

When Does Cap-and-Trade Increase Regulated Firms' Profits?

PRELIMINARY AND INCOMPLETE: PLEASE DO NOT CITE

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Many recent studies have concluded that cap-and-trade programs for greenhouse gases with free allocation of permits would increase regulated firms' profits, particularly for the electric power sector. It is likely that future greenhouse gas programs would cause reductions in abatement costs and the costs of generating electricity from low-emissions sources, such as wind power. Past research has not considered the effects of endogenous cost reductions on profits in detail, however. This paper investigates these effects and calculates the share of permits that would need to be auctioned to keep profits constant. A simple analytical model illustrates that technological change or subsidies to abatement equipment or renewables would likely decrease the profits of regulated firms. The simulation results of a detailed partial equilibrium model of the electric power sector confirm these conclusions and suggest that cost reductions are likely to significantly decrease profits.

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JEL codes: Q58, Q40, Q52

1 Introduction

As the policy debate over reducing greenhouse gas emissions has intensified, particular attention has been devoted to the effect of regulation on incumbent firms' profits. Numerous modeling studies predict that a carbon dioxide cap-and-trade program in the U.S. with 100% free allocation of permits would increase the profits of regulated firms, particularly those in the electric power sector (e.g., Goulder and Bovenberg, 2001 and Burtraw *et al.*, 2002). Evidence from the European Union's Emissions Trading System (EU ETS) for carbon dioxide (CO₂) appears to show that profits of electric power producers have increased (Sijm *et al.*, 2006). The seemingly counter-intuitive result arises from the fact that a large share of the emissions reduction would be due to a reduction in output. Because output demand is price-inelastic, the increase in revenue more than offsets the increase in costs.

Policy makers have responded to the modeling results by proposing to auction a share of the permits to ensure that regulated firms' profits do not increase. For example, the European Parliament approved a post-2012 EU ETS with auctioned permits (100% in the electric power sector) in order to prevent the average profits of regulated firms from increasing.¹

The modeling studies cited above are essentially static in nature, however. In particular, they do not consider the effect of cap-and-trade programs on costs, which in turn affect incumbents' profits. For two reasons, it is highly likely that cap-and-trade programs for greenhouse gases cause reductions in abatement costs and in the cost producing electricity from sources with low emission rates, such as renewables. First, there is considerable evidence that cap-and-trade programs cause innovation and technology adoption (e.g., Popp, 2002, Bellas and Lange, 2005 and Linn, 2008). Regulation-induced innovation and technology adoption could reduce the cost of abatement technologies, such as carbon capture and storage (CCS), and the cost of renewable energy sources, such as wind and solar. Second, in recent CO₂ cap-and-trade programs and

¹ The auction revenue represents a transfer from the regulated firms to the government, provided that the auction revenues are not refunded to the affected firms. The regulator can control total emissions by setting the cap, and can influence the effect of the regulation on profits through the fraction of permits it provides freely.

proposals for future programs, a share of the auction revenue is used to subsidize abatement technology and renewables. Similarly to regulation-induced technological change, these subsidies would reduce abatement costs and the cost of producing electricity from renewable sources. Understanding the effect of cap-and-trade on profits therefore requires a more flexible approach that accounts for endogenous changes in costs.

This paper provides a framework for understanding how cap-and-trade programs affect profits in a dynamic setting. We first use a simple analytical model in which firms can reduce total emissions under a cap-and-trade program by reducing output or by using direct abatement technology to reduce the average rate of emissions per unit of output. (Direct abatement technologies include those controls that can be retrofit to an existing facility or added to a new facility to reduce the emission rate.) The more firms reduce output, the greater the increase in profits. Alternatively, considering an increase in regulatory stringency – a decrease in the cap – the greater is the magnitude of the (negative) elasticity of total output to emissions, the greater is the increase in profits. Several numerical examples illustrate the main intuition and provide insight into the likely effect of endogenous decreases in costs on profits. The main predictions are, first, that a decrease in the cost of direct abatement technologies, either because of regulation-induced technological change or subsidy, may reduce profits if firms are less likely to reduce output. Second, decreases in the cost of low-emission generation sources are also likely to reduce profits because they decrease the elasticity of total output to emissions.

