to comply with the regulation. Hence, we propose a decision-making model to minimize total costs for a given total production of electricity as Yu and Mallory (2017) assumed the output is fixed in order to customize the objective function for ETS market players. Accordingly, the total obligation for renewable use is assumed to be constant in this study.

Producing electricity from renewables can also decrease the amount of emissions compared to the baseline calculated from the past emission records. Power sector can reduce carbon emissions within the ETS scheme as if they improve efficiency of power facilities or fuel switching when using renewables. Since RPS and ETS are indirectly linked, offset credits can be converted to RECs. The following equation describes the correlation between these two credits.

$$REC = conversion\ rate * q\ (offset\ credit) \tag{1}$$

The units for the two credits used in each scheme differ: REC is in MWh, whereas, ETS permit is in $/ton. Therefore, to compare relative value of both usages, we need to determine a conversion rate to match both types of performance to the same unit of value. The base unit for REC credits is defined as megawatt hour (/MWh), and the unit of carbon offset credits is defined as CO_2 equivalent ton. Since the conversion rate, CO_2 / MWh, is unique for each country depending on the level of power generation efficiency, we set the value based on Greenhouse gas reporting: conversion factors from Department for Business, Energy and Industrial Strategy in U.K.[2]

Since regulatory authorities over the two systems intend for both markets to operate independently in principle, the amount of GHG reduced from renewable offset projects can be used to comply either for ETS or RPS. Reductions from using renewables cannot be used as offsets for ETS unless reductions are not made outside the boundaries of the company. To avoid double-counting, such offsets are no longer used for ETS compliance purposes once the renewable offsets are used as RECs, and vice versa. Therefore, market participants operating renewable projects should consider the market in which the outcomes are to be used, and which market is more profitable than the other. Therefore, if the price of carbon offset is lower than the price of the RECs converted to the unit of 1 equivalent GHG ton, all renewable projects should be used for RPS compliance until the two market prices are balanced.

The total energy production from renewables is the summation of the amount of credits used for RPS and renewable offset credits for ETS use, hence, the objective function of a power generator needs to define the total amount of emissions reduction by renewables, q, to be used either for ETS or RPS. This step requires activities to be split into two different variables separately, q_1 (renewable credits to be used for RPS obligation) and q_2 (renewable offsets to be used for ETS compliance), as follows.

$$q = q_1\left(RPSuse\right) + q_2\left(ETSuse\right) \tag{2}$$

The model can be simplified by using a single representative agent in both schemes. Most carbon offset projects are associated with uncertainty from various sources such as litigation and claims, cash flow, or technological problems. Therefore, the expected renewable offsets delivered as offset credits or RECs can be defined as a prorated value of intended emissions reduction by renewable project, q1, by the uncertain discount factor, δ.

$$Q\left(q|\delta\right) = q_1\delta \tag{3}$$

2. https://www.rensmart.com/Calculators/KWH-to-CO_2. The robustness of this paper is not affected by this as it only uses the coefficient values for calibration purposes.

The representative power generator obligated to comply with the RPS regulation is assumed to pay a penalty ($PP_{penalty}$) per unit if the reduction achieved for the RPS obligation target, $q_1\delta$, is less than the emissions reduction for the RPS obligation, R.[3]

$$PP_{penalty} \cdot max\left[R - q_1\delta, 0\right] \tag{4}$$

The total cost of power generation from renewables, which the power company aims to minimize, is defined as follows.

$$PP_{penalty} TC_{REC}\left(q_1 + q_2\right) \tag{5}$$

In this case, these regulated entities can also benefit from taking advantage of additional revenues, $TR_{offset}\left(q_2\varepsilon\right)$, from renewable offset credits issued successfully. Therefore, the objective function of renewable suppliers under RPS obligations is as follows.

$$\underset{q_1, q_2}{Min}\, TC_{REC}\left(q_1 + q_2\right) - TR_{offset}\left(q_2\delta\right) + PP_{penalty} \cdot max\left[R - q_1\delta, 0\right] \tag{6}$$

The total cost for the utility company is defined as the total cost of electricity production and expected penalties after the deduction of additional revenue from selling renewable offsets in the ETS market. An individual power company need to purchase outcomes from renewables, but we assume a representative company in RPS. Since the net sales of RECs in RPS are always zero, we can exclude the compliance cost for buying RECs. Therefore, the first order conditions with respect to renewable credits to be used for RPS (q_1) and renewable offsets to be used for ETS compliance (q_2), are as follows.[4]

$$0 = MC_{REC}\left(q_1\right) + \frac{\partial PP_{penalty} \cdot max\left[R - q_1\delta, 0\right]}{\partial q_1} \tag{7}$$

$$0 = MR_{offset}\left(q_2\delta\right) \tag{8}$$

q_2^*, in equilibrium, is the maximum eligible quantity of renewable offset credits. The actual value for q_2^*, will be driven from the demand curve of the objective function. Although the optimized offset amount, q_2^*, is derived from this objective function, this does not mean the actual amount of offset consumption is in ETS. Since most of ETS markets have a limit (or maximum demand) for offset usage, the total number of offsets, q_2^*, supplied by agents under the RPS obligation could be greater than the maximum demand of offsets. The actual number of offsets are therefore redefined, q_2^*, after which the real demand from the ETS side is optimized.

In addition, the ETS model associated with the objective function for utility companies which participate in the ETS market under GHG regulations is important. These companies should satisfy the following conditions. If companies emit more than the allowances of the emissions they hold, they should reduce emissions in order to avoid penalties. The following formulae represent

3. For model simplicity, it is assumed that the equivalent penalty rate per 1 ton of CO_2 emission equivalent is fixed in ETS and RPS even though the actual penalty rates are determined by the average market price for each market. If the model incorporates this price-linked penalty feature, it is difficult to derive a closed form solution as discussed by Kim and Yu (2018). This partial equilibrium model suggests that emissions reduction or reproducible production may differ from the requirements of RPS and ETS during the optimization process. The equation describes the following situations; for example, if the penalty rate of the RPS is lower than the marginal renewable production cost, regulated firms may be fined due to insufficient credit. On the other hand, if the penalty rate is high, the excess of credit in the RPS market can cause the REC price to fall or the residual to be used in ETS.

4. It is assumed that there are no transaction costs involved in selling renewable offsets

the cost structure of entities under ETS regulations. Entities can choose one of the three following options in order to comply with ETS regulations: (1) self-imposed emissions reduction, u, (2) offset credits from offset projects, Q, or (3) emissions allowances allocated by the government, L.

$$\underset{u,q}{Min}\, E_y E_\delta \left\{ \underbrace{C(u,q)}_{Cost\ of\ Compliance} + \underbrace{B(u,Q)}_{Penalty\ for\ Noncompliance} \right\} \tag{9}$$

However, total amount of successfully delivered offset credits, Q, may not always coincide with the intended amount of offset credits purchased, q. Uncertainties exist in each different project phase from planning offset projects to delivery of offset credits in ETS market. Therefore, the expected renewable offsets delivered as offset credits can be defined as a prorated value of originally intended amount of reductions by renewable project, q_2, by the random discount factor, δ. In addition, the upper limits to use offset credits for ETS compliance should be considered to define the actual amount of renewable offset credits using a specific rate, θ.

$$Q(q|\delta, L, \theta) = \min[q_2\delta, L\theta] \tag{10}$$

Under the assumption that power companies develop renewable energy projects, their total revenue to sell renewable offset credits in the ETS corresponds to the total cost of purchasing the offset credits in the ETS.

$$TR_{offset}(q_2) = C_{offset}(q_2) \tag{11}$$

Hence, the total costs that regulated company should pay, $C(u, q_2)$, are comprised of their abatement costs, $TAC(u)$, and total payment to purchase offset credits, $C_{offset}(q_2)$. We also assume the presence of a representative company in ETS so that the control variables can be omitted for allowing trade between all market participants. This is because the net purchase amount of all participating companies always becomes zero under this setup.

