Renewable Portfolio Standards: When Do They Lower Energy Prices?

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Some studies of renewable portfolio standards find that regulations increase electricity generation costs; others find that the reduced demand for nonrenewable energy sources lowers natural gas prices and that electricity prices follow. This paper presents reasons for why these predictions can vary in the direction as well as the magnitude of their effects. The two driving factors are the elasticity of electricity supply from renewable energy sources relative to nonrenewable ones and the effective stringency of the target. The availability of other baseload generation helps to determine that stringency, and demand elasticity influences only the magnitude of the price effects, not the direction of those effects. The paper also evaluates circumstances under which higher standards can decrease both certificate prices and renewable energy supply. Sensitivity analysis indicates that assumptions about renewable energy supply slopes are more important than those about nonrenewable supplies in predicting the retail price impacts of renewable portfolio standards.

1. INTRODUCTION

Concerns about air quality, global climate change, and energy security have increased interest in the potential of renewable energy to displace fossil fuel sources. In 2003, renewable energy sources provided 9.4 percent of the total electricity generation in the United States, although excluding hydropower, that share amounted to only 2.3 percent (EIA 2004). Globally in 2003, hydropower contributed 16 percent of electricity supply, waste and biomass contributed 1 percent, and other renewable sources supplied another 1 percent (IEA 2006). The targets for expanding nonhydro renewable electricity generation are ambitious.

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The Obama Administration aims to ensure that 10 percent of electricity production in the United States comes from renewable sources by 2012, and 25 percent by 2025.[1] Meanwhile, the European Union has set itself the well-publicized target of increasing the share of renewables in energy use to 20% by 2020.

One of the most frequently advanced policies for supporting renewable energy sources in electricity generation is the renewable portfolio standard (RPS). RPSs, also known as renewable obligations and green certificates, require either producers or users to derive a certain percentage of their electricity from renewable sources. Currently, 34 of the U.S. states and the District of Columbia have established an RPS or a state-mandated target for renewables.[2] Australia, Austria, Belgium, Brazil, Czech Republic, Denmark, Finland, Italy, Japan, the Netherlands, Norway, South Korea, Sweden, and the United Kingdom have planned or established similar programs.[3] As these policies gain in popularity and stringency, understanding their costs and impacts becomes more important. However, little consensus has emerged among analyses of policies for renewable energy, particularly with respect to consumer impacts.

Simple intuition would lead one to expect a regulatory constraint to impose costs. Indeed, many economic models for climate and energy policy analysis find that policies to reduce greenhouse gas emissions from the electricity sector, including RPSs, raise economic costs and electricity prices (EIA 1998, 2000, 2001, 2002, 2003, 2004; Palmer and Burtraw 2005). However, other inquiries find little or no price impacts, including Bernow, Dougherty, and Duckworth (1997) and others by the Tellus Institute (2002). Yet other studies find that policies can actually result in lower consumer prices. Prominent examples include studies by the Union of Concerned Scientists (UCS), including Clemmer, Nogee, and Brower (1999) and Nogee, Deyette, and Clemer (2007). Elliot et al. (2003), writing for the American Council for an Energy-Efficient Economy (ACEEE), reaches comparable conclusions.[4] A recent analysis by Wiser and Bolinger (2007) finds that a wide range of results has been produced just by studies of RPS policies using different variations of the National Energy Modeling System (NEMS)—which include the Energy Information Administration (EIA), UCS, Tellus, and ACEEE efforts. The driving factor behind lowered electricity prices in the UCS and ACEEE studies is hypothesized to be the partial displacement of gas-turbine generation by renewable energy. The decrease in demand for natural gas–based energy lowers the price of natural gas, and thus gas-fired generation costs and electricity prices subsequently fall.

1. (http://www.whitehouse.gov/agenda/energy_and_environment/). Accessed 02/25/2009.
2. Source: Database of State Incentives for Renewables and Efficiency (http://www.dsireusa.org).
3. Source: International Energy Agency (http://www.iea.org/textbase/pm/grindex.aspx).
4. Elliot et al. (2003) do not model electricity price effects explicitly but conjecture this result due to their strong gas price impacts.

Other theoretical models have revealed the possibility of counterintuitive effects of RPS policies. Amundsen and Mortensen (2001) modeled a proposed Danish green certificate system that includes price ceilings, floors, a CO_2 price, and electricity imports; they found indeterminate relationships of the standard's effects on renewable capacity as well as the certificate price. Jensen and Skytte (2002), comparing an RPS with emissions regulation, find that green certificates can reduce electricity prices. Fischer and Newell (2008), comparing the welfare effects of different policies for reducing emissions from the power sector and inducing technological progress among renewable sources, also find that an RPS may lead to lower electricity prices.

Because the effects of mandated renewable energy on electricity prices are of keen interest to policymakers, it is important to reconcile these contradictory results. This paper asks, simply, when are RPSs likely to lower electricity prices? To answer this question, we first show that the debate has been inordinately focused on the role of natural gas markets and generation. We then present a model that demonstrates that the driving factor is instead the relative responsiveness of renewable energy to electricity price changes as compared both to the responsiveness of the nonrenewable sources and to the stringency of the RPS. Other things being equal, the greater the relative responsiveness of renewable to nonrenewable energy supplies, the lower the potential rate impacts of an RPS and vice versa. The stringency of the regulatory constraints, however, can have offsetting impacts that need to be considered in tandem with the relative supply changes. The availability of other baseload generation helps to determine the effective stringency of the regulation and therefore whether the relative supply changes are sufficient to allow retail prices to fall. In contrast, demand responsiveness influences the magnitude of the price effects but not their direction.