These predictions are confirmed by simulations of a detailed market model of the U.S. electricity sector. The baseline simulation reproduces the findings of the previous literature that a carbon dioxide cap-and-trade program increases profits. However, we also find that profits are increasing in the elasticity of output to emissions. Moreover, the effect of abatement costs and the costs of renewables on profits is quantitatively large, implying that endogenous cost reductions are likely to have a significant effect on profits. The paper concludes by discussing the implications of these results for auction design. In particular, using auction revenue to subsidize new abatement technology or renewables substantially reduces the profits of existing generating units.

2 Background

This section briefly summarizes firms' compliance behavior in cap-and-trade programs, which is modeled more formally below, and summarizes the recent literature. The imposition of a cap-and-trade program leaves firms in the regulated industry with essentially two compliance options: reduce output or reduce the rate of emissions per unit of output. The emissions rate can be reduced by switching to a cleaner fuel, such as substituting natural gas for coal, or by installing abatement equipment, such as carbon capture and storage (CCS). Regulated firms in a competitive market choose the profit-maximizing compliance behavior, based on the output price and permit price; the output price represents the cost of reducing output and the permit price represents the benefit of reducing output as well as the benefit of reducing the emission rate. If firms primarily respond to the regulation by reducing output and the demand curve for output is relatively inelastic (as in the case of electricity), then the regulation causes profits to increase. In this case the the limit on emissions acts as a limit on output and firms behave similarly to a cooperative oligopoly in which firms restrict output to increase profits (Mansur, 2007).

The other option is to reduce the rate of emissions per unit of output, either by installing abatement equipment or by switching to fuels with low emission rates. In this paper, direct abatement refers to a reduction in the emission rate obtained by installing capital equipment such as CCS. Fuel switching under a cap-and-trade program is more costly when the price of permits is arbitrated into the price of the cleaner fuels (Keohane and Busse, 2007). If firms comply entirely by reducing their emissions per unit of output, profits must decrease because production costs increase and there is no effect on the output market. Therefore, whether firms abate by reducing output or reducing the emission rate influences the effect of a cap-and-trade program on profits.

The incentive for firms to choose a decrease in output versus a decrease in the emissions rate depends crucially on the availability of low-cost direct abatement technology and low-emissions generating entrants. These two factors essentially decrease the elasticity of abatement costs with respect to (w.r.t) output. If the elasticity is high, this can be interpreted as a case where emissions and output can be unattached and the cap-and-trade program will no longer act as an

output constraint. If the elasticity is low, emissions and output are attached and the cap-and-trade program will act as an output constraint allowing firms to reduce production, increase prices and profits.

Many potential greenhouse gas policies include substantial auctioning of permits with plans to use the auction revenue to subsidize direct abatement technology (e.g., CCS) and low-emissions generating entrants (e.g., renewables).² The post-2012 EU ETS calls for full auctioning in the electricity sector in 2012 and full auctioning in other sectors by 2020. The auction revenues will be used to fund CCS demonstration projects and renewable technologies. Every recent greenhouse gas legislative proposal in the 110th US Congress called for some auctioning of emissions allowances, while a share of allowances is provided to incumbent emitters in part to keep their profits “whole” in the face of the cap. For example, the Lieberman-Warner Climate Security Act specifies that 21% of permits be auctioned in 2012, increasing to 69% in 2031 and staying at 69% until 2050. Approximately 13% and 18% of auction proceeds would be used to subsidize renewable energy (Title IV-Subtitle D-Section 4406) and research into sequestration technology (Title IV-Subtitle D-Section 4403), respectively. The Regional Greenhouse Gas Initiative, a cap-and-trade program in the Northeast, requires that 25% of permits be auctioned and the proceeds used to fund investment in energy efficiency or low-emissions generation. The states can decide how to allocate the remaining 75%, although most states have announced they will auction off a large percentage of their permits.

Maloney and McCormick (1982) first explore the possibility that environmental regulations may cause firms to reduce production, which would increase the output price and perhaps profits. They note the importance of free allocation and entry costs in determining the effect of regulation on profits.

Dinan (2003) provides a broad overview of the literature related to firm and consumer compensation with the imposition of a cap-and-trade regulation. Goulder and Bovenberg (2001) use a general equilibrium model of the U.S. to determine the percentage of allowances that

² Other compelling reasons for auctioning abound. For a survey of these arguments, see Burtraw and Evans (2008).

should be grandfathered (i.e., allocated freely to existing units) to hold profits constant under an economy-wide cap-and-trade program for carbon dioxide (CO₂). They conclude that for many sectors, especially electricity and fossil fuel, full grandfathering would increase profits, so that less than 100 percent of the permits should be grandfathered to leave profits unaffected.

