The Impact of Rate-of-Return Regulation on Electricity Generation from Renewable Energy

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Abstract

Traditional electric utility companies face a trade-off between building generation facilities that utilize renewable energy (RE) and non-renewable energy (non-RE). The firm's input decision to build capacity for either source depends on several constraining factors, including input prices, policies that promote or discourage RE use, and the type of regulation faced by the firm. This paper models the utility company's decision between RE and non-RE capital types. From the model, two main results are derived. First, rate-of-return (ROR) regulation decreases the investment in RE capital relative to the unregulated firm. These findings suggest restructuring electricity generation markets, which removes the ROR on generating assets, can increase the relative use of RE. Second, the renewable portfolio standard (RPS) increases the investment in capital and labor that requires RE as a source of electricity, as expected. The model shows that the impact of an RPS depends on the amount of ROR regulation.

JEL classification: L2, L51, L94, Q2, Q3.
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1. Introduction

Rate-of-return (ROR) regulation is well-known in the electricity industry, and in regulation literature, several articles have demonstrated that ROR regulation affects the firm's input decision between capital and labor (Averch and Johnson, 1962; Petersen, 1975; Sherman, 1992; Spann, 1974). Typically, an electric utility is given the right as the sole generator, and distributor of electricity in a region. In exchange, the utility is regulated by a public commission that determines the rate for selling electricity. The rate includes a fair return on capital investments.

However, different types of capital can generate electricity. For example, renewable energy (RE) and non-renewable energy (non-RE) differ in their generation turbines, environmental abatement technologies, and the requirements for land development and heat-waste water. Moreover, RE sources are typically more costly to build, provide intermittent output, and have an uncertain capacity to generate revenue.[1] The inexperience with RE technologies makes them a riskier investment. Thus, the cost of capital is higher for RE sources.

ROR regulation also affects the decision to invest in different types of capital. Specifically, ROR regulation acts as a subsidy for capital, lowering the price of capital compared to labor and lowering the relative price of cheaper capital. Since RE is typically more expensive and riskier, the ROR increases the relative price of RE, and the firm utilizes less RE capital than an unregulated firm.

This paper examines how ROR regulation affects the utility company's decision to generate electricity from RE sources and non-RE sources. Following Averch and Johnson (1962), I extend the ROR model to account for two different types of output: electricity

[1] The EIA estimates biomass, hydro, geothermal, solar, and wind to have a greater total levelized cost than conventional coal, advanced coal, and natural gas fired plants (EIA, 2010).

generated from RE and electricity generated from non-RE. The results show that ROR decreases the firm's incentive to invest in relatively expensive capital for RE sources of electricity. ROR regulation causes the firm to over-invest in capital, and over-invest in capital that utilizes non-RE sources.

One policy consideration is the restructuring of the electricity markets from a monopoly to allowing retail competition in the generation sector. Restructuring, ideally, removes the allowable return on capital assets used for generation. Several papers have suggested mixed results for the impact of restructuring on RE technologies. Wiser, Porter, and Clemmer (2000) argue that restructuring may help RE because of the new attention given to RE policies. Madlener and Stagl (2005) suggest that such electricity market liberalization can allow for the differentiation of products and increase the potential for 'green' markets. On the other hand, Kumbaroglu, Madlener, and Demirel (2008) suggest that liberalization decreases the incentive to invest in renewable technologies. Empirically, Carley (2009) finds that deregulation decreases the share of renewable electricity generated but increases the total amount renewable energy generation. This paper shows that restructuring that removes or decreases the allowed ROR can also promote the relative use of RE.

The model allows us to examine the impact of a second regulatory constraint of a renewable portfolio standard (RPS). For several years, advocates for renewable energy (RE) have sought to create a national RPS (Darmstadter, 2004). In the last decade alone, Congress has rejected fourteen proposals that establish a national standard. In April 2009, the US House of Representative's subcommittee on Energy held hearings on a bill that implements a national RPS. The policy requires that generation from renewable resources fulfill a certain percentage of electricity sold. The current bill requires utility companies to generate 6% of their retail sales from RE by 2012, and 25% by 2025.[2] RPSs have increased in popularity at the state level with over half the U.S. population living in states with an RPS. By 2011 twenty-nine states had enacted legislation that mandated utility companies to provide consumers with electricity generated from RE.