$$C(u, q_2) = TAC(u) + C_{offset}(q_2) \tag{12}$$

As in the case of RPS, regulated entities are assumed to pay a penalty, $P_{penalty}$, per unit emission when they emit more than their holding allowance in consideration of offset credits and reductions by themselves.

$$B(u, q_2) = P_{penalty} \cdot max[y - L - u - Q, 0] \tag{13}$$

The following formula represents the objective function of ETS participants, minimizing the total cost to comply with ETS enforcement.

$$\underset{u,q_2}{Min} \underbrace{TAC(u) + C_{offset}(q_2)}_{Cost\ of\ Compliance} + E_y E_\delta \underbrace{\left[P_{penalty} \cdot max\left[y - L - u - \min[q_2\delta, L\theta], 0\right]\right]}_{Potential\ Penalty\ of\ Noncompliance} \tag{14}$$

The first order conditions for cost minimization with re spect to emissions reduction and offset credits purchased are as follows.

$$0 = \frac{\partial TAC(u)}{\partial u} + \frac{\partial P_{penalty} \cdot EEmax\left[y - L - u - \min[q_2\delta, L\theta], 0\right]}{\partial u} = MAC(u^*) - MB(u^*|q_2) \tag{15}$$

$$0 = MC_{offset}(q_2) + \frac{\partial P_{penalty} \cdot EEmax\left[y - L - u - \min[q_2\delta, L\theta], 0\right]}{\partial q_2} = MC_{offset}(q_2^*) - MB(q_2^*|u) \tag{16}$$

From the above first order conditions, we can derive the equilibrium quantities, $\left(u^*, q_2^*\right)$ by solving simultaneous equations. The equilibrium prices are derived from the quantity equilibrium. Under competitive market conditions, the price equilibrium equals to the marginal benefit and marginal cost. Note that the derivative of expected penalty payment with respect to quantities refers to the marginal benefit of producing additional renewable or emission abatement quantities. Thus the price equilibria are driven from the quantities, $\left(u^*, q_1^*, q_2^*\right)$. [5]

$$P(q_1) = MC_{REC}\left(q_1^* | u^*, q_2^*\right) = -\frac{\partial PP_{penalty} \cdot max\left[R - q_1\delta, 0\right]}{\partial q_1} \tag{17}$$

$$P(u) = MAC\left(u^*\right) = MB\left(u^* | q_1^*, q_2^*\right) = -\frac{\partial P_{penalty} \cdot EEmax\left[y - L - u - \min\left[q_2\delta, L\theta\right], 0\right]}{\partial u} \tag{18}$$

$$P\left(q_2^*\right) = MC_{offset}\left(q_2^*\right) = MB\left(q_2^* | q_1^*, u^*\right) = -\left\{\frac{\partial P_{penalty} \cdot EEmax\left[y - L - u - \min\left[q_2\delta, L\theta\right], 0\right]}{\partial q_2}\right\} \tag{19}$$

Under the provision that outcomes from renewables cannot be used simultaneously in both ETS and RPS, companies must a decision between the two. With the constant conversion rate defined between REC offsets and renewable offset credits in ETS, the prices for the RECs, allowances, and offset credits are described as follows.

$$price\ of\ REC\ \left(P_{REC}\right) = \delta * P\left(q_1\right) \tag{20}$$

$$price\ of\ CO_2\ allowances\left(P_{allowance}\right) = P(u) \tag{21}$$

$$price\ of\ offset\ credits\ \left(P_{offset}\right) = P\left(q_2^*\right) \tag{22}$$

As this paper aims to calibrate the market equilibrium derived from the objective function and to review policy effects described above, a partial equilibrium model is employed to assess the impact on both markets in response to changes in rules of climate and renewable energy policy options. A convex cost function is adopted for power generation using renewables and linear marginal cost with the coefficient, c.

$$TC_{REC}\left(q_1 + q_2\right) = \frac{c}{2}\left(q_1 + q_2\right)^2 \tag{23}$$

Likewise, the functional form of abatement cost and its marginal cost for ETS regulation are defined to be convex and in a linear form with a coefficient, k, respectively.

$$TAC(u) = \frac{k}{2}u^2 \tag{24}$$

We use parameters from Korea because this is the only country, which implements both ETS and RPS at national level: e.g., although EU members share one single market for ETS at regional level, each member sets its own RPS target with different approach integrated with subsidies policy such as FIT. The business risk of renewable projects, $f(\varepsilon) \sim U\left(0, \overline{\delta}\right)$, and the uncertainty

5. Some studies on ETS and RPS focus on market power issues, but we assume a perfectly competitive market (Limpaitoon et al, 2014; Pérez et al, 2016). Competitive pricing (price is equal to MC = MB) is assumed in this paper for two reasons: to the best of our knowledge, there is little evidence individual firms in RPS or ETS markets have a dominant influence in these markets. The second reason is that a closed form solution can be easily derived from assuming competitive markets.

of the amount of GHG emissions, $g(y) \sim U(0, \bar{y})$, follow a uniform distribution to achieve closed-form solutions. The major calibration parameter for RPS enforcement is the quota obligation, R, to generate electricity from renewable energy sources; which are planned to increase annually starting from 2.0% of total electricity generation in 2012, 3.5% in 2016, and reaching 10% in 2024 and beyond. Hence, this study sets R at 3.5% considering the current level. It is assumed that the coefficient of the marginal cost of generating electricity using renewable energy, c, reflects the actual current price of REC in Korea. Likewise, parameters in the ETS model can be derived from this calibration process. The coefficient for marginal cost in ETS, k, is determined to reflect the current actual carbon price. For modeling simplicity, the penalty, $P_{penalty}$, assumes a constant of 100,000 KRW, the maximum penalty being provided by the ETS Act. It is assumed that the maximal emissions, $\bar{y}$, to let the average of BAU emissions reflect the national cap in Korea. The initial allowances, L, are defined as the total amount allocated by the government when grandfathering is applied. In order to calibrate different scenarios on policy options, the limit of offset credits in ETS compliance is set as 0.1 (10% of total allowances). Numeric values of coefficients used in this model are summarized in Table 1. The marginal GHG abatement cost coefficient, k, and the marginal power generation cost coefficient using renewables, c, are chosen to imitate credit prices in the actual average prices (Carbon price = 11,000KRW/CO_2, REC price = 12,500 MWh) during the recent compliance period (2015~2016) .

Table 1: Descriptions on basic parameters

	Parameters	Values*
RPS side	Cost coefficient for Renewable Project, c	0.004
	Minimum requirement using renewables, R	0.035
	Penalty rate, $PP_{penalty}$	300k Korean won*
	Uncertain credit delivery risk limit, $\bar{\varepsilon}$	1
Conversion rate	Value conversion rate between REC and offset, δ	0.43
ETS side	Cost coefficient for abatement, k	70
	Penalty rate, $P_{penalty}$	100k Korean won
	Uncertain emission upper limit, $\bar{y}$	13,000
	Free endowment of allowances, L	6,000
	Offset usage limit, θ	0.1

* In order to simplify market design for RPS, the maximum penalty for RPS regulation is assumed to be three times of ETS penalty (= 6 times 0.5), reflecting the current REC price (on January 2016 basis) is six times of the current carbon price and penalty rate for RPS regulation is equivalent to 150% of the weighted market price of REC, while that of ETS is 3 times the carbon price in the market.