Cameron *et al.* (2006) uses a Cournot model to determine the percentage of grandfathered permits needed to hold industry profits constant under a CO₂ program. Using UK and European industry data for electricity, cement, steel, and newspaper generation, they find that these industries require no more than 65% of permits to be grandfathered to ensure that the industries' profits are constant; the electricity industry requires no more than 6%. Burtraw and Palmer (2007) use a detailed partial equilibrium model of the US electricity sector to compare alternative allocation methods.³ Results show that grandfathering permits to electricity generators leaves virtually all of them better off and the largest firms substantially better off.

The conclusion that the imposition of a cap-and-trade program may lead to increased profits is not limited to carbon dioxide. Burtraw and Palmer (2003, 2004) show that grandfathering allowances under cap-and-trade programs for sulfur dioxide, nitrogen oxides and mercury would also lead to an increase in total profits for the electricity sector. Parry (2004) addresses a similar question from a different perspective, focusing on the effect of cap-and-trade programs on household wealth. For small reductions in emissions, households in the top wealth quintile, who are most likely to own shares of firms affected by the regulation, are made better off with the introduction of emissions caps on sulfur dioxide, nitrogen oxides and carbon dioxide when allowances are fully grandfathered. Parry (2004) uses an aggregated partial equilibrium model of the US electricity sector with a linear marginal abatement cost function and argues that a convex function would exacerbate the regressivity of permits. Mansur (2007) uses the imposition of a

³ Burtraw and Palmer (2007) and Burtraw *et al.* (2002) are part of a series of studies that look at the effect of different allocation schemes for cap-and-trade programs in the electricity sector on producer and consumer surplus using the model used in this paper. Generally they find that firms prefer grandfathering, followed by auctioning of allowances and finally allocating allowances based on recent production levels (output-based updating) regardless of the pollutant being regulated. Furthermore, all of the allocation methods yield to higher total profits for all firms in the industry (although some are certainly worse off). In part this is due to the nature in which electricity is priced, as described below.

tradable permit scheme for nitrogen oxides (NO_x SIP Call) to show that firms reduced output more than in a competitive market in an effort to raise prices. Fischer (2003) argues for the use of an output-based allocation of permits in order to offset the potential output reduction discussed above.

While many models of the effect of potential greenhouse gas legislation on firms' profits find they will be overcompensated, other modeling (Farrell *et al.*, 1999) and empirical (Linn, 2006) studies of cap-and-trade programs for conventional pollutants have found that these programs reduce profits of affected firms. Farrell *et al.* (1999) uses a detailed partial equilibrium model of the US electricity sector to investigate the effect of a cap-and-trade program for nitrogen oxides. Linn (2006) finds that the stock prices of regulated firms decreased in anticipation of a regional cap-and-trade program for nitrogen oxides.

3 The Relationship Between Profits, Abatement Costs, Entry Costs and Baseline Emissions

3.1 Increasing Profits with a Cap-and-Trade Program

We begin by demonstrating the possibility that profits can increase with the imposition of a cap-and-trade program. The analysis focuses on a representative firm. Let q be the total production/consumption of the output in the market subject to the cap and trade regulation. Uncontrolled emissions equal qz , where z is the uncontrolled emissions per unit of q (i.e., the emissions intensity of q), while actual emissions are represented by e . Abatement is then $a \equiv qz - e$. The abatement technology is represented by the cost function: $f(qz - e)$, where $f'(qz - e) \geq 0$ and $f''(qz - e) \geq 0$. Marginal-willingness to pay for output is represented by $P(q)$ while the cost of producing q net of emissions control costs is $C(q)$ and these functions are assumed to have the usual shape ($P'(q) \leq 0$, $C'(q) \geq 0$ and, $C''(q) \geq 0$).