2. BACKGROUND

Wiser and Bolinger (2007) focus on the role of gas markets in explaining disparate results among a dozen studies that, with one exception, all used the NEMS as a foundation.[5] "While the shape of the short-term natural gas supply curve is a transparent, exogenous input to NEMS, the model (as well as other energy models reviewed for this study) does not exogenously define a transparent long-term supply curve; instead, a variety of modeling assumptions are made which, when combined, implicitly define the supply curve" (p. 299, Wiser and Bolinger 2007). Many of the studies exclusively evaluated an RPS; others also looked at energy-efficiency measures and environmental policies. The review from Wiser and Bolinger reveals a range of predicted impacts among the RPS

5. The U.S. Department of Energy's Energy Information Administration developed, operates, and revises NEMS annually to provide long-term (e.g., to 2020 or 2025) energy forecasts.

studies (Table 1).[6] For the most common scenario of 10 percent RPS by 2020, retail electricity price changes ranged from +1.4 to –2.9 percent; for 20 percent RPS by 2020, they ranged from +4.3 to –0.4 percent.

From the information embedded in these studies on renewable energy Wiser and Bolinger (2007) derived implicit long-term inverse price elasticities[7] of natural gas supply (as opposed to generation from gas sources). They also compared the long-term elasticities implicit in NEMS with those of other national energy models by using data from a recent study by Stanford's Energy Modeling Forum (EMF 2003). Table 2 reports these results in terms of the more familiar direct price elasticities. It shows a range of elasticities in the 2010 scenarios of 0.1 to 1.0—in other words, all but one of the scenarios assume relatively inelastic natural gas supply in the short-to-medium run. In the long run (2020), the elasticities ranged from 0.2 to 9.1 (the most elastic being NEMS). The central tendency among these studies is for a 1 percent reduction in the quantity of natural gas supplied to be associated with an expected wellhead price reduction of 0.75 to 2.5 percent in the long term. Despite a dearth of empirical estimates in Wiser and Bolinger's review of the literature, this range is nonetheless consistent Krichene's (2002) estimate of the long-term supply elasticity for natural gas for 1973–1999 of 0.8, which corresponds to an inverse elasticity of 1.25.

Were natural gas the main story for how an RPS affects consumer prices, one would expect models with bigger gas price changes to predict smaller electricity price increases. Figure 1 plots the implied (inverse) price elasticities for natural gas with the retail electric price increases in the RPS studies compiled by Wiser and Bolinger (2007).[8] The scatter reveals that the expected relationship does not hold with any apparent consistency. Thus, other factors must be at play.

Most obviously, Wiser and Bolinger (2007) focused on the assumptions related to natural gas supplies, but they did not evaluate the role of different estimates in forming the underlying assumptions for the elasticity of supply from

6. The studies included "(1) five studies by the EIA focusing on national RPS policies, two of which model multiple RPS scenarios; (2) five studies of national RPS policies by the Union of Concerned Scientists (UCS), two of which model multiple RPS scenarios, and one of which also includes aggressive energy-efficiency investments; (3) one study by the Tellus Institute that evaluates three different standards of a state-level RPS in Rhode Island (combined with the RPS policies in Massachusetts and Connecticut); and (4) an ACEEE study that explores the impact of national and regional RE and EE deployment on natural gas prices. The EIA, UCS, and Tellus studies were all conducted in NEMS (note that NEMS is revised annually, and that these studies were therefore conducted with different versions of NEMS), while the ACEEE study used a gas market model from Energy and Environmental Analysis (EEA)" (Wiser and Bolinger 2007, 3–4). Table 1 excludes the two studies with an energy-efficiency focus.

7. The inverse price elasticity is the percentage change in price due to a percentage change in quantity, as opposed to the more conventional direct price elasticity, which is the percentage change in quantity due to a percentage change in price.

8. Studies that include energy-efficiency policies are excluded for easier comparison.

renewable energy technologies.[9] Because the price sensitivity of renewable generation influences the equilibrium change in natural gas–fired generation, the renewables supply curve also helps to determine the corresponding shift in demand for natural gas and the subsequent downward pressure on wellhead prices. As a result, the correlation between natural gas price elasticities and the effect of an RPS on electricity prices is indirect and depends on other factors. To understand these factors more fully, let us turn to the following model of the relationship among renewable energy, gas-fired generation, electricity markets, and RPSs.

Table 1. Implied Natural Gas Price Elasticities and Retail Electricity Price Increases

		Implied Elasticity of Natural Gas Supply		Retail Electricity Price Increase	
Source	**RPS***	**Direct: dQ/Q/(dP/P)**	**Indirect: dP/P/(dQ/Q)**	**Change: %**	**Cents/ kWh**
EIA 1999	7.5—2020	0.20	5.08	1.7	0.10
EIA 1998	10—2010	0.26	3.79	3.6	0.21
Tellus Institute 2002	10—2020†	Infinite	0.00	0.1	0.02
EIA 2003	10—2020	Infinite	0.00	0.6	0.04
UCS 2002b	10—2020	1.40	0.71	–1.1	–0.07
EIA 2002	10—2020	0.57	1.76	1.4	0.09
UCS 2004	10—2020	0.52	1.94	–1.8	–0.12
EIA 2001	10—2020	0.48	2.10	0.2	0.01
UCS 2002a	10—2020	0.35	2.89	–2.9	–0.18
UCS 2003	10—2020	0.09	10.67	–2.0	–0.14
Tellus Institute 2002	15—2020†	1.75	0.57	–0.3	–0.05
UCS 2004	20—2020	3.10	0.32	1.3	0.09
Tellus Institute 2002	20—2020†	1.00	1.00	–0.4	–0.07
EIA 2001	20—2020	0.62	1.61	4.3	0.27
EIA 2002	20—2020	0.57	1.76	2.9	0.19
UCS 2002a	20—2020	0.50	1.99	3.0	0.19

*percent—year; entire United States unless otherwise specified, †Rhode Island only.
Source: Adapted from Wiser and Bolinger (2007).