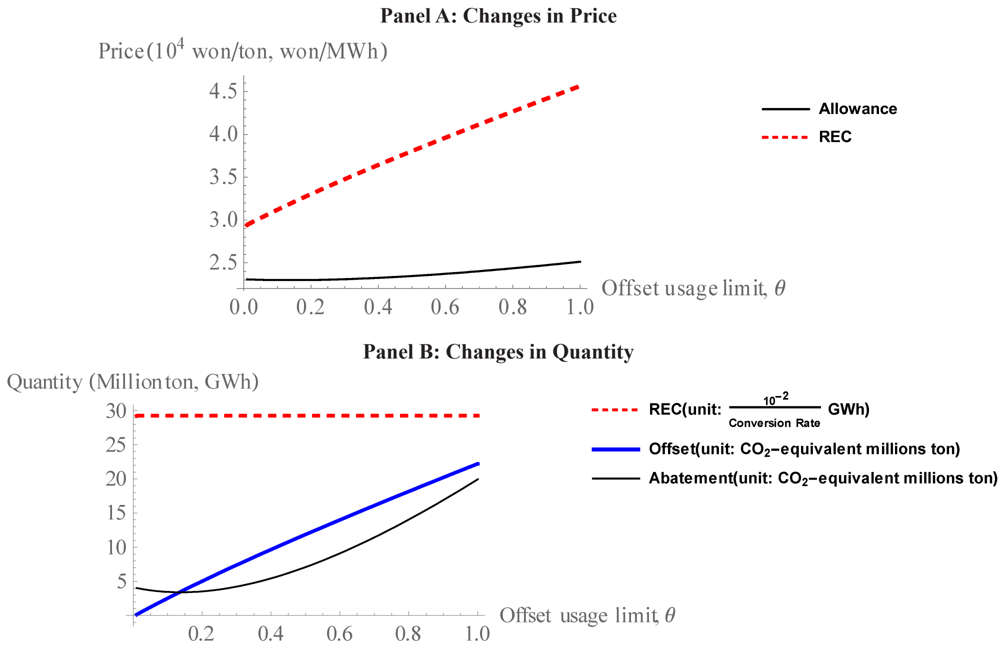
3. RESULTS AND DISCUSSION

This section calibrates the closed form solutions and interprets the results. Each figure illustrates the effect of changing the policies or market parameters used in the model.

Figure 2 describes the effect of the offset usage limit in the ETS. The offset usage limit, θ, is defined as the maximum share of offset credits compared to the total number of allowances for the purpose of complying with the ETS scheme. The objective of offset usage limit is to prevent offsets from flooding the carbon market, thus eliminating the incentive to reduce emissions in regulated firms. We assume the offset usage limit, 10% cap by default.[6] Regarding the model, it is true that

6. The actual percentage for offset imports in Korea ETS.

Figure 2: Effects of the offset usage limit



the level of "ex-post" total renewable production is equivalent to the sum of RPS requirement and offset usage. In practice, total renewable output may not be equal to the sum of RPS demand and offset usage in a short period of time, creating an imbalance between renewable supply and demand. This affects the price of REC (or offset), and changes the additional renewable output or carbon reduction accordingly. Therefore, total renewable usage does not necessarily have to be the same as the RPS requirement, and if it is insufficient, a penalty will be imposed. In this paper, assuming a single-period model, regulated firms can bank or borrow credits between sub-compliance periods, so the net amount of credit movements during a single compliance period can eventually be assumed to be zero. As shown in Figure 2, offset credit usage limit can vary from 0% to 100%, or even higher than 100%. Panel A illustrates the changes in price when the offset usage limit varies: RECs are in red, carbon allowances are in blue. Panel B depicts changes in quantity: accredited RECs from renewable project generations represented in red, GHG reduction in blue, and converted offset credits from renewable projects such as CO_2 reduction as a dotted line.

In panel A, loosening the restrictions on limiting the use of offset credits spurs on the REC market since an increase in the demand for offsets from renewables pushes the marginal cost of generating RECs upward. However, the ETS market responds to the restrictions on limiting use of offset credits, which is different from the case of the REC market. In the early stages, the carbon price declines due to the additional supply of offset credits, but eventually the price of carbon allowances allocated from the government increases because an increase in the marginal cost of renewable power pushes up the price of offset credits. When the usage limit for offsets is restrictive and firms do not use enough of them, Yu and Mallory (2017) show that the price spread between allowances and offsets is large. Therefore, regulated firms in ETS demand offsets at a low usage limit, and the supply effect by loosening the limit (a positive price effect in allowances) dominates the effect of a marginal cost increase (a negative price effect in allowances) when the offset usage limit is low. Once the demand for offsets is met, the effect of increasing marginal cost becomes greater than the supply effect.

In panel B, a volume of accredited RECs, portrayed with a red line, is not affected by offset usage limits, as the number of total RECs for RPS compliance is not related to ETS. The amount of offsets used for ETS compliance in the dotted line increases as the usage limit allows more offsets to be used in place of allowances. Hence, there is a linear relationship between the actual use of offsets and the usage limit. The amount of GHG reduction, shown as a blue line, initially decreases, but this eventually increases in tandem with the amount of offsets used. Regulated firms under ETS can reduce GHG by themselves or purchase allowances or offsets for compliance. The level of GHG reduction includes both 1) reductions by regulated firms and 2) reductions from outside a regulated group issued as offset credits. If the regulator allows more offset credits to be awarded for ETS compliance, regulated firms would be forced to rely on purchasing offsets instead of reducing GHG by themselves, as illustrated in panel B.

Our research question is about how the offset import limit (the role of indirect linkage between ETS and RPS through renewable electricity generation also abating GHG emissions) affects the policy effects. If a renewable power generation with a GHG reduction attribute cannot be used in both RPS and ETS markets due to additionality or double counting issues, then regulated entities need to sell or surrender the credits in either of two markets at the highest bidding price. For example, firms might wish to generate carbon offset credits to meet the ETS requirement through energy efficiency improvements or fuel switching rather than by generating electricity using renewables if using renewables as offsets is relatively profitable. Likewise, our model highlights the role of "conduit for offsets" by contrasting the imaginary case that no offsets are transferable. We separately calibrate all results as the two groups: all panels in Figure 3a ~ Figure 8a show policy effects by allowing offsets to be transferred between ETS and RPS markets, whereas, Figure 3b ~ Figure 8b do not allow renewables to be used in ETS if initially renewables targets for RPS compliance. By comparing these two groups, we can see how variations in policy parameters affect the both markets differently. Apparently, all ETS policy instruments affects ETS market only (no changes

Figure 3a: Effects of Penalty in ETS market (with offset transfer)