Each firm in this market is subject to an emissions cap represented by A , so that compliance requires that $A \geq e$. We assume that the regulated firms do not have market power, and therefore take the output price, P , as given. The profit maximization for the firm is (accounting for variables under its control):

$$(1) \quad \begin{aligned} \max \quad & \pi \equiv Pq - C(q) - f(zq - e) \\ \text{s.t.} \quad & A \geq e \end{aligned}$$

The first order conditions of this problem (assuming the allowance constraint binds) are:

$$P - C'(q) - zf'(zq - e) = 0$$

$$f'(zq - e) - \lambda = 0$$

$$A - e = 0$$

where λ is the shadow value on the emission constraint and is therefore the permit price.

The effect on profits of tightening the cap (i.e. reducing A ,) depends on how A affects production, emissions and the allowance price. After substituting $P = P(q)$ in the first order conditions, it can be shown that:

$$\frac{dq}{dA} = \frac{zf''(qz - e)}{SOC} \geq 0$$

$$\frac{de}{dA} = 1$$

$$\frac{d\lambda}{dA} = \frac{[P'(q) - C''(q)]f''(qz - e)}{SOC} \leq 0$$

where $SOC = -P'(q) + C''(q) + z^2 f''(qz - e) \geq 0$. The first equation shows that the production of q increases as the cap is loosened. Critical to the hypothesis being explored here, the increase in production from an increase in the cap is larger if the rate of increase in the cost of directly controlling emissions rises (i.e., notionally $dq^2/dA df''(\cdot) \geq 0$). Production is more responsive to the level of allowable emissions if direct emissions control is more expensive. Therefore, we see that the reduction in production is greater if A decreases and direct abatement is increasingly

costly. The second and third equations show that, unsurprisingly, emissions rise in proportion to A , and the allowance price falls with A .

Total profits to the industry can be expressed as:

$$(2) \quad \Pi \equiv P(q)q - C(q) - f(zq - e) - \lambda(1-s)A$$

The expression $\lambda(1-s)A$ represents the value of the allowance rent that the government retains where the share of grandfathered allowances to emitters is s . The expression can be thought of as the total payment paid by the industry to purchase the share of the allowances that is auctioned.⁴ This term was not included in the exercise above because we assume that firms take the allowance price as given (also note that if $s=1$ the regulated firms capture the entire scarcity rent of the cap). Therefore, profits equal industry revenues minus production, abatement costs, and the share of the scarcity rent from the allowances no longer allocated to industry.

Taking the total derivative of (2) with respect to the cap, we can demonstrate the ambiguity of industry profits to a decline in the cap. Applying the profit maximization relationship that price equals marginal production cost, and that the cap binds such that the change in allocation equals the change in the cap, we obtain:

$$(3) \quad -\frac{d\Pi}{dA} \equiv -\underbrace{[P'(q)q]}_{(+)} \underbrace{\frac{dq}{dA}}_{(-)} - s \underbrace{\lambda \frac{de}{dA}}_{(-)} + \underbrace{A(1-s)}_{(-)} \frac{d\lambda}{dA}$$

The first term of this expression shows that profits increase from reducing the cap due to the contraction of production that in turn raises inframarginal revenues.⁵ The more responsive

⁴ We are assuming that the method of auctioning allowances yields an allowance price that equals the shadow value of the allowance constraint.

⁵ This expression would not be present in the case of regulating a monopolist. This is because the monopolist is already accounting for the inframarginal change in revenues as supply is contracted. If the supply side of the market were characterized by monopoly pricing, then the amount of compensation required to keep profits neutral will be higher than if the market is characterized by marginal cost pricing.

demand is to a change in production (i.e, the bigger the absolute value of $P'(q)$), the greater is this first term. The second term captures the decrease in the value of the allowances allocated to firms as a result of the cap being smaller. Of course, as the cap falls, the allowance price will also rise, and these additional allowances must be purchased from the government. This effect is represented by the last term in (3). If all allowances were allocated freely ($s=1$), then the entire expression would simply equal the change in inframarginal revenues from tightening the cap minus the marginal cost of the direct control technology.⁶ If $s=1$, it is straightforward to show that if the marginal cost of the direct control technology is increasing rapidly ($f''(\cdot)$ is large), then firms are made better off by tightening the cap.

Note that partial equilibrium electricity sector models of cap-and-trade programs often ignore the potential for a production response by looking solely at the direct abatement costs of the firm. In these cases the first term in (3) is ignored and it may be incorrectly concluded that the policy makes firms worse off.