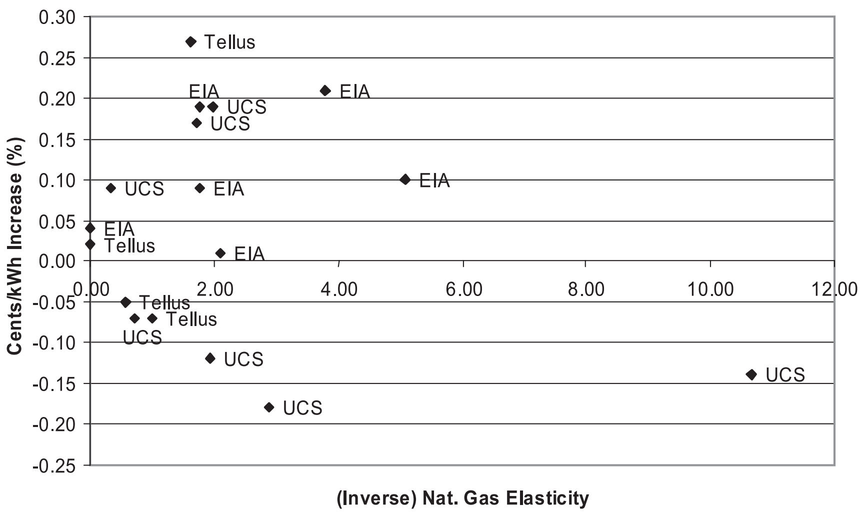
9. Nogee et al. (2007) did compare results with alternative assumptions about renewable energy supply in NEMS; however, as they combined more pessimistic assumptions about supply constraints with more optimistic assumptions about costs, the implicit effect on renewable supply elasticities is not transparent, nor are the assumptions about natural gas price elasticities.

Table 2. Implicit Gas Price Elasticities in a Range of National Energy Models

	Implied Price Elasticity of Natural Gas	
Energy Model	**2010**	**2020**
NEMS	0.5	9.1
E2020	1.0	1.4
CRA	0.4	1.1
POEMS	0.6	0.6
MARKAL	0.5	0.5
NARG	0.1	0.4
NANGAS	0.1	0.2

Notes: NEMS = National Energy Modeling System; E2020 = Energy 2020; CRA = Charles River Associates; POEMS = Policy Office Electricity Modeling System; MARKAL = MARKet ALlocation; NARG = North American Regional Gas model; NANGAS = North American Natural Gas Analysis System.
Source: Adapted from Wiser and Bolinger (2007).

Figure 1. Combinations of Electricity Price Increases and Natural Gas Price Elasticities in Review by Wiser and Bolinger (2007)



3. MODEL

A simple yet general model of energy supplies and demand demonstrates how the relative slopes of these curves determine the price incidence of portfolio standards. Unlike previous theoretical studies, this model explicitly considers several different kinds of nonrenewable energy sources so that subsequent sensitivity analysis can explore which supply curves are the most important drivers of electricity market outcomes under an RPS.

Consider four different types of generation: baseload technologies x, natural gas g, other fossil fuels f, and renewable energy r. Baseload generation is characterized as fixed and fully utilized generation capacity, such as nuclear energy and (often) large-scale hydropower, although in some circumstances coal might also be considered baseload if little output variation is anticipated. The fossil fuel sources other than natural gas are oil and primarily coal. Renewable energy sources include wind, solar, biomass, geothermal, and so on; hydropower is often excluded from the renewable sources eligible for preferential treatment because it also functions as a baseload technology.

Whereas the baseload supply curves are fixed and perfectly inelastic (i.e., $dx = 0$), the nonbaseload types of generation are assumed to have inverse supply curves [$S_g(g)$, $S_f(f)$, and $S_r(r)$ (where $S_i' \geq 0$ for all i)] that are weakly upward sloping. One can think of these supply curves as marginal cost curves and assume that these technologies receive competitively determined prices, so that their marginal costs are equal to the price received. Alternatively, one can allow the supply curves more generally to represent the price demanded for an additional unit of generation at the amount supplied. Given that the electricity market is only partially deregulated, this latter characterization may be more appealing.

The renewables policy causes the prices received by suppliers to diverge according to the energy source. Although the price received by baseload generation (P_g) is the same as that of generation from fossil fuels, the price received by generation from renewable sources (P_r) may be higher. Let P be the consumer price of electricity. Let consumer (indirect) demand be represented by $D\,(g + f + r + \chi)$, a downward-sloping function of total consumption, where $D' < 0$.

The market-clearing conditions are simply that the quantities supplied equal the quantities demanded at the prevailing market prices:

$$\begin{aligned} P_g &= S_g(g) \\ P_f &= S_f(f) \\ P_r &= S_r(r) \\ P &= D(g + f + r + x) \end{aligned} \tag{1}$$

Next, one can evaluate the effects of different renewable energy policies on consumer prices. Totally differentiating the market-clearing equations yields

$$\begin{aligned} &dg = dP_g / S_g'; \quad df = dP_f / S_f'; \quad dr = dP_r / S_r'; \\ &dP = (dg + df + dr)D' \end{aligned} \tag{2}$$

Notice that this framework abstracts from transmission costs or other markups that would place a wedge between the supply and demand prices for the marginal technology. Because the results are driven by price changes, the analysis is not affected as long as those markup costs are fixed and unaffected by the renewable energy policy.

3.1 Renewable Production Subsidy

One means of supporting renewable energy is by a direct subsidy to production. For example, the United States has the Renewable Energy Production Incentive of 1.9 cents per kilowatt-hour (kWh), and 24 individual U.S. states have their own subsidies. Germany has been especially generous in supporting wind energy, and some other European countries, Canada, and Korea also offer some form of production subsidies. In addition, the United States has a 10 percent investment tax credit for new geothermal and solar electric power plants. In the long run, investment subsidies like this—which lower the costs of building and expanding capacity—can also have the effect of subsidizing production.