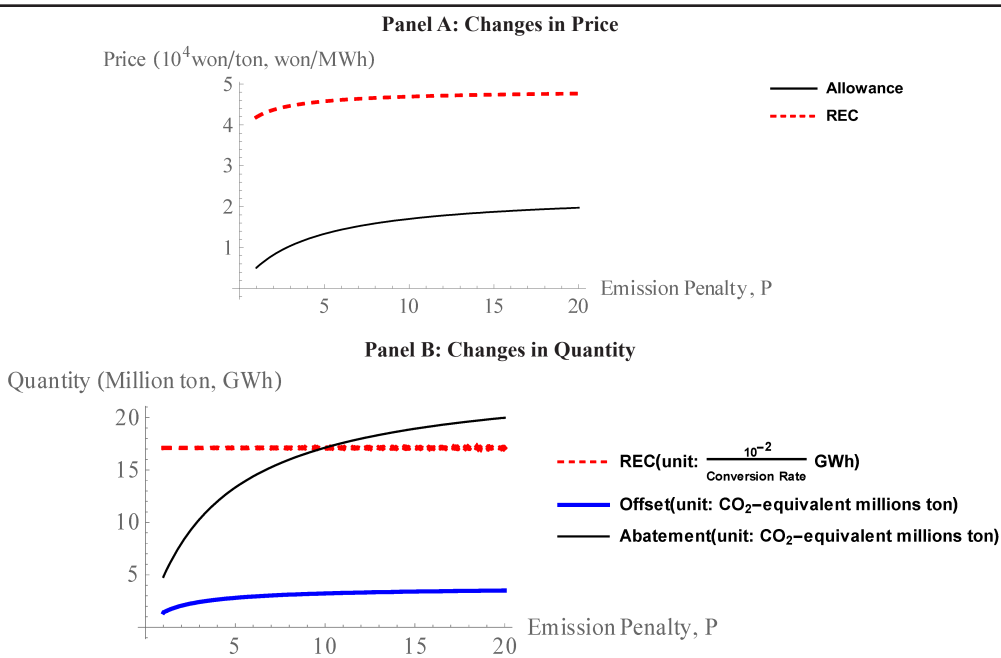
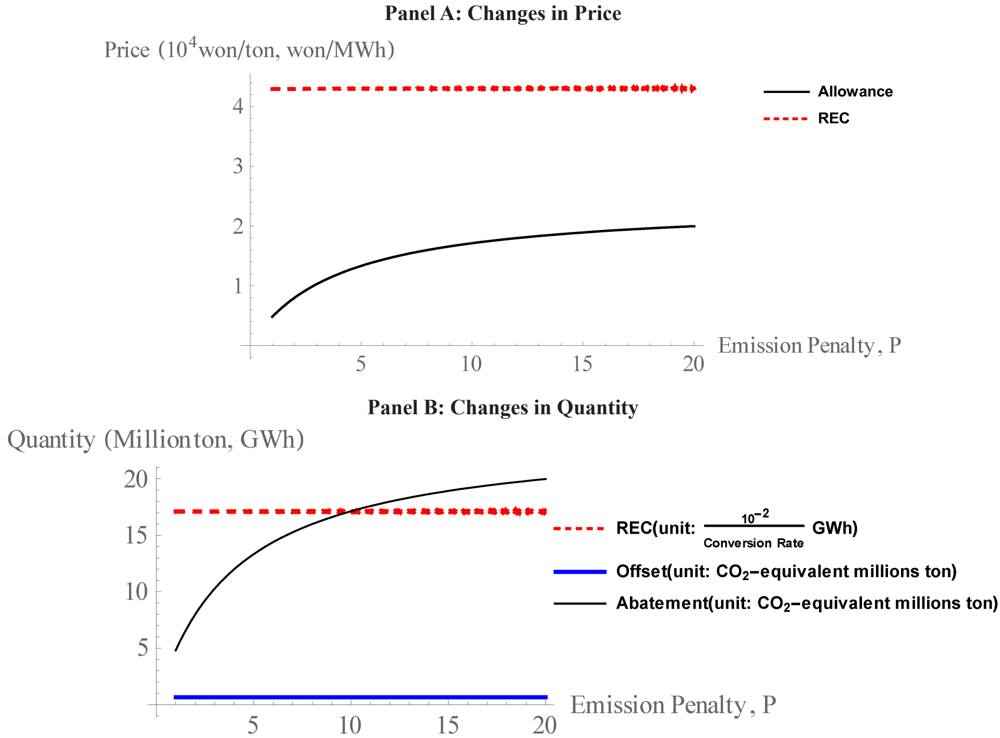


Figure 3b: Effects of Penalty in ETS market (without offset transfer)



in REC prices and in the amount of renewables for RPS compliance), and likewise, all RPS policy instruments solely impact the RPS market (no changes in carbon prices and in the amount of GHG abatement) in Figure 3b ~ Figure 8b.[7]

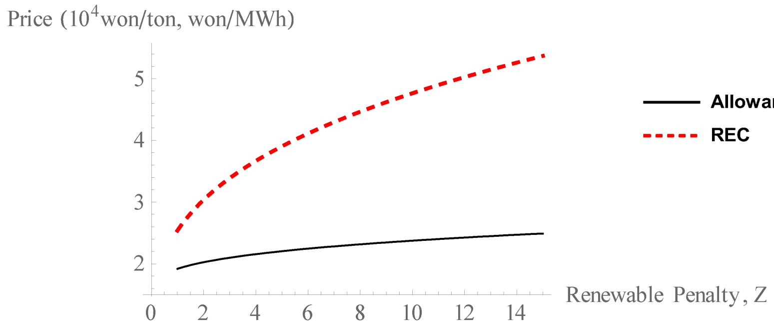
In the following we focus on the policy impact when the both markets are indirectly linked by renewable offsets. Figure 3a illustrates how the ETS market penalty affects both the ETS and REC markets. In panel A, as the ETS market imposes a higher penalty, the increase in carbon price is relatively high compared to the increase in REC price. We can explain that a change in the penalty of ETS directly affects the ETS market with a bigger price change, whereas it affects the RPS market indirectly. We can also explain the changes of prices in the quantity perspective in panel B. First, the committed quantity of RPS obligation is not sensitive to policy variations in the ETS market. Second, overall reduction of GHG would increase as a result of any restrictive penalty, which pushes up the marginal cost of GHG abatement and the price of carbon. Third, the increases in supply of offsets from renewables are limited because of the fixed offset usage rate; however, the increase in the number of offsets is not negligible. This result is due to escalated demands for GHG reductions and offset purchases as the penalty for ETS increases.

Figure 4a displays changes in both markets when a non-compliance penalty for RPS obligation varies. In panel A, as the non-compliance penalty of the REC market increases, a price increase of REC is relatively large compared to an increase of carbon price. While a change in RPS penalty directly affects the REC market with a higher price change, it only affects the ETS market indirectly. As shown in panel B, an increased RPS penalty raises the amount of renewable power

7. For practical purposes, we assume the parameter value for the offset import limit as an arbitrarily small value (= 0.0001) since calibrating generates computational problems.

Figure 4a: Effects of Penalty in REC market (with offset transfer)

Panel A: Changes in Price



Panel B: Changes in Quantity

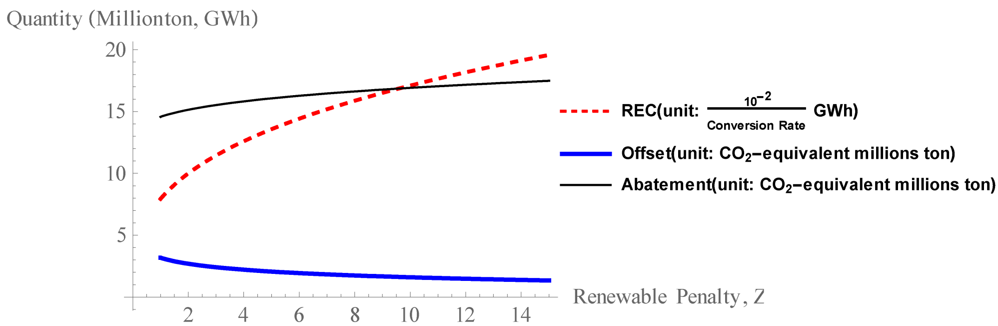
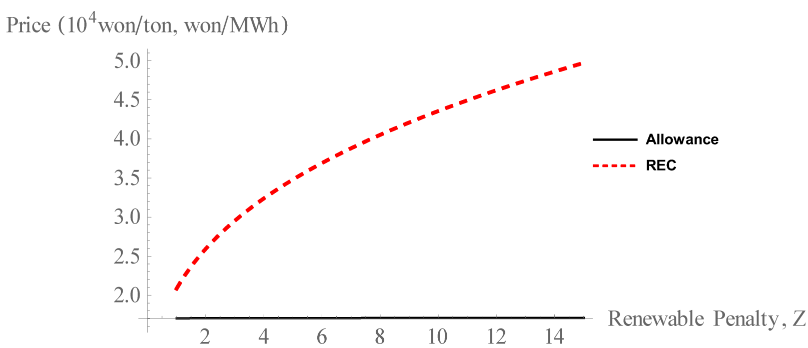
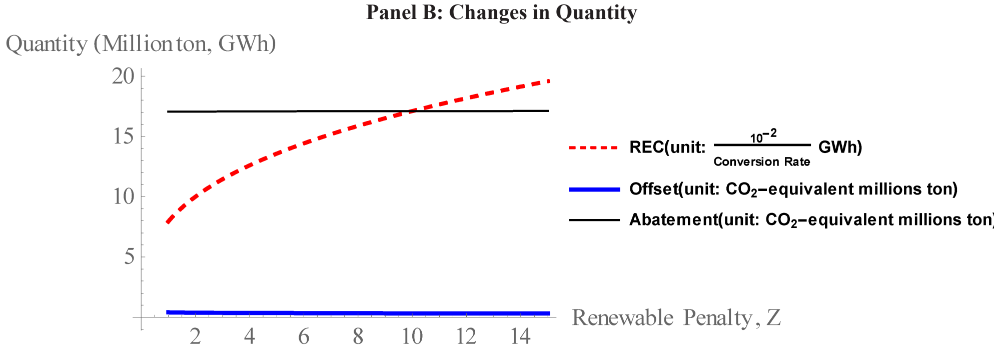


Figure 4b: Effects of Penalty in REC market (without offset transfer)

Panel A: Changes in Price



Panel B: Changes in Quantity



generation since regulated firms under RPS wish to secure enough records of renewable power to avoid penalties. Second, the higher the RPS penalty imposed, the greater the decline in the number of renewables converted for ETS use. This is because firms can earn more profits by selling offsets in ETS would be smaller than the potential volume of penalties imposed in RPS. Lastly, as fewer offsets are supplied, regulated firms in ETS need to reduce more emissions to compensate for the decreased number of available offsets.