3.2 Extending the Model to Multiple Producer Types

The preceding analysis provides important intuition, and this section extends the analysis to include two important features of electricity markets: heterogeneous producers with different uncontrolled emission rates. It is assumed that there is marginal cost pricing and particular functional forms are chosen for electricity demand, generation costs, and the direct abatement cost function. There are two types of electric generating units, which have different fixed and marginal costs, where all fixed costs are assumed to be entirely sunk. Base load units, denoted with the subscript b , have relatively high fixed costs, and low marginal generating costs, equal to mc_b . Peaking units have lower fixed costs but higher marginal costs of $mc_p > mc_b$. Each base load unit has a maximum generating capacity of \bar{q}_b and each peaking unit has a maximum generating capacity of \bar{q}_p . There are n_b and n_p base load and peaking units in the market,

⁶ Note that the change in profits from lowering the allocation is not linear in s . As s increases the previously grandfathered allowances have a bigger influence on the change in the value of those allowances. However, the effect of the higher allowance price on the share that must be purchased from the government declines.

meaning that they have all paid their sunk costs. The electricity market is competitive, and each unit operates at full capacity as long as the price exceeds its marginal operating costs.⁷ The demand curve for electricity has a constant elasticity of substitution (CES), and is given by:

$$P = \gamma(n_b q_b + n_p q_p)^{1/\delta},$$

where γ and δ are constants and q_b and q_p equal the output of each base load and peaking unit; δ is the own-price elasticity of demand.

Figure 1 illustrates the market equilibrium. The supply curve is horizontal at mc_b until all base load units are operating at full capacity, at which point the supply curve is horizontal at mc_p . The supply curve is vertical when peaking units are also operating at full capacity. The figure shows the long run equilibrium, where all units earn zero profits. Price exceeds marginal costs for all units, and operating revenue exactly covers fixed costs (recall that the base load units have higher fixed costs).

Starting from long run equilibrium, the government unexpectedly announces that there will be a cap-and-trade program for carbon dioxide emissions. The cap is set at C and permits are grandfathered. Peaking units have zero emissions, while base load units have uncontrolled emission rates of $z > 0$. However, base load units may reduce their emissions according to the function:

$$x = f(qz - e) = \alpha(qz - e)^\beta,$$

where α and β are positive constants, with $\beta > 1$. The variable x equals abatement expenditure and e is the unit's emissions. The abatement cost function has positive and increasing marginal

⁷ In this model, high and low cost units operate in a competitive market and we abstract from time-varying electricity demand.

abatement costs, and the elasticity of emissions with respect to abatement expenditure is constant.

Base load units are price-takers in both the electricity and permit markets. They choose the profit-maximizing level of output and abatement expenditure. Under the cap-and-trade program, they must hold enough permits to cover their emissions. Their optimization problem is given by:

$$\begin{aligned} \max_{q_b, x_b} & q_b(p - mc_b) - f(qz - e) - \pi(zq_b - (x/\alpha)^{1/\beta} - a_b) \\ \text{s.t.} & q_b \leq \bar{q}_b, \end{aligned}$$

where π is the equilibrium permit price and a_b is the number of permits allocated to the unit. The first order condition for output is:

$$p - mc_b - \pi z - \mu = 0,$$

where μ is the multiplier on the production constraint. The marginal operating cost of the base load unit now includes the marginal cost of generating electricity, plus the product of the permit price and the uncontrolled emission rate. The first order condition illustrates a central result: as long as the permit price is sufficiently low, the constraint binds and base load generating units operate at full capacity. However, high permit prices may cause the base load units to reduce their output below full capacity.

The optimization problem of a peaking unit is similar, except for the fact that peaking units have zero emissions and therefore do not choose abatement.

$$\begin{aligned} \max_{q_p} & q_p(p - mc_p) + a_p \pi \\ \text{s.t.} & q_p \leq \bar{q}_p \end{aligned}$$

Because peaking units have zero emissions, the permit price does not appear in their first order condition. As a result, peaking units always operate at full capacity.⁸ The equilibrium electricity and permit prices, as well as the effect of the cap on profits, depend on the cap and other parameter values. The following subsections investigate the effect on generating units' profits of the cap and the elasticity of abatement costs.