Let s be a simple subsidy for renewables in the model. In the new market equilibrium, $P_g = P_f = P$ and $P_r = P + s$. Using Eq. (2), as well as $dP_g = dP_f = dP$ and $dP_r = dP + ds$, one can solve for dP, dg, df, dr resulting from a change in the subsidy. In this case, we find that an increase in the subsidy causes consumer prices to fall:

$$\frac{dP}{ds} = \frac{1/S_r'}{1/D' - 1/S_g' - 1/S_f' - 1/S_r'} < 0 \tag{3}$$

In other words, as long as natural gas supply is strictly upward sloping, part of the incidence of the renewable generation subsidy will be passed on to consumers as lower electricity prices. The subsidy shifts the renewable generation supply curve downward, resulting in an equilibrium with more renewables, less generation from fossil fuel sources, and lower prices.

3.2 Nonrenewable Production Tax

Another common way of favoring renewable energy is by taxing fossil fuel sources or by exempting renewable sources from an energy tax. This policy measure is used in the United Kingdom, Germany, Sweden, and the Netherlands. Similarly, an emissions tax or permit-trading program also effectively taxes nonrenewable sources disproportionately by imposing a price on their embodied emissions.

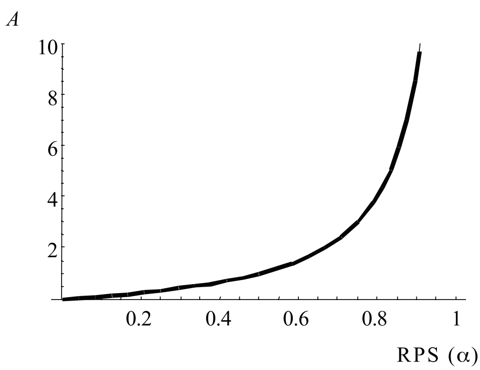
Let t be a tax on nonrenewable supply. In the new supply-and-demand equilibrium, $P_g = P - t$ and $P_r = P$. Again, totally differentiating and solving for dP, dg, dr gives

$$\frac{dP}{dt} = \frac{1/S_g{}' + 1/S_f{}'}{-1/D' + 1/S_g{}' + 1/S_f{}' + 1/S_r{}'} > 0 \qquad (4)$$

Therefore, a fossil fuel tax (or emissions price) will necessarily increase consumer prices as long as the supply curves are upward sloping and demand curves are downward sloping. The nonrenewable production tax shifts the supply curve for generation from fossil fuel sources upward. This upward shift results in substitution toward more expensive renewable sources and conservation, which in turn raises the electricity price.

3.3 Renewable Portfolio Standard

The RPS combines elements of the two preceding policies. Generators of energy from renewable sources receive a subsidy in the value of their certificates, *s,* whereas generators of energy from nonrenewable sources must pay a tax proportional to the certificates they need to fulfill the standard, α. Let $A = \alpha/(1 - \alpha)$ be the ratio of generation from renewable sources to generation from nonrenewable sources, which represents the number of certificates required to accompany an additional unit of nonrenewable generation. This ratio is a monotonic, increasing function of the standard.



Under this policy, the prices received are

$$P_r = P + s$$
$$P_g = P_f = P - As \qquad (5)$$

In addition to the previous market-clearing conditions, the RPS adds the following condition:

$$r = (f + g + x)A \tag{6}$$

In other words, a fixed share of the electricity supply (excluding hydro and nuclear) must derive from renewable sources. (This constraint is typical of many RPS programs, although the standard can also apply to all electricity consumed; since these other sources are fixed, however, the definition has no impact on the results, other than by determining the effective stringency.)

$$\begin{aligned} dg &= (dP - Ads - sdA)/S_g' \\ df &= (dP - Ads - sdA)/S_f' \\ dr &= (dP + ds)/S_r'(r) \\ dP &= (dg + dr + df)D' \\ dr &= (f + g + x)dA + A(dg + df) \end{aligned} \tag{7}$$

which gives a set of five equations and five variables (*dg, dr, df, dP,* and *ds*) responding to *dA*, and correspondingly to $d\alpha$.

Substituting and solving for the price change induced by a change in the standard, one sees the impact on consumer prices of an increase in the renewable requirement:

$$\frac{dP}{dA} = \left(\frac{(1+A)s + (AS_r' - \sigma)(f + g + x)}{(1+A)^2 - (\sigma + A^2 S_r')/D'} \right) \tag{8}$$

where $\sigma = S_f' S_g' / (S_g' + S_f')$ is a measure of the joint slope of nonrenewable generation. (Note that $dP / d\alpha = (dP/dA)/(1 - \alpha)^2$.)

The denominator of this expression is necessarily positive because of the assumptions of upward-sloping supply curves and downward-sloping demand curves. With the numerator then determining the sign, the price of electricity will fall if the combined supply curve for nonrenewable generation is sufficiently steep relative to the renewables supply curve slope:

$$dP / d\alpha < 0 \quad \text{if} \quad \sigma > AS_r' + s(1+A)/(f + g + x) \tag{9}$$

Of course, the relative slopes of the supply curves for fossil fuels and renewables are not the only factors. Eq. (9) clearly shows that the electricity price is more likely to fall at low levels of the RPS requirement. Suppose the constraint is nonbinding, implying that $s = 0$ and $A = A_0$. Then $A_0 S_r' < \sigma$ suffices to cause consumer prices to drop initially as the standard is raised. Thus, the supply curve for fossil fuel need not be steeper than that for renewable energy—only steeper than the renewable slope in proportion to the renewable share of total production. However, as the stringency of the standard increases, consumer prices also are likely to increase, unless the combined nonrenewable supply curve is very steep. Note that the second term on the right side of Eq. (9) increases along with three factors—the RPS share, the implicit subsidy, and the reduction in output from nonrenewable sources—all of which increase with program stringency. Overall, as the standard is made more stringent, the right-hand side increases, making it less likely that conditions will allow the retail price to fall. Indeed, Palmer and Burtraw (2005) find a distinct nonlinearity in the electricity price response to more stringent portfolio standards.