Figure 5 shows the market responses according to changes in initial allowances allocation of ETS by grandfathering. As shown in panel A, the more allocation provided by grandfathering logic, the lower carbon price changes are expected because of the supply effect of carbon credit market, whereas REC price increases because of a decrease in REC supply. Panel B explains the supply effect behind price changes. In quantity, there is no reason that the amount of required renewable power in RPS obligation is affected by the tradable volume of allowances in ETS. Regarding the eligibility of offsets, note that the total number of offsets acceptable in the ETS is defined as the share of total allowance allocation. Therefore, if the usage limit of offsets is fixed as 10% of the total amount of surrendered allowances, an increase in total amount of allowance allocation proportionally increases the maximum number of offsets to be surrendered. This effect explains why the price of the REC shows a slight increase in some renewables used for offsets; therefore, the overall marginal cost of renewables rises. Regarding the level of reduced GHG emissions, increased allowances under a grandfathering scheme discourages regulated firms in ETS from reducing GHG emissions. Instead of reducing emissions, firms would end up with surrendering flooded free allowances and additionally converted offsets from the RPS side.

Figure 5a: Effect of initial free allowance allocation in ETS (with offset transfer)

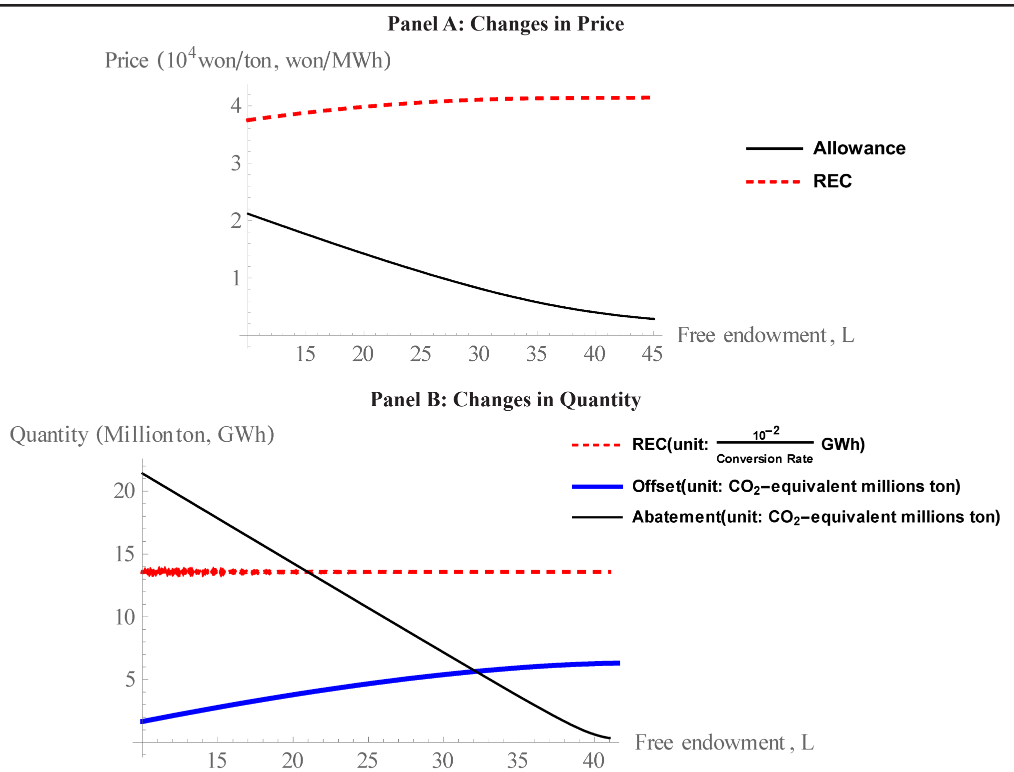


Figure 5b: Effect of initial free allowance allocation in ETS (without offset transfer)

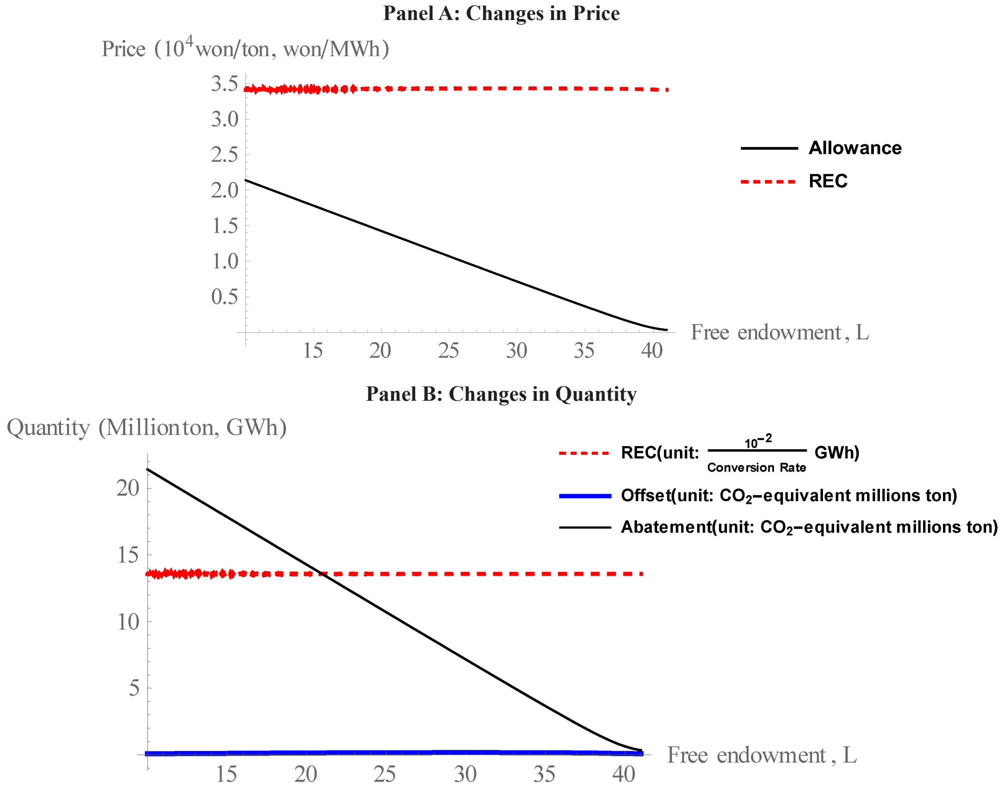
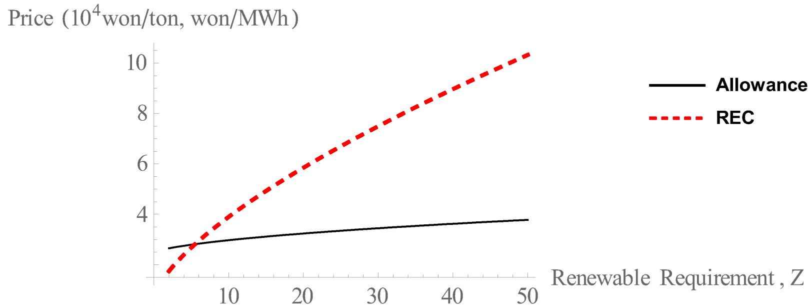


Figure 6 explains how the ETS and RPS markets respond to changes in RPS requirements (the minimum amount of renewable power generation). As companies are committed to stronger obligations to use renewable energy, which means a rise in demand for renewables, the price of REC would increase; as shown in panel A. Therefore, as can be seen in panel B, the increased price of REC would eventually lead the supply of REC to escalate. At the same time, the strengthened regulation of RPS would induce firms to use renewables for RPS compliances without converting them to offsets for ETS; therefore, the supply of offsets would decline as more restrictive RPS requirement is introduced. Since firms under ETS now have fewer offsets available, they need to further reduce emissions (see panel B), which increases the marginal cost of abatement and the price of carbon, as illustrated in panel A.