3.2.1 Effect of the cap on profits

Figures 2a and 2b show how the equilibrium varies with the emissions cap, A , for particular parameter values. In both figures, the horizontal axis shows the required abatement under the cap, which is equal to the difference between unregulated emissions and A . The figures show as functions of total abatement the equilibrium output and abatement expenditure of base load units; and the permit price, electricity price and total industry output. The figures correspond to the short run equilibrium, in which entry of new generating units is not possible.⁹

Figure 2a shows that as total abatement increases from zero, abatement expenditure and the permit price increase. However, the permit price never becomes sufficiently high that base load units reduce output (base load generating capacity is set equal to 4 in these simulations). Figure 2b shows that as total abatement increases, industry profits decrease. The reason is that under this set of parameter values, increasing total abatement (i.e., decreasing A) does not affect the electricity market, as all generating units continue to operate at full capacity; as the figure shows, the price of electricity does not change with the cap. As total abatement increases, however, base load units must increase their abatement expenditure to reduce emissions sufficiently to meet the cap, which reduces profits. Note that although permits are allocated freely to generating units, total profits are lower than if there were no cap. We next show that this result arises because

⁸ The assumption that peaking units have zero emissions is for simplicity, however, and does not affect the main results.

⁹ Focusing on the short run simplifies the exposition, but allowing for long run entry would not significantly affect the main conclusions.

regulation does not affect the equilibrium level of electricity production. That is, profits decrease when output and emissions are uncorrelated in equilibrium.

3.2.2 *Effect of the abatement function on profits*

We now demonstrate one of the main results of this section: as abatement becomes more costly, profits may increase. Subsequently, we will interpret this result in the context of recent policy proposals to support innovation in abatement technologies, which would reduce their costs. For the simulations, total abatement is fixed at 50. The value of β varies from 1 (the value used in Figure 2) up to 5. Figures 3a and 3b plot as functions of β the equilibrium output and abatement expenditure of base load units; and the permit price, electricity price and total industry output. An increase in β represents an increase in the elasticity of abatement costs w.r.t output. That is, higher values of β reflect more costly abatement.

For low and moderate values of β , increasing the elasticity of abatement costs operates similarly to an increase in total abatement, which was shown in Figure 2. When the elasticity increases, for a given A , abatement expenditure increases and the permit price increases. Electricity production is not affected, and profits decrease.

A striking change occurs when β is greater than about 3: an increase in β causes industry profits to increase, even though abatement is more expensive. The first order condition for base load output provides the intuition. For low values of β , the permit price is low and the output price exceeds the marginal operating cost for base load units, which therefore operate at full capacity. As β increases, however, the permit price increases as well, and at some point the price of electricity no longer exceeds marginal operating costs. Therefore, base load plants reduce output, which causes the electricity price to rise. There are therefore two effects of increasing β , while holding A constant. The first is that abatement costs increase, which reduces profits. On the other hand, electricity production also decreases, which increases profits because electricity demand is price-inelastic. Under the particular parameter values chosen for these simulations, the second

effect is greater in magnitude, and an increase in β leads to higher profits when β is sufficiently large. Note that when β exceeds 3, total industry profits are greater than when there is no cap on emissions; this case is commonly referred to as overcompensation.

In the extreme case where base load units cannot reduce their emissions rates at all, which is roughly the case for carbon dioxide regulation, all abatement occurs via curtailing base load generation. That is, all abatement occurs via fuel switching, in which the share of generation of high-marginal cost peaking units increases at the expense of base load units. In this case, even a very large A could significantly increase firms' profits. On the other hand, when abatement is relatively inexpensive, as with nitrogen oxides or sulfur dioxide, there is likely to be a much smaller effect on electricity production, and a small or moderate cap may decrease profits.

3.2.3 *Entry of Zero Emission Rate Generating Units*

We now discuss the effect of the entry of generating units with zero emission rates, such as wind or solar, which will be referred to as renewable generating units. It is assumed that the renewable technology has fixed costs of F_r , zero marginal costs and a maximum generating capacity of \bar{q}_r ; renewable generators enter as long as the output price exceeds F_r / \bar{q}_r . There is an unlimited number of renewable generating units that could potentially enter the market. Therefore, once the cap-and-trade program is implemented, renewable generators will enter the market until the output price equals F_r / \bar{q}_r . That is, the renewable technology amounts to a cap on the price of electricity.