One can also see how the rest of the system responds to an increase in the portfolio requirement:

$$\frac{dg}{dA}=\frac{-s-\left(AS_r'-(1+A)D'\right)(f+g+x)}{\chi(S_f'+S_g')/S_f'}<0 \tag{10}$$

$$\frac{df}{dA}=\frac{-s-\left(AS_r'-(1+A)D'\right)(f+g+x)}{\chi(S_f'+S_g')/S_g'}<0 \tag{11}$$

$$\frac{dr}{dA}=\frac{\overbrace{\left(\sigma-(1+A)D'\right)(f+g+x)}^{+}\overbrace{-As}^{-}}{\chi} \tag{12}$$

$$\frac{ds}{dA}=\frac{\overbrace{(f+g+x)(\sigma S_r'-D'(\sigma+S_r'))}^{+}\overbrace{-s(AS_r'-(1+A)D')}^{-}}{\chi} \tag{13}$$

where $\chi=\sigma+A^2S_r'-D'(1+A)^2$, as in the denominator of Eq. (8). Because $\chi>0$, it follows with no surprise that $dg/dA<0$. However, the signs of *ds* and *dr* are ambiguous.

Eq. (10) and (11) reveal that an increase in the RPS necessarily reduces nonrenewable generation of both types. The relative magnitudes of the decreases depend on the relative slopes of the gas-fired and coal-fired generation supply curves; the source with the flatter supply curve will face deeper reductions.

Eq. (12) reveals that at low levels of the policy target, renewable generation increases with policy stringency. However, as the target gets more stringent, renewable generation can possibly decrease if demand and nonrenewable supplies are sufficiently flat relative to the subsidy. That is, at high levels, additional portfolio requirements may be easier to meet by cutting back on demand rather than by expanding renewable energy.

Similarly, Eq. (12) raises the possibility of a Laffer curve for green credits. The subsidy to renewables may fall for large values of A, that is, if

$$A > \frac{\left(\sigma(S_r' - D') - S_r'D'\right)(f + g + x) + sD'}{s\left(S_r' - D'\right)}.$$

This kind of Laffer curve does not apply to the effective tax on nonrenewable generation, however; the effective tax will always increase with the stringency of the standard:

$$\begin{aligned} \frac{d(As)}{dA} &= s + A\frac{ds}{dA} \\ &= \frac{s(\sigma - D'(1+A)) + A(f+g+x)(\sigma S_r' - D'(\sigma + S_r'))}{\chi} > 0 \end{aligned} \tag{14}$$

Thus, a falling equilibrium renewable subsidy indicates a point at which it is more cost effective to cut back on generation from nonrenewable sources than to add more renewable sources. Still, the present analysis is limited to the range in which energy generation from the fossil fuel sources is not crowded out completely, although this point may be attainable.

The effect on total consumption is the sum of the changes in all generation sources. By definition, it moves in the opposite direction of the electricity price. Consumer responsiveness, in the form of the slope of the demand curve, plays an important role in the equilibrium for all of these variables. First, for the retail price change in Eq. (8), the slope of electricity demand appears only in the denominator, meaning that it plays a role in the magnitude of the price effect, but not the direction. When demand is steep and consumption will not adjust much as prices change, the price impacts tend to be larger. Second, for the changes in the other variables [Eq. (10) through (13)], the demand slope appears in both the numerators and denominators, suggesting countervailing and ambiguous effects on the magnitudes of those changes.

Although we do not consider energy-efficiency programs explicitly, they can certainly interact with RPS policies. First, by reducing demand, energy-efficiency programs have their own direct effect of lowering retail prices, and they have indirect effects on the certificate prices needed to meet the standard. In this analysis framework, a demand shift would move the point of departure from which we assess changes in the RPS. Second, demand-side policies may also change how retail prices respond to increases in the RPS by changing the D' parameter in Eq. (9). If demand-side policies change consumer sensitivity to electricity prices—in particular, by making demand flatter—they can reduce the severity of the retail price change as the RPS becomes more stringent.

Similarly, although baseload generation is assumed to be in fixed supply in this analysis, we may partially intuit its role. Note that x influences the numerator in Eq. (8) both directly and indirectly, since s is implicitly a function of the baseload in equilibrium. Thus, its effect on the effective stringency of the RPS is not entirely clear. Like a (net) demand reduction, an expansion of baseload capacity would crowd out both renewable and nonrenewable generation sources, with the proportions determined by the relative supply slopes. Depending on these proportions, the RPS may or may not become easier to achieve from that point, but overall consumer prices would still be lower. However, if baseload generation is also part of the RPS formula, then an expansion of baseload capacity would clearly call for more renewable generation along with it, further crowding out nonrenewable, nonbaseload sources and raising green certificate prices.

3.4 Sensitivity Analysis

To understand the role of the different supply curve slopes in determining these outcomes, we parameterize a simple version of the model to reflect the U.S. electricity sector. The parameterization follows that in Fischer and Newell (2008); while that analysis looks at the additional, longer range issues of technical innovation, the simulation model here is simplified to address a single time period.