Figure 7 shows the response of both markets to changes in marginal GHG reduction costs. Higher marginal abatement costs discourage companies from reducing CO_2 emissions; hence, panel B shows a steep decrease in the level of carbon reductions. Given the predetermined amount of emissions, if firms drastically reduce their emissions, they should pay a penalty relevant to the number they fail to surrender. This step might prove to be a financially practical decision, since the unit penalty per ton of emissions can be lower than the marginal abatement costs per ton of emissions, meaning that firms could quickly give up abatements as they face higher marginal abatement costs. Our model assumes an upper limit of emissions; therefore, the level of abatement given up by firms would gradually decrease above a certain threshold. When emission reductions decrease, this will ultimately stimulate the alternative demand for compliances by using offset credits instead of allowances. Regarding the market prices in panel A, the price of carbon would steeply increase to comply

Figure 6a: Effect of RPS requirement (with offset transfer)

Panel A: Changes in Price



Panel B: Changes in Quantity

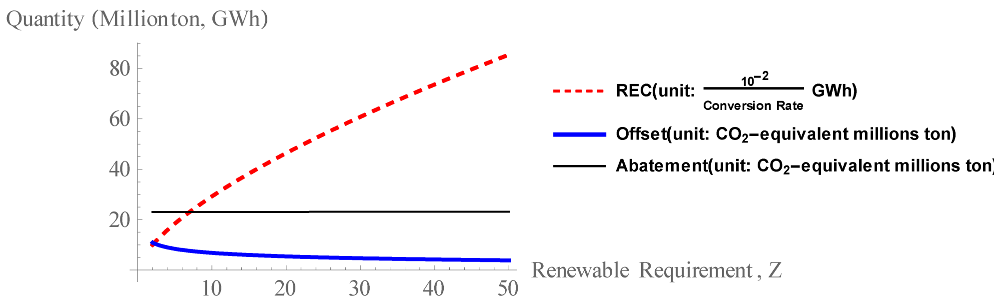
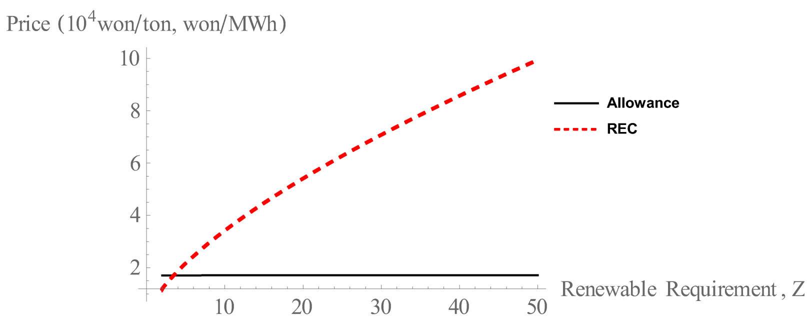


Figure 6b: Effect of RPS requirement (without offset transfer)

Panel A: Changes in Price



Panel B: Changes in Quantity

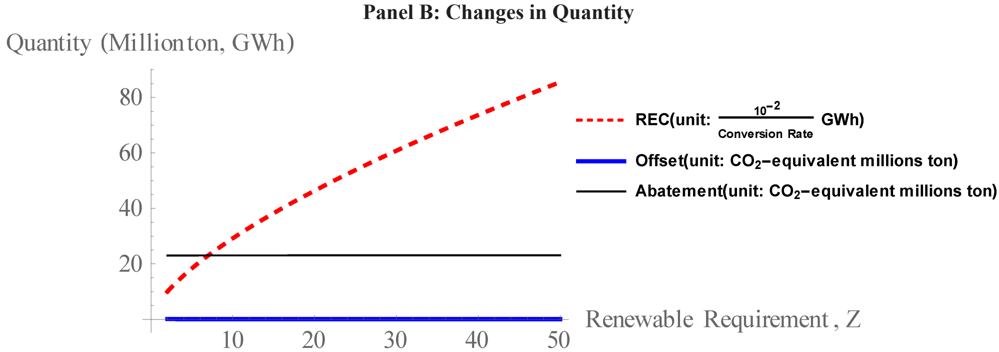


Figure 7a: Effect of marginal cost in reducing GHG emissions (with offset transfer)

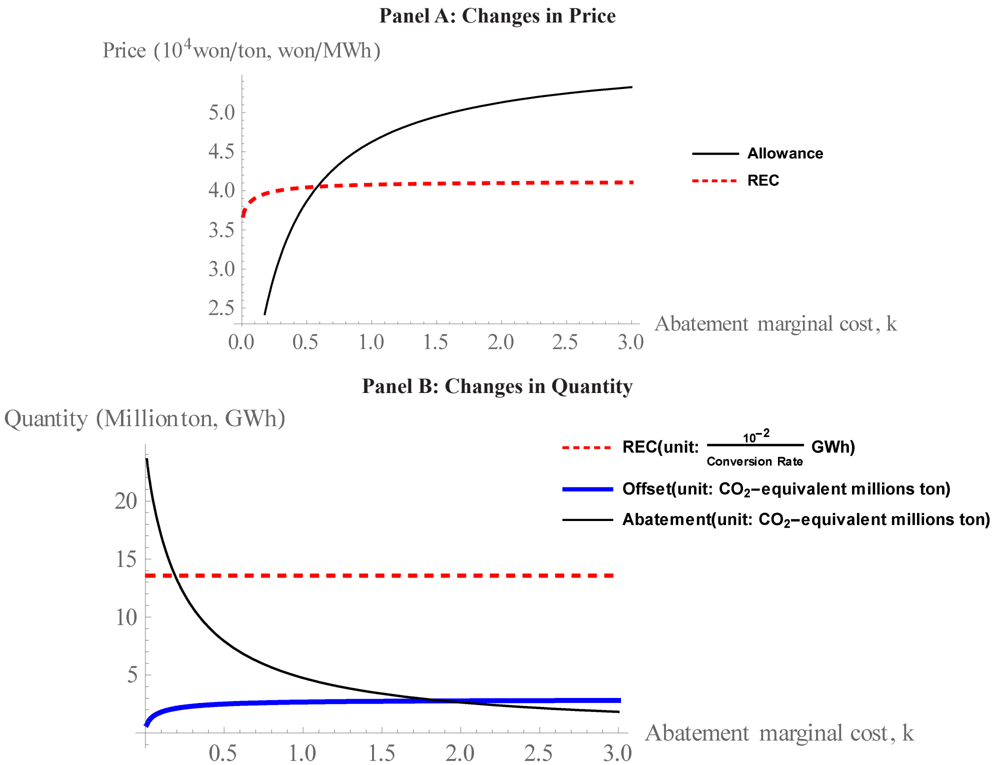
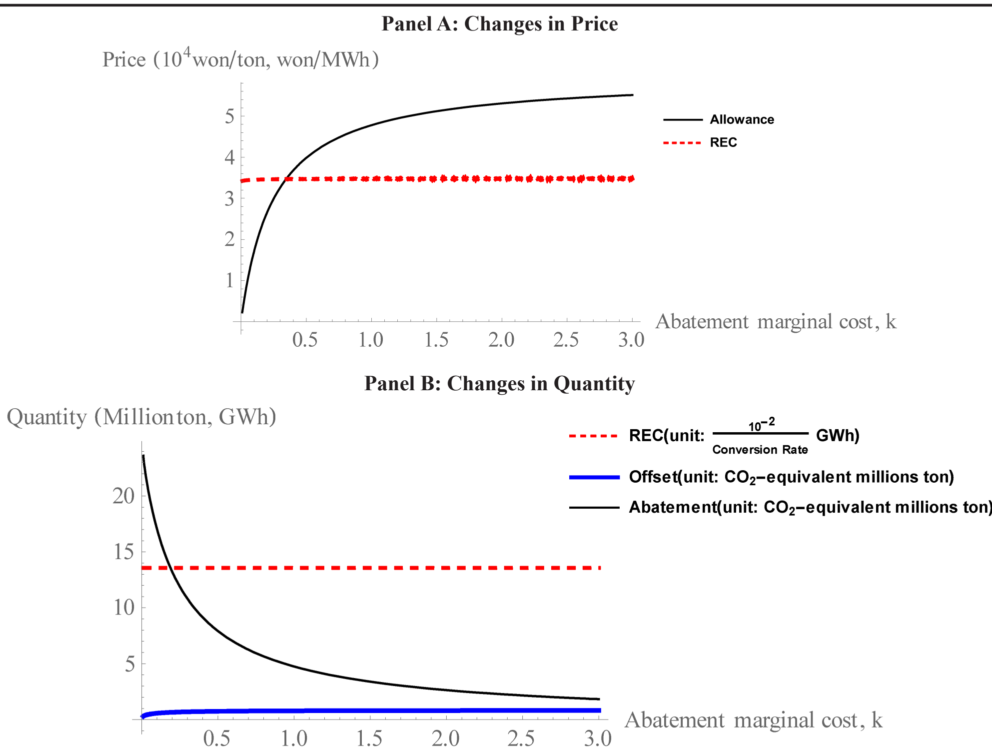