Fischer (2006) models the impact of the RPS as a tax on non-RE sources and a subsidy on RE sources; however, the RPS is actually a proportion constraint requiring the utility to produce electricity using at least a minimum ratio of RE to non-RE sources. This paper contributes to the RPS literature by presenting an alternative approach to modeling the RPS that is more consistent with the incentives faced by the firm, and accounts for ROR regulation. I examine the utility company's input decision with a proportional constraint on RE and non-RE sources for electricity generation. By modeling the decision of the firm to choose between two different sources of electricity, I can examine the mix of inputs caused by a change in the RPS policy. The results for the RPS are similar to that of a tax/subsidy approach, but the model of the firm accounts for the impact of ROR regulation. The results suggest that a RPS will have varying impacts that depend on ROR regulation. A national RPS will then have differing impacts on regulated and restructured states.

In regulated industries, policymakers are often cautious of firms attempting to implement new and expensive technologies, and have consumers bear the burden of the cost with uncertain improvements in output. For example, the cost of smart grid technologies in the electricity industry are often thought to be difficult to recover because their benefits to consumers are often unknown or unmeasurable. Additionally, solar technologies are often thought to be too expensive for consumers. The results of this study suggest that ROR

[2] According to the Energy Information Administration (EIA), in 2009 10% of the nation's electricity generated came from RE, including hydro.

regulation creates additional barriers to new technology adoption by incentivizing the firm to over-invest in cheaper, less risky technologies.

The paper proceeds with a discussion of the electricity industry in section 2. A theoretical model of firm behavior under the constraint of ROR regulation with two capital types is presented in section 3. Section 4 extends the model to include the RPS. Section 5 concludes with a discussion of policy implications.

2. Electricity Generation, Regulation, and Restructuring

The supply of electricity starts at a generating power plant. Generated electricity comes from coal, natural gas, water, wind, solar, and other energy sources, but the source of generation becomes indistinguishable once the electricity is placed on the transmission grid. A network grid of transmission substations, transmission lines, power substations, and transformers distributes power to consumers for final use (Warwick, 2002). Although electricity demand varies throughout the day or season, a minimum level is supplied through what is termed baseload generation, typically supplied by coal or nuclear power plants because of their ability to produce a constant level of energy. Variable sources, such as wind, geothermal and solar energy, supply power when the fuel sources provide enough energy to generate electricity. Natural gas, a more consistent source, typically fills peak-load demand, because starting up such a generator has a low fixed cost compared to coal or nuclear generators.

The supply of electricity from power plant to consumer is more complicated than a simple competitive firm model. Utility companies take part in generating, transmitting, or distributing electricity for sale to the consumers. Due to presumed economies of scale and scope or cost subadditivity, utility companies within a state or region are often granted monopoly power but are regulated by their prices and service conditions (Christensen and

Greene, 1976; Greer, 2008). A few states have restructured markets with competition among generating utilities, but a monopolist remains in the transmitting and distributing sector (Saplacan, 2008).

Due to the ability to generate electricity from different sources, the vertically integrated electric utility is faced with a decision to invest in different capital types. For example, coal-fired generation plants are reliable and well-known. On the other hand, wind turbines are more capital intensive per MW, require more land and labor, and provide intermittent output. As a consequence, wind energy, as well as most RE sources, provide uncertain revenue for developers, making it a riskier investment and difficult to acquire financing for new wind projects. Thus, RE sources typically have a higher cost of capital than non-RE sources.

In the next section, we examine how the ROR affects the firm's input decisions between these two capital types.