Let us specify linear electricity supply curves for each fuel that pivot around the baseline (no-policy) point: $S_g'(g) = P_0 + c_g(g - g_0)$, $S_f'(f) = P_0 + c_f(f - f_0)$, and $S_r'(r) = P_0 + c_r(r - r_0)$. This formulation allows us to evaluate the role of the supply slopes while maintaining the baseline calibration. The nonrenewable supply slopes are calibrated to a recent set of simulations of the electricity market impacts of alternative CO_2 reduction goals from NEMS (EIA 2006). The assumed values are $c_g = 1.8 \text{ x } 10^{-14}$, $c_f = 2.2 \text{ x } 10^{-14}$.

The model assumes a constant elasticity of aggregate electricity demand with respect to the price of electricity, ε, so that $D = D(P_0) + (P - P_0)\, dD/dP$, where $dD/dP = \varepsilon D(P_0)/P_0$. The elasticity parameter is set to $\varepsilon = -0.20$, based on the implied elasticity from the EIA-NEMS climate policy study discussed above. The baseline price of electricity is 7.3 cents per kWh based on projected future values of the average price of electricity (EIA 2006). All monetary values are inflation adjusted to year 2004 values. Baseline levels of coal, natural gas, and baseload generation (nuclear and large hydro) are $f_0 = 2.314 \times 10^{12}$, $g_0 = 0.843 \times 10^{12}$, and $x_0 = 1.043 \times 10^{12}$, respectively.

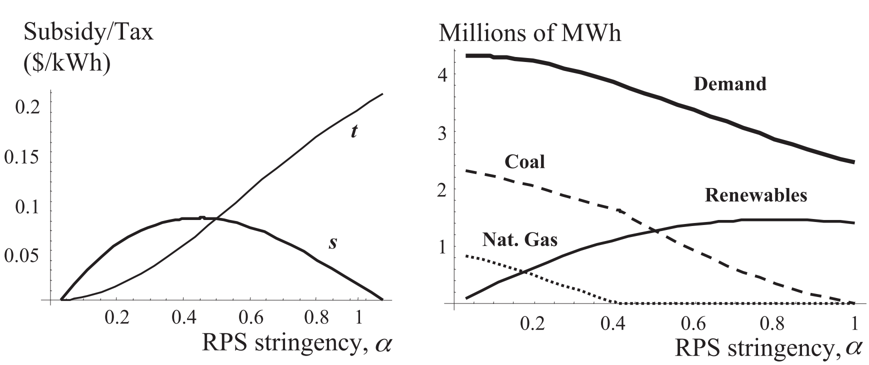
The slope of the renewable supply function, c_r, was derived from recent studies of proposed national RPSs (EIA 2003; Palmer and Burtraw 2004), which suggest that a 10 percent renewable share would lead to a renewable credit price of about 0.03 \$/kWh. This implies a slope of the renewable supply function of $c_r = 1.2 \times 10^{-13}$ \$/kWh^2. The projected baseline annual renewable generation for 2010 is 1.4×10^{11} kWh (EIA 2006).

With these parameters, we simulate an RPS formulated as a share of total nonbaseload electricity supply [i.e., $r = A(f + g)$]. This formulation implies a somewhat less stringent standard than requiring the same share of total demand; in other words, a 100 percent renewable share crowds out all nonrenewable generation, but not baseload.

The left panel in Figure 2 demonstrates the earlier result that the implicit tax on nonrenewable sources increases monotonically, although it is not strictly convex. We see the Laffer curve effect, in which the renewable energy certificate (REC) price declines at higher levels of portfolio requirements. Within these parameters, the peak REC price occurs at an RPS of 46 percent of nonbaseload generation, or about 32 percent of total generation. After the peak, the higher tax crowds out nonrenewable generation and provides higher retail prices to support renewable generation, such that less of the subsidy is needed to achieve the standard.

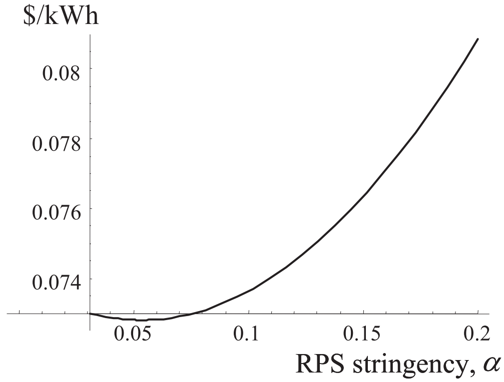
In the right-hand panel of Figure 2, we see that near this point, natural gas–fired generation is actually driven out of the market, and at very high levels, renewable supply begins to decline, as was postulated. Furthermore, as prices rise, consumers begin increasingly to conserve; essentially, it becomes relatively more cost effective to reach higher renewable shares by reducing demand rather than by continuing to push up the marginal cost curve for renewable supply. Of course, one should recognize that, while useful for illustrative purposes, this parameterized model is likely to have limited predictive ability for large deviations from current practice. In subsequent graphs we will limit the range of the RPS under consideration.

Figure 2. REC Price, Implicit Nonrenewable Tax, and Production as a Function of RPS



Next, we consider the effect of the RPS on the price of electricity (Figure 3). Over an initial range—from the current 3 percent to about 7.5 percent—the RPS does slightly lower the retail price relative to the baseline. However, more ambitious standards raise retail prices, and increasingly so as we enter the 10 to 20 percent range of many policy targets.

Figure 3. Electricity Price as a Function of RPS



Since previous research suggests that natural gas supply elasticity may be a key factor in determining the magnitude and range of the RPS effect on electricity price, we next investigate how sensitive these results are to the supply slopes. Figures 4 and 5 map the price impacts over the range of portfolio standards for the central scenario parameters, as well as doubling and halving the slope of natural gas–fired generation (Figure 4) and renewable generation (Figure 5). Although not reported, the sensitivity of the price to the coal supply slope looks similar to that of the natural gas supply slope.