Figure 7b: Effect of marginal cost in reducing GHG emissions (without offset transfer)



with ETS regulations, since an increase in marginal abatement costs functions as a supply shock in carbon prices. Afterwards, many firms would not buy expensive carbon credits, since they could simply pay a penalty to make the compliance costs cheaper; hence, this limited demand makes price growth more gradual. Panel A shows that the growth rate of carbon prices marginally decreases when the marginal cost increases. Regarding the price of REC, initially regulated firms under ETS look for more offsets so that some renewables can be converted to offsets, which increases the price of REC. However, this price increase would be stagnant because the demand for offsets has an upper boundary set by the offset usage limit under ETS.

Figure 8 shows the effect of changing production costs to produce electricity using renewable energy. Higher marginal abatement costs dampen electricity generation using renewables, hence the fact that panel B shows a steep decrease in the number of RECs. This enables firms to initially reduce renewable power generation as they face higher marginal abatement costs, but thereafter, the number of decreased renewables is not proportional to the increase in marginal cost because many firms would simply prefer to pay a penalty rather than having more renewables. The expensive marginal cost for renewables also makes converting offsets from renewables costly. Therefore, firms need to increase abating emissions slightly to make up for the decreased number of converted offsets. As shown in panel A, the price of RECs would steeply increase, since the stricter RPS regulation functions as a supply shock in the REC market. Conversely, the expensive REC and offsets from the supply shock causes the firm under ETS to reduce more emissions. This phenomenon is a demand shock in the carbon market, as firms should reduce more or purchase carbon credits; as a result, the price of carbon increases.

Also, note that when renewables become rival goods between ETS and RPS by the implicit linkage and renewables, the calibrated results in Figure 3a ~ Figure 8a consistently show that the

Figure 8a: Effect of marginal cost in renewable power (with offset transfer)

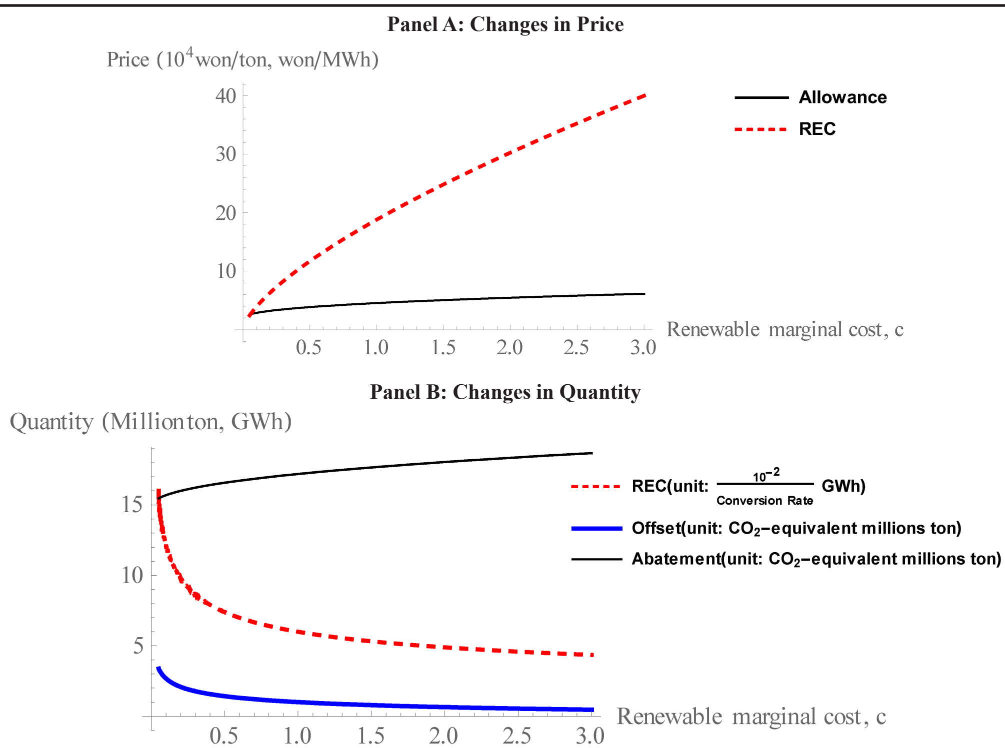
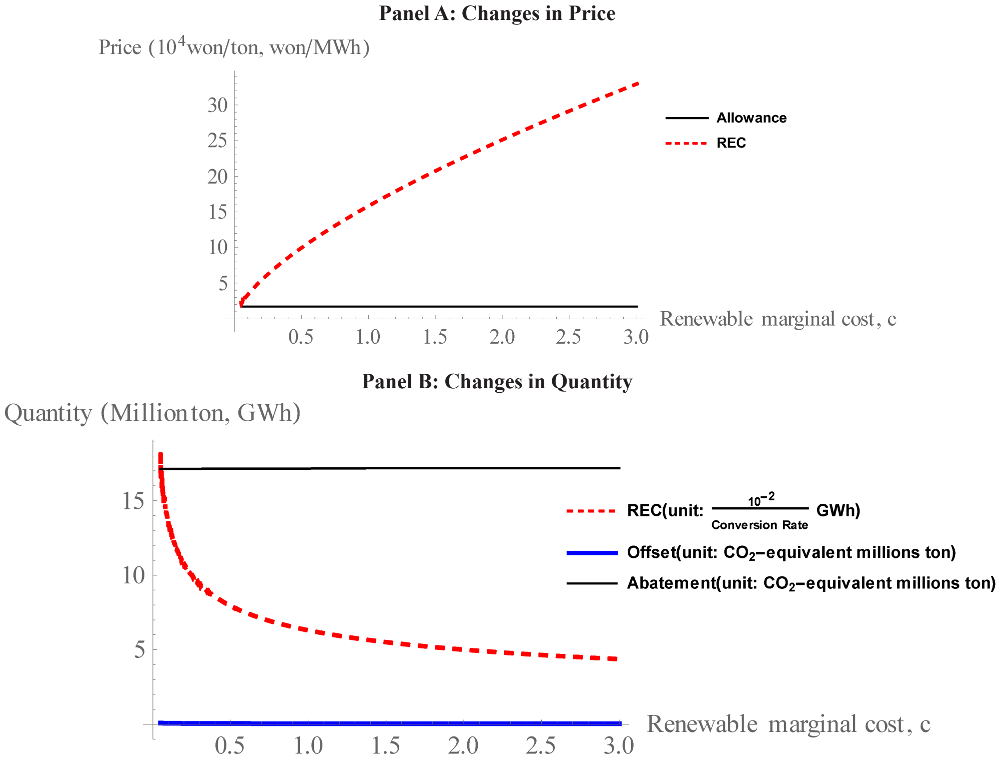


Figure 8b: Effect of marginal cost in renewable power (without offset transfer)>



overall prices of either schemes are higher compared to Figure 3b ~ Figure 8b. By allowing renewables originally targeted for one market to be used in the other, a renewable producer has more options to sell at a profitable market with a stringent policy standard. We interpret that this overall price elevation is caused by the fact that excess credits from the less restrictive policy are utilized for a stricter policy obligation instead, thereby reducing the likelihood of non-binding.