3. The utility company's decision under Rate-of-Return regulation

Consider the vertically integrated utility that is granted monopoly power. The utility's decision is to determine which sources of energy to use given historical trends in electricity demand and knowledge of electricity generation in that region. If the utility is a profit maximizer, then the firm's input decision can be modeled as:

$$\max_{k_r,k_n,l_r,l_n} \pi = p \cdot z - r_r \cdot k_r - r_n \cdot k_n - w \cdot (l_r + l_n) \tag{1}$$

subject to

$$\frac{p \cdot z - w \cdot (l_r + l_n)}{k_n + k_r} \leq s_k \tag{2}$$

$$\text{where} z \equiv z_r + z_n \tag{3}$$

$$z_r = z_r(k_r, l_r) \tag{4}$$

$$z_n = z_n(k_n, l_n) \tag{5}$$

where a utility's total output, z, comes from electricity generated by RE sources, z_r, or by non-RE sources, z_n. To produce electricity, the utility chooses a mix of the four inputs: labor and capital for RE sources, l_r and k_r, and labor and capital for non-RE sources, l_n and k_n. Each energy source requires some labor but also resource specific capital. For example, electricity generated from wind sources require wind turbines, but the capital for wind cannot be used to generate electricity from fossil fuels. Production of electricity requires both labor and capital, such that $z_r(k_r, 0) = z_r(0, l) = 0$ and $z_n(k_n, 0) = z_n(0, l) = 0$. The marginal products are positive, implying that an increase in an input increases output, $\frac{\partial z}{\partial k_n} > 0, \frac{\partial z}{\partial k_r} > 0, \frac{\partial z}{\partial l_n} > 0, \frac{\partial z}{\partial l_r} > 0$. Let r_r, r_n, and w represent the factor prices for RE capital, non-RE capital, and either type of labor. Finally, assume the utility is a monopoly that faces an inverse demand given by $p = p(z)$, where p is the price of electricity and z the amount of electricity generated (Averch and Johnson, 1962).

The ROR is calculated as a return percentage or the gross revenue net of labor cost over the rate base.[3] Equation (2) shows the ROR regulatory constraint, s_k, as a limit on the maximum allowed percentage return, set by the government's utility commission. If the ROR constraint is binding then, we expect a tighter constraint to decrease profit, and $\frac{\partial \pi *}{\partial s_k} > 0$ implies $\lambda_k > 0$. If the regulatory maximum is set too low, then the firm would be better off shutting down.[4] I examine the case where the constraint is set higher than the cost of at least one capital factor, $s_k > r_i$, and the firm is not at a corner solution, i.e., $k_n > 0, k_r > 0$, and $l_r > 0, l_n > 0$.

Assuming the constraint is binding, the first order conditions are

$$r_r = \frac{\partial z_r}{\partial k_r}\left(z\frac{\partial p}{\partial z} + p\right)[1-\lambda_k] + \lambda_k s_k \tag{6}$$

$$r_n = \frac{\partial z_n}{\partial k_n}\left(z\frac{\partial p}{\partial z} + p\right)[1-\lambda_k] + \lambda_k s_k \tag{7}$$

$$w = \frac{\partial z_r}{\partial l_r}\left(z\frac{\partial p}{\partial z} + p\right) \tag{8}$$

$$w = \frac{\partial z_n}{\partial l_n}\left(z\frac{\partial p}{\partial z} + p\right). \tag{9}$$

The results from equations (6) through (9) are similar to the Averch-Johnson model. Equation (6) discloses that the marginal cost of capital for RE sources, r_r, is greater than the marginal value product for RE capital, where $\left[p + z\frac{dp}{dz}\right]\frac{\partial z_r}{\partial k_r}$ is marginal revenue times the marginal product of k_r. Equation (7) shows a similar result for non-RE sources, and equation (8) and (9) shows that the result for marginal product of either labor type equals the wage

[3]The return is calculated as a percentage of the rate base, $c_1k_n + c_2k_r - U_1 - U_2$, where the acquisition cost of capital is c_i and cumulative depreciation is U_i. Similar to Averch and Johnson (1962) for simplification, I assume that depreciation is zero and that capital acquisition costs equal one so that the rate base equals the physical quantity of capital.