Figure 4. Sensitivity of Electricity Price Effects of RPS to Natural Gas Supply Slope (1/2, 1, and 2 times baseline slope)

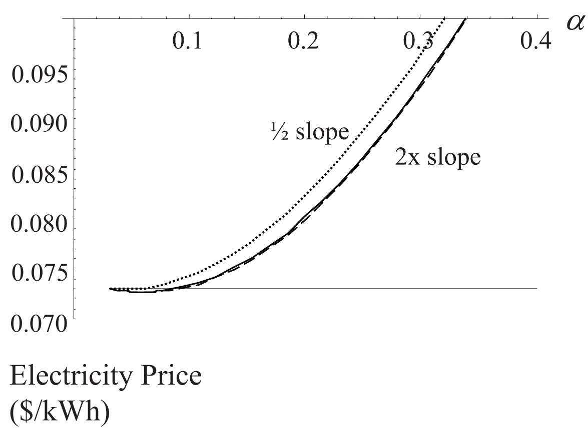


Figure 5. Sensitivity of Electricity Price Effects of RPS to Renewable Supply Slope (1/2, 1, and 2 times baseline slope)

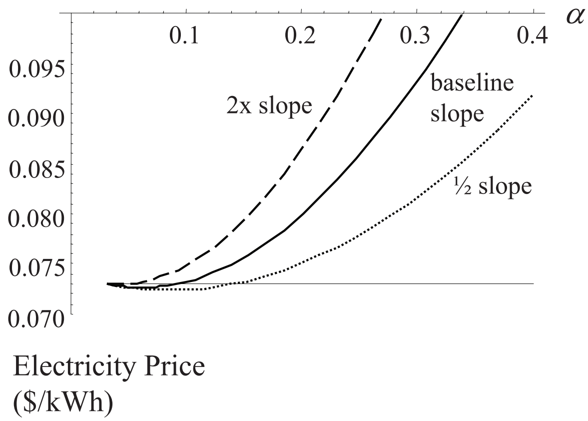
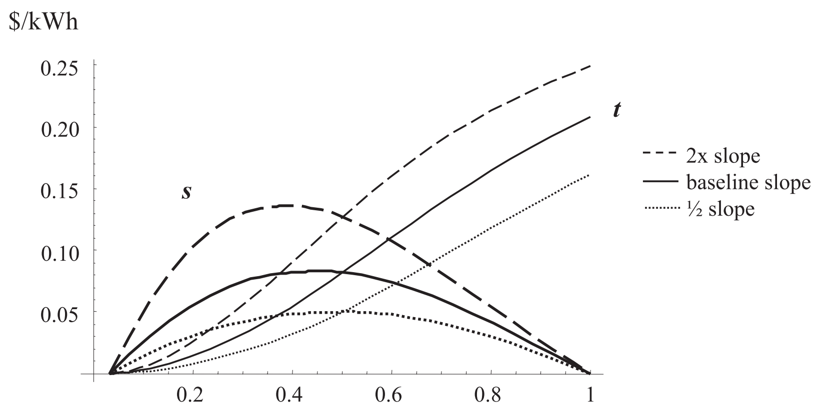


Figure 6. Sensitivity of Certificate Price and Implicit Nonrenewable Generation Tax to Renewable Supply Slopes



These results indicate that the slope of the natural gas (or coal) supplies is likely to be less important than the slope of the renewable generation supply curve. The reason lies in the fact that nonhydro renewables remain a very small share of overall generation, not to mention a small share of the RPS targets we are considering. The slope of the renewable supply curve determines the scope for their expansion, which has a bigger impact on the ease of achieving the RPS than the nonrenewable supplies.

This effect is evident again when we look at the sensitivity of the green certificate price and the implicit nonrenewable energy tax to the slope of the renewable supply curve (Figure 6). With the steeper slope, the certificate price rises more sharply and peaks earlier. The implicit tax is uniformly higher, reflecting the greater cost of expanding renewable energy. When the renewable supply curve is flatter, the implicit tax is lower, as is the range of certificate prices, and the peak falls at a higher RPS.

4. DISCUSSION

An RPS in essence combines both a subsidy and an implicit tax. The subsidy is given to producers of energy from renewable sources in the value of a credit. The implicit tax is levied on producers of energy from nonrenewable sources in the form of the cost of credits that must be purchased to accompany its production. When the supply curves of nonrenewable generation are not perfectly flat, a subsidy for renewables tends to depress electricity prices overall, whereas a tax on energy production from fossil fuel sources tends to raise consumer prices. The price impacts of an RPS can therefore be ambiguous, depending on whether the tax or subsidy effect dominates.

However, both the analytical and numerical modeling suggest that rate reductions are only likely at lower RPS shares. At higher RPS shares, in contrast, the implicit tax quickly dominates and electricity prices increase rapidly. The exact point at which this happens, as well as the magnitude of the price changes, depends on the various assumptions about the generation technology supply and demand curves. In particular, as this paper demonstrates, relative elasticities are more important for electricity price effects than the elasticity of the natural gas price alone. Indeed, the elasticity of renewable generation is likely to be the more important component. Other generation supplies remain a factor, so for long-run modeling, the relative elasticities of coal and other options will also help to drive outcomes. Demand elasticity remains important for estimating the magnitude of the price effects but not their direction. Still, the influence of demand creates a role for energy-efficiency policies; if such policies make consumers more sensitive to electricity prices in the long run, they can mitigate the rate changes associated with more stringent RPS targets.

To understand why different models produce very different results, one must evaluate the assumptions in the RPSs about the relative slopes (or elasticities) of the supply curves for generation from natural gas and from renewable sources. One should also assess how other fossil fuel energy sources, baseload generation, and the RPS requirements are presented. Models are more likely to predict that RPSs will produce lower consumer electricity prices when they embed rigidities in natural gas supply, assume that large portions of nonrenewable generation are fixed, parameterize relatively flat marginal costs for renewables, or target modest increases.