4. CONCLUSION AND POLICY IMPLICATIONS

Most ETS and RPS systems interact simultaneously with the offset market, and any changes in one market can cause unintended policy effects in the other. By design, therefore, it is necessary to pre-coordinate the effectiveness of the energy/environmental policies before enforcement when each system is administrated under different supervising agencies. In most countries, policies on renewables/electricity/energy are under different controls from environmental authorities that oversee GHG mitigation and adaptation policies.

To achieve the goal of this paper when discussing market interactions, we use the policy instruments such as a penalty (price control) and stringencies of the quantities (emission cap & renewable quantity target). As the renewables become rival goods, our model shows policy effects are transmitted to the other market and the overall prices of both schemes are affected since renewable producer has alternative markets that could offer better prices from austere policies. We also illustrate the effect of market linkage by contrasting the case where the conduit for offsets is completely blocked as a default.

Also, we show that any policy changes impact its own market directly incurring high price volatilities, and that the other market shows relatively smaller indirect responses in price. These asymmetric price responses from policy changes might give some comfort to policy makers unless they intentionally aim to influence the other market where they are not responsible. Calibrated results give policy implications on the degree to which the level of penalty and quota in carbon and renewable credit markets affect market participants' behavior or prices: e.g., the penalty of ETS predominantly impacts the marginal permit price of the ETS, although the price of REC directly responds to changes in the penalty level of RPS; the amount of initial allowances affects carbon price directly, whereas a renewable target is critical to changing REC price. Further extension can add more complexities of schemes such as adding features of inter-temporally transferred credits across multiple compliance periods.

ACKNOWLEDGMENTS

We would like to thank the referees for their insightful comments and suggestions on the earlier draft of this paper. Our appreciation also goes to Sanghee Yu, the former chairman of Korea Power Exchange, for his support and precious comments. This work was supported by 2020 Hongik University and the Korea Power Exchange.

REFERENCES

Amundsen, E.S. and J.B. Mortensen (2001). "The Danish Green Certificate Market: Some Simple Analytical Results." *Energy Economics* 23(99): 489–509. https://doi.org/10.1016/S0140-9883(01)00079-2.

Bird, L., C. Chapman, J. Logan, J. Sumner, and W. Short (2011). "Evaluating Renewable Portfolio Standards and Carbon Cap Scenarios in the U.S. Electric Sector." *Energy Policy* 39(5): 2573–2585. https://doi.org/10.1016/j.enpol.2011.02.025.

Chen, Y. and L. Wang (2013). "Renewable Portfolio Standards in the Presence of Green Consumers and Emissions Trading." *Networks and Spatial Economics* 13(2): 149–181. https://doi.org/10.1007/s11067-012-9176-0.

Curtis, J., V.D. Cosmo, and P. Deane (2014). "Climate Policy, Interconnection and Carbon Leakage: The Effect of Unilateral UK Policy on Electricity and GHG Emissions in Ireland." *Economics of Energy & Environmental Policy* 3(2): 145–158. https://doi.org/10.5547/2160-5890.3.2.jcur.

Del Río Gonzalez, P. (2007). "The Interaction between Emissions Trading and Renewable Electricity Support Schemes. An Overview of the Literature." *Mitigation and Adaptation Strategies for Global Change* 12(8): 1363–1390. https://doi.org/10.1007/s11027-006-9069-y.

Fais, B., M. Blesl, U. Fahl, and A. Voß (2014). "Analyzing the Interaction between Emission Trading and Renewable Electricity Support in TIMES." *Climate Policy* 15(3): 1–19. https://doi.org/10.1080/14693062.2014.927749.

Fischer, C. and L. Preonas (2010). "Combining Policies for Renewable Energy – Is the Whole Less than the Sum of Its Parts?" *International Review of Environmental and Resource Economics* 4: 51–92. https://doi.org/10.1561/101.00000030.

Gawel, E., S. Strunz, and P. Lehmann (2013). "A Public Choice View on the Climate and Energy Policy Mix in the EU – How Do the Emissions Trading Scheme and Support for Renewable Energies Interact?" *UFZ Discussion Papers 5/2013*. Leipzig.

Johnstone, N. (2003). "The Use of Tradable Permits in Combination with Other Environmental Policy Instruments." *Organization for Economic Co-operation and Development (OECD), Working Party on National Environmental Policy*.

Kim, W. and J. Yu (2018). "The Effect of the Penalty System on Market Prices in the Korea ETS." *Carbon Management* 9(2): 145–154. https://doi.org/10.1080/17583004.2018.1440852.

Latham, Watkins (2011). "California's Cap and Trade Regulation and Renewables Portfolio Standard: Two Significant Regulatory Programs Affecting California's electricity sector." *Client Alert*.

Limpaitoon, T., Y. Chen, and S. Oren (2014). "The Impact of Imperfect Competition in Emission Permits Trading on Oligopolistic Electricity Markets." *The Energy Journal* 35(3): 145–166. https://doi.org/10.5547/01956574.35.3.7.

Perez, A.P. and E. Sauma (2016). "Comparison of Incentive Policies for Renewable Energy in an Oligopolistic Market with Price-Responsive Demand." *The Energy Journal* 37(3): 159–198. https://doi.org/10.5547/01956574.37.3.mdea.

Perez, A.P., E.E. Sauma, F.D. Munoz, and B.F. Hobbs (2016). "The Economic Effects of Interregional Trading of Renewable Energy Certificates in the U.S. WECC." *The Energy Journal* 37(4): 267–296. https://doi.org/10.5547/01956574.37.4.aper.

Rausch, S. and V.J. Karplus (2014). "Markets versus Regulation: The Efficiency and Distributional Impacts of U.S. Climate Policy Proposals." *The Energy Journal* 35(S1): 119–227. https://doi.org/10.5547/01956574.35.SI1.11.

Sorrell, S. and J. Sijm (2003). "Carbon Trading in the Policy Mix." *Oxford Review of Economic Policy* 19(3): 420–437. https://doi.org/10.1093/oxrep/19.3.420.

Thurber, M.C., T.L. Davis, and F.A. Wolak (2015). "Simulating the Interaction of a Renewable Portfolio Standard with Electricity and Carbon Markets." *Electricity Journal* 28(4): 51–65. https://doi.org/10.1016/j.tej.2015.04.007.

Tsao, C., J. Campbell, and Y. Chen (2011). "When Renewable Portfolio Standards Meet Cap-and-Trade Regulations in the Electricity Sector: Market Interactions, Profits Implications, and Policy Redundancy." *Energy Policy* 39(7): 3966–3974. https://doi.org/10.1016/j.enpol.2011.01.030.

Yu, J. and M.L. Mallory (2017). "Carbon price interaction between allocated permits and generated offsets. *Operational Research*: 1–30. https://doi.org/10.1007/s12351-017-0345-2.