In practice, F_r might decrease because of technological change or because of government subsidies (e.g., an investment tax credit). The first case to consider is the one in which the capacity constraint does not bind. A decrease in F_r reduces the price of output and profits unambiguously fall. The more interesting case is when the capacity constraint does not bind, i.e., as in the right section of Figure 3.

For this case, Figure 4 plots the equilibrium outcomes as functions of the price of electricity. That is, as F_r decreases, the electricity price decreases, moving from right to left in the diagram. The simulations use the baseline parameter values from Figure 3, setting $\beta = 5$, and varying F_r . In the diagram, the minimum price is the price of electricity if there were no cap-and-trade program, and the maximum price is the price from Figure 3 when $\beta = 5$.

Consider first the case in which F_r is sufficiently high that there is no entry of renewable in equilibrium. As Figure 3 shows, base load units comply with the cap by abatement expenditure and reducing output. The output constraint does not bind and the price of electricity exactly equals operating costs $mc_b + \pi_z$. Now consider a decrease in F_r large enough that renewable units enter the market. The price of output decreases, but the permit price must also decrease so that the first order condition for base load output continues to be satisfied. Therefore, abatement expenditure decreases. To comply with the cap, base load units must decrease output. Thus, there are two effects on industry output. Base load units decrease production while renewable units increase production. The latter effect is greater in magnitude, so the output price falls and industry profits decrease.

Recall that the simulations reported in Figures 2-4 assume that there is no entry of base load or peaking units. The results in Figure 4 indicate that allowing for such entry generally offsets any increase in profits, to the extent that entering units have a lower emission rate than the average unit.

3.2.4 Emissions Rates of Peaking Units

One of the reasons for distinguishing base load and peaking units is that we can investigate the importance of relative (uncontrolled) emission rates of the two classes of units. Figure 5 shows the effect of increasing the emission rate of peaking units from the baseline value of zero to 0.4. It is assumed that the direct abatement technology is not available to peaking units, so that they cannot reduce their emission rate. This assumption which seems reasonable given that abatement technology is typically characterized by having high fixed costs and low marginal costs; i.e.,

peaking units will not generally find it optimal to install abatement equipment even when base load units do install such equipment.

Intuitively, increasing the emission rate of peaking units amounts to increasing total abatement or decreasing the cap. Figure 5 shows that for low emission rates of peaking units, increasing the emission rate has the same effect as increasing total abatement, which was depicted in Figure 2. Base load units comply by reducing their emission rate instead of decreasing output, which leaves the output price unaffected and decreases profits.

When the emission rate of peaking units increases above about 0.1, the permit price is sufficiently high that base load units reduce output in addition to reducing their emission rate. As a result, the output price and profits increase, and the cap-and-trade program results in greater profits.¹⁰

3.3 *Summary of Modeling Results*

The numerical results suggest that the greater the reduction in total industry output, the greater are profits. That is, the greater the (negative) elasticity of output to emissions, the greater the effect on profits. Therefore, a reduction in abatement costs may decrease profits because firms are less likely to reduce output in response to a cap. Greater entry of renewables or a reduction in emissions rates of non-base load units would have a similar effect. The next section shows that these results hold in a detailed model of the electric power sector and quantifies the magnitude of these effects.

¹⁰ This result implies that if Figure 2 were extended to show the effect of greater total abatement, there would be a similar inflection point, when base load units begin restricting output and profits begin to increase. Furthermore, if the emission rate of peaking units becomes sufficiently high, they may begin to reduce output. This causes profits to increase at an even greater rate.

4 Demonstrating the Importance of Abatement Opportunities using a Detailed Electricity-Sector Model

4.1 *Model Setup*

This section uses a detailed partial equilibrium model of the U.S. electricity sector to analyze how incumbents' profits are affected by a reduction in direct abatement costs, the cost of renewable generation, or the emission rate of non-base load units. We use the Haiku electricity sector model developed at Resources for the Future (Paul, 2004). Haiku has been used primarily to study national and regional environmental and market structure policies that affect this sector. Haiku solves via an iterative tâtonnement algorithm in the prices for both electricity production and major fuel inputs, including coal and natural gas, as well as the price of emissions allowances. Welfare includes both consumer and producer surplus in the electricity market adjusted by any changes in government revenues. The model allows for dynamic investment and compliance behavior. For the purposes of this study the model is solved for five simulation years over a 20-year time horizon.