Given these wide-ranging predictions, better empirical evidence is needed to understand how renewable energy, natural gas markets, and other supplies will respond to these policies. Because all supplies, as well as demand, tend to be more elastic in the long run, the relative elasticities could evolve in either direction. Therefore, decreases in electricity prices as a result of RPSs may not necessarily be a short-run phenomenon. However, given the ambitiousness of many RPS targets relative to current market shares, the potential price changes are quite large. States or countries considering such targets should pay particular attention to understanding the price sensitivity of renewable generation as well as their overall generation mix.

Finally, while price changes can be a useful indicator of important distributional impacts of renewable energy policies, they are not necessarily good indicators of cost effectiveness. Renewable energy policies often have multiple goals, not only of promoting emerging technologies but also of reducing emissions of pollutants like greenhouse gases from the power sector. In this case, lower electricity prices can be counterproductive to the environmental objective, as they discourage conservation. Nor do renewable energy policies distinguish among nonrenewable sources according to their pollution characteristics; indeed, with a flatter supply curve, one expects natural-gas-fired generation to be displaced more rapidly than relatively dirty coal-fired generation as renewable energy expands.[10] All of these factors should be considered in setting policy and political goals for promoting clean energy.

REFERENCES

Amundsen, E.S., and J.B. Mortensen (2001). "The Danish Green Certificate System: Some Simple Analytical Results." *Energy Economics* 23: 489-509.

Bernow, Stephen, William Dougherty, and Mark Duckworth (1997). "Quantifying the Impacts of a National, Tradable Renewables Portfolio Standard." *The Electricity Journal* 10(4): 42-52.

Clemmer, Steve, Alan Nogee, and Mark Brower (1999). *A Powerful Opportunity: Making Renewable Electricity the Standard.* Cambridge: Union of Concerned Scientists.

Energy Information Administration (EIA, 1998). *Analysis of S. 687, the Electric System Public Benefits Protection Act of 1997.* SR/OIAF/98-01. Washington: EIA.

EIA (2000). *Annual Energy Outlook 2000.* DOE/EIA-0383. Washington: EIA.

EIA (2001). *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide, Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio Standard.* SR/OIAF/2001-03. Washington: EIA.

EIA (2002). *Impacts of a 10-Percent Renewable Portfolio Standard.* SR/OIAF/2002-03. Washington: EIA.

EIA (2003). *Analysis of a 10-Percent Renewable Portfolio Standard.* SR/OIAF/2003-01. Washington: EIA.

EIA (2004). *Renewable Energy Trends,* 2004 edition. Accessed at http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends04.html.

EIA (2006). *Energy Market Impacts of Alternative Greenhouse Gas Intensity Reduction Goals.* Washington: EIA.

10. See Fischer and Newell (2008) for a fuller discussion of the efficiency tradeoffs of renewable energy policies.

Elliot, R. Neal, Anna Monis Shipley, Steven Nadel, and Elizabeth Brown (2003). *Natural Gas Price Effects of Energy Efficiency and Renewable Energy Practices and Policies.* Report E032. Washington: American Council for an Energy-Efficient Economy.

Energy Modeling Forum (EMF, 2003). *Natural Gas, Fuel Diversity and North American Energy Markets.* EMF Report 20, Volume I. Stanford: Stanford University.

Fischer, Carolyn, and Richard Newell (2008). "Environmental and Technology Policies for Climate Mitigation." *Journal of Environmental Economics and Management*. 55(2): 142-162.

International Energy Agency (IEA, 2003). *Renewables Information.* Paris: Organisation for Economic Co-operation and Development.

IEA (2006). *Renewables in Global Energy Supply: An IEA Fact Sheet.* Paris: Organisation for Economic Co-operation and Development. Accessed at http://www.iea.org/Textbase/Papers/2006/renewable_factsheet.pdf.

Jensen, S.G., and K. Skytte (2002). "Interactions between the Power and Green Certificate Markets." *Energy Policy* 30(5): 425-435.

Krichene, N. (2002). "World Crude Oil and Natural Gas: A Demand and Supply Model." *Energy Economics* 24: 557-576.

Nogee, Alan, Jeff Deyette, and Steve Clemmer (2007). "The Projected Impacts of a National Renewable Portfolio Standard." *The Electricity Journal* 20(4): 33-47.

Palmer, Karen, and Dallas Burtraw (2004). *Electricity, Renewables, and Climate Change: Searching for a Cost-Effective Policy*. Washington: Resources for the Future.

Palmer, Karen, and Dallas Burtraw (2005). "Cost-Effectiveness of Renewable Electricity Policies." *Energy Economics* 27(6): 873-894.

Tellus Institute (2002). *Modeling Analysis: Renewable Portfolio Standards for the Rhode Island GHG Action Plan.* Boston: Tellus Institute.

Union of Concerned Scientists (UCS, 2002a). *Renewing Where We Live.* Cambridge: UCS.

UCS (2002b). *Renewing Where We Live.* Cambridge: UCS.

UCS (2003). *Renewing Where We Live.* Cambridge: UCS.

UCS (2004). *Renewable Energy Can Help Ease the Natural Gas Crunch.* Cambridge: UCS.

U.S. Department of Energy (DOE, 2003). *The Department of Energy Strategic Plan: Protecting National, Energy, and Economic Security with Advanced Science and Technology and Ensuring Environmental Cleanup.* Washington: DOE. Accessed at http://strategicplan.doe.gov/Draft%20SP.pdf.

Wiser, Ryan, and Mark Bolinger (2007). "Can Deployment of Renewable Energy Put Downward Pressure on Natural Gas Prices?" *Energy Policy* 35(1): 295-306.