[4]The appendix includes a proof that the firm shuts down when $s_k < r_1$ and $s_k < r_2$.

rate.

Due to the added term, $\lambda_k s_k$, in equations (6) and (7), we begin to demonstrate the distortion caused by the ROR and it's impact on the marginal rate of substitution (MRS) between inputs. Using the first order conditions to obtain the marginal revenue (MR), $\left(p + z\frac{dp}{dz}\right)$, in (6) and substituting it into (7), we can determine the MRS between the two capital types. Similar methods can be used to determine the MRS between capital and labor. The equilibrium value of MRS between the factor inputs are:

$$MRS_{k_r,k_n} \equiv \frac{MP_{k_r}}{MP_{k_n}} = \frac{r_r - s_k\lambda_k}{r_n - s_k\lambda_k} \tag{10}$$

$$MRS_{l_r,l_n} \equiv \frac{MP_{l_r}}{MP_{l_n}} = 1 \tag{11}$$

$$MRS_{k_r,l_n} \equiv \frac{MP_{k_r}}{MP_{l_n}} = \frac{r_r - s_k\lambda_k}{w\left[1 - \lambda_k\right]} \tag{12}$$

$$MRS_{k_n,l_r} \equiv \frac{MP_{k_n}}{MP_{l_r}} = \frac{r_n - s_k\lambda_k}{w\left[1 - \lambda_k\right]} \tag{13}$$

$$MRS_{k_r,l_r} \equiv \frac{MP_{k_r}}{MP_{l_r}} = \frac{r_r - s_k\lambda_k}{w\left[1 - \lambda_k\right]} \tag{14}$$

$$MRS_{k_n,l_n} \equiv \frac{MP_{k_n}}{MP_{l_n}} = \frac{r_n - s_k\lambda_k}{w\left[1 - \lambda_k\right]}. \tag{15}$$

Examining equation (10) discloses that the MRS_{k_r,k_n} is greater than the case of the unregulated monopoly because of the additional $\lambda_k s_k$ term from ROR. The regulated firm must substitute toward the relatively cheaper type of capital in order to maximize profits.[5] If RE capital is more expensive than non-RE capital, $r_r > r_n$, then the unregulated firm's

[5] As shown by Averch and Johnson (1962), if s_k increases, the firm shifts from using labor to using more capital. This result holds for electricity produced from both RE and non-RE fuel sources, as shown by the MRS in equations (14) and (15), and for cross-source substitution in equations (12) and (13).

MRS is $\frac{r_r}{r_n} > 1$. Adding an ROR regulatory constraint decreases the top and bottom by the same amount, $s_k\lambda_k$. The regulated firm's MRS must be greater than the unregulated firm. For equation (10) to hold, the regulated firm must substitute away from k_r toward more k_n, increasing the equilibrium value of MRS.

Interestingly, as the regulatory allowed rate increases, i.e. s_k increases, then the constraint becomes less binding, and RE capital becomes more expensive relative to non-RE capital. Thus, even an increase in the allowed ROR decreases the incentive to invest in the riskier, more expensive RE capital.

The result implies that relative prices matter. By including the same allowed ROR for different types of capital, regulators act as if they implement the same subsidy level on both capital types. If non-RE is cheaper, then firms have an increased incentive to invest in non-RE capital relative to having no ROR regulation. Furthermore, if restructuring decreases or removes ROR regulation, then the investment in RE capital relative to non-RE capital will increase, *ceteris paribus.*

However, other policies that are meant to encourage the use of RE sources may impact the firm's input decision. In the next section, we examined the case of the renewable portfolio standard by adding that constraint to the ROR regulated firm.

4. The utility company's decision under an RPS and ROR regulation

The renewable portfolio standard (RPS) is a proportional constraint on the generation of electricity. The utility is required to generated X% of electricity from renewable sources, which impacts the utility's decision to generate electricity from both capital types. The firm's decision becomes

$$\max_{k_r,k_n,l_r,l_n} \pi = p \cdot z - r_r \cdot k_r - r_n \cdot k_n - w \cdot (l_r + l_n) \tag{1}$$

subject to

$$\frac{p \cdot z - w \cdot (l_r + l_n)}{k_n + k_r} \le s_k \tag{2.a}$$

$$s_g z_n \le z_r \tag{2.b}$$

$$\text{where} z \equiv z_r + z_n \tag{3}$$

$$z_r = z_r (k_r, l_r) \tag{4}$$

$$z_n = z_n (k_n, l_n). \tag{5}$$

The RPS constrains the decision of the firm by requiring that the ratio of RE to non-RE generation be equal to or greater than a specified amount, s_g, as shown by equation (2.b). The two policy constraints in equations (2.a) and (2.b) are assumed to hold with equality.

The first order conditions for profit maximization are

$$r_r = \frac{\partial z_r}{\partial k_r}\left(z\frac{\partial p}{\partial z} + p\right)[1 - \lambda_k] + \lambda_g \frac{\partial z_r}{\partial k_r} + \lambda_k s_k \tag{6'}$$

$$r_n = \frac{\partial z_n}{\partial k_n}\left(z\frac{\partial p}{\partial z} + p\right)[1 - \lambda_k] - s_r \lambda_g \frac{\partial z_n}{\partial k_n} + \lambda_k s_k \tag{7'}$$

$$w[1 - \lambda_k] = \frac{\partial z_r}{\partial l_r}\left(z\frac{\partial p}{\partial z} + p\right)[1 - \lambda_k] + \lambda_g \frac{\partial z_r}{\partial l_r} \tag{8'}$$

$$w[1 - \lambda_k] = \frac{\partial z_n}{\partial l_n}\left(z\frac{\partial p}{\partial z} + p\right)[1 - \lambda_k] - s_r \lambda_g \frac{\partial z_n}{\partial l_n} \tag{9'}$$

where λ_g is the change in profits from implementing the RPS. Equations (6') through (9') show that at the optimal choice of inputs, the price of an input equals the marginal revenue of product of that input.

As before, the marginal revenue in equation (6') is substituted into equation (7') to determine the MRS between the two types of capital. Similar methods are used to determine the MRS between capital and labor. The equilibrium value of MRS between the factor inputs are:

$$MRS_{k_r,k_n} \equiv \frac{MP_{k_r}}{MP_{k_n}} = \frac{r_r - \lambda_g \frac{\partial z_r}{\partial k_r} - s_k \lambda_k}{r_n + s_g \lambda_g \frac{\partial z_n}{\partial k_n} - s_k \lambda_k} \tag{10'}$$

$$MRS_{l_r,l_n} \equiv \frac{MP_{l_r}}{MP_{l_n}} = \frac{w\left[1-\lambda_k\right] - \lambda_g \left(\frac{\partial z_r}{\partial l_r}\right)}{w\left[1-\lambda_k\right] + s_g \lambda_g \left(\frac{\partial z_n}{\partial l_n}\right)} \tag{11'}$$

$$MRS_{k_r,l_n} \equiv \frac{MP_{k_r}}{MP_{l_n}} = \frac{r_r - \lambda_g \frac{\partial z_r}{\partial k_r} - s_k \lambda_k}{w\left[1-\lambda_k\right] + s_g \lambda_g \left(\frac{\partial z_n}{\partial l_n}\right)} \tag{12'}$$

$$MRS_{k_n,l_r} \equiv \frac{MP_{k_n}}{MP_{l_r}} = \frac{r_n + s_g \lambda_g \frac{\partial z_n}{\partial k_n} - s_k \lambda_k}{w\left[1-\lambda_k\right] - \lambda_g \left(\frac{\partial z_r}{\partial l_r}\right)} \tag{13'}$$

$$MRS_{k_r,l_r} \equiv \frac{MP_{k_r}}{MP_{l_r}} = \frac{r_r - \lambda_g \frac{\partial z_r}{\partial k_r} - s_k \lambda_k}{w\left[1-\lambda_k\right] - \lambda_g \left(\frac{\partial z_r}{\partial l_r}\right)} \tag{14'}$$

$$MRS_{k_n,l_n} \equiv \frac{MP_{k_n}}{MP_{l_n}} = \frac{r_n + s_g \lambda_g \frac{\partial z_n}{\partial k_n} - s_k \lambda_k}{w\left[1-\lambda_k\right] + s_g \lambda_g \left(\frac{\partial z_n}{\partial l_n}\right)}. \tag{15'}$$

By implementing a binding RPS, the MRS_{k_r,k_n} gains the terms λ_g and s_g, implying a decrease in the MRS_{k_r,k_n}, as shown by equation (10').[6] The regulator increases the RPS by increasing s_g. As the constraint becomes more restrictive, the relative price of non-RE capital increases, and the utility shifts away from using non-RE capital, k_n, toward more

[6] We expect the RPS to decrease profit, and from the envelope theorem, $\frac{\partial \pi *}{\partial s_g} = -\lambda_g^* z_n^*$. If $\frac{\partial \pi *}{\partial s_g} < 0$, then $\lambda_g > 0$.

RE capital, k_r. Similar to implementing a subsidy and a tax, the equilibrium value of the MRS_{k_r,k_n} decreases (Fischer, 2006). Thus, the higher the RPS, the greater the relative use of RE sources to non-RE sources.[7]

The model can be adjusted to examine regions that have restructured their electricity market from a monopolist to a more competitive market structure among generators. Restructuring allows the incumbent utility to retain operation of transmission and distribution facilities, but generating firms can sell electricity wholesale to the distributing utility through a power exchange that simulates a competitive market.[8] Consumers have a choice of determining their electricity generator, but distribution continues from the incumbent utility (Warwick, 2002).[9] This model can be applied to the distributing utility, still a monopolist, who must purchase inputs at a specified ratio, i.e. wholesale electricity from generating companies that produce electricity from RE sources and non-RE sources.

To illustrate the impact of the RPS on the restructured utility's decision consider figure 1. On the vertical and horizontal axes are generation from non-RE sources and RE sources. Let z_0 and z_1 represent the isoquants of electricity production, and consider the firm's cost minimization problem. To generate a level of electricity of z_1 with no RPS, the firm chooses an optimal level of inputs based on (z^*_{nA}, z^*_{rA}) at point A. A binding RPS increases the ratio

[7]The RPS constraint has a similar affect on the MRS between RE and non-RE labor. With a higher RPS the utility shifts away from using labor for non-RE toward more RE sources as shown by equation (11). Equations (12) and (13) show the cross-source substitution between capital and labor. For these MRSs, the $s_g\lambda_g$ is added to the non-RE input and λ_g is subtracted to the RE input. The firm always substitutes away from the non-RE input toward the RE input. Equation (14) presents the MRS between labor and capital for RE sources, and equation (15) presents the same MRS for non-RE sources. For both MRSs, an increase in s_g has an indeterminable affect on the MRS. The MRS between labor and capital depends on the factor prices and the marginal product of both inputs.

[8]A power exchange determines which plants operate by conducting bid-offer auctions, and allows all participants to observe the market price.

[9]Typically, the residential and commercial sector of consumers choose to remain with the incumbent utility for their generation, and the incumbent utility must follow the RPS guidelines when selling electricity.

of RE to non-RE fuels sources, $\frac{z_r}{z_n}$, to a level along the RPS line between the points B and C. To remain at the same output level, z_1, the firm must increase total cost. Alternatively, the firm could decrease output to as low as z_0 to maintain the same total cost.

For the distributing utility operating as a monopolist in a restructured state, the results for the RPS constraint are still to increase the ratio of RE to non-RE generation. However, the distributing utility does not own generating capital assets, and thus are not ROR regulated on generating capital investments. The capital rate base is smaller and the firm's input decision is less distorted by ROR.

For the vertically integrated and regulated firm, equation (10') shows that ROR regulation can impact the decision to invest in RE capital or non-RE capital. Thus, the impact of an RPS depends largely on the restructuring status of a state.

5. Results and Discussion

ROR regulation increases the incentive of the firm to overinvest in capital relative to labor. However, in the electricity industry, different types of capital are used to generated electricity, some less risky and cheaper than others. We have modeled the trade-off between two capital types from renewable and non-renewable energy sources. The results show that ROR distorts the investment decision of the firm in RE capital.

The model can also account for the impact of an RPS, which has had varying impacts on the market for electricity (Bernow, Dougherty, and Duckworth, 1997; Carley, 2009; Fischer, 2006; Palmer and Burtraw, 2005). This paper contributes to research on RPSs by presenting an alternative method for analyzing the RPS as a proportional constraint faced by the firm to generate electricity from renewable and non-renewable sources. I examine the impact of the RPS on the firm's input decision between potential energy sources, accounting for ROR regulation.

Three main implications are considered. First, ROR regulation distorts the firm's input decision and creates an incentive to invest more in capital relative to an unregulated market. Specifically, the regulated firm invests relatively more in cheaper, nonrenewable capital and less in expensive, renewable capital than the unregulated firm. The risky and uncertain nature of RE technologies creates several barriers to its development. Regulators are often cautious to approve technology updates that have uncertain output or quality at a high cost to consumers, and firms are less likely to adopt the new expensive technologies because the ROR increases their relative cost.

Second, restructuring electricity markets removes the ROR on capital assets used for the generation of electricity. Typically, the distributing utility is not allowed to own capital for the purposes of generation, and instead must purchase generation from a competitive wholesale electricity market. With no ROR regulation on generating capital, the restructured market produces more electricity from RE sources and less non-RE generation, compared to a vertically integrated market structure with ROR on all capital, *ceteris paribus*. Restructuring that removes the allowed ROR on capital assets can also promote growth in RE capital investments.

Finally, the RPS constraint affects the decision of the firm by requiring generation at a proportional amount of RE and non-RE generation. If the RPS is binding, *ceteris paribus*, the policy decreases the firm's MRS between renewable and nonrenewable sources, increasing the relative use of RE technologies. However, the impact of the RPS depends largely on the ROR constraint. For the regulated firm, the ROR has an opposite effect on the use of RE capital assets, by causing over-investment in non-RE capital. Thus, the same RPS will cause a greater increase in the MRS for a regulated firm than an unregulated or restructured utility.

Policymakers should be cautious when implementing a national RPS. Such a federal standard will reach across various market structures and regulation types. A national RPS will create more market distortions for generation across regulated and restructured states. Such distortions on the market equilibrium are left for future research.

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Appendix - Proof of Firm Shut Down Point

If $s_k < r_n$ and r_r, then the actual cost of capital is greater than allowable rate-of-return. If this holds then the firm will shut down. To see this examine profit

$$\begin{aligned} \pi &= p \cdot z - r_n k_n - r_r k_r - (l_n + l_r) \cdot w \\ &= p \cdot z - s_k k_n + (s_k - r_n) k_n - s_k k_r + (s_k - r_r) k_r - (l_n + l_r) \cdot w \end{aligned} \tag{1}$$

Given the rate-of-return constraint (2.b) and if $s_k < r_n$ and r_r, equation (1) must be less than zero.

$$p \cdot z - s_k k_n + (s_k - r_r) k_n - s_k k_r + (s_k - r_n) k_r - (l_n + l_r) \cdot w \leq 0$$

If $s_k < r_n$ and r_r, then the firm would maximize profit where $k_n = 0$ and $k_r = 0$. This level of input produces no electricity, so the firm shuts down.

Figure 1: Flexible Inputs for Electricity Generation with RPS Constraint