The model divides the contiguous states of the U.S. into 21 regional electricity markets roughly defined by historical regional electricity reliability council boundaries, plus some further spatial disaggregation. Electricity demand is price responsive and distinguished by consumer class (residential, industrial, commercial), season (summer, winter, spring/fall), and time of day (base load, shoulder, peak, and super-peak); there are 756 distinct retail electricity markets in each simulation year. Interregional trade is modeled endogenously subject to transmission capacity constraints between regions. The wholesale electricity market is assumed to be competitive so that prices are based on the relationship between marginal generating costs in different regions. Each of the 21 regional retail markets can be characterized by either average (cost-of-service) or

marginal cost pricing.¹¹ Whether a region is treated as an average cost or marginal cost pricing region depends on the pricing structure faced by the majority of consumers in that region.

Electricity generators are represented by “model plants” defined by nine criteria: location, vintage (existing or new), prime mover, fuel, relative operating cost (for those generators using natural gas or nuclear fuel), and, for coal-fired boilers, coal demand region, capacity, and the expected presence of SO₂ and NO_x post-combustion abatement controls in 2010. Generator dispatch at any time is determined by a model plant’s short-run operating cost. Capital stock investment and retirement, as well as investment in pollution control technologies, are determined by the expected profitability of generation assets over time. Assumptions regarding the performance of new generation capacity and pollution control technologies are drawn from a variety of sources.

The possibility that firms are subject to average-cost pricing adds an additional nuance to the analysis that is not captured in the simple model in the previous section. Emissions allowances in average-cost pricing regions are treated in the rate base at their original costs, i.e. zero. If the entire market is characterized by average cost pricing then fully grandfathering allowances will have no direct effect on the output price (Burtraw et al, 2002). While we do not consider an approach where allowances are auctioned, it should be noted that auctioning allowances has been shown to increase welfare relative to grandfathering allowances. In a perfectly competitive markets this would not be the case; total welfare would be the same with both auctioning and grandfathering and the only difference would be the wealth transfer between the government and the regulated firms.¹² Because average-cost pricing causes the price of electricity to differ from marginal generating costs, auctioning increases welfare by reducing the difference.

The Haiku model has been used in other studies exploring different dimensions of the question of the effect of cap-and-trade programs on the profits of incumbent firms, including the

¹¹ M marginal cost pricing refers to “average marginal costs” over time blocks in a particular season, as opposed to time-of-day pricing.

¹² Subject to the caveat that the receiving grandfathered allowances is not conditional on operating the plant, so that there is no distortion in the entry/exit decisions of affected firms.

composition of the portfolio of generating technologies of firms and the method of allocation allowances (Burtraw et al. 2002, Burtraw and Palmer, 2007). Furthermore, outputs from this model have been used to calibrate more aggregate models of the electricity sector used in the literature on the incidence of environmental regulations (Parry, 2004 and Bovenberg *et al.* 2005).

Results not yet available.

5 Conclusion

The effect of a cap-and-trade program on profits depends crucially on the availability of low cost abatement options and generating sources with low emissions. These two conditions essentially determine the relationship between output and emissions; the greater the elasticity of output to emissions, the greater the increase in profits. A simple model of the electricity industry demonstrates this point, which is confirmed in the simulations of the Haiku model.

An important policy implication of this result is that technological change or economic incentives for renewable generating units reduces profits of existing generating units. Such changes therefore reduce the share of permits that must be auctioned to prevent these units from earning positive profits under regulation. Extensions to this analysis include exploring how the level of the cap affects compensation, the importance of the emission rate of the marginal producer of the final good, and the pricing regime in the market (i.e., whether regulated sources face marginal cost or cost-of-service pricing as is common in the electricity sector), as well as the elasticity of demand.

Future work may focus on how the allocation of allowances to clean units will affect the compensation to dirty firms, and that R&D policy will over time affect the relationship between output and emissions. Of course, the latter needs to be considered in the context of the lifetime of capital; in a partial equilibrium model it is only the incumbent firms that may realize positive profits from the cap (entry of all others is subject to a zero-profit condition). If the benefits of R&D are only realized in the long run, after a full turnover of the existing stock of capital, then it may not have an influence on the profits of incumbent firms. However, the incentive to bank

allowances under a cap that declines over time may fall, and there may still be a welfare effect on incumbents